A DESCRIPTION OF LOWER EXTREMITY MUSCULOSKELETAL CHARACTERISTICS, INJURY, AND INJURY RISK FACTORS IN NCAA DIVISION I ATHLETES PARTICIPATING IN LOWER EXTREMITY DOMINANT SPORTS

by

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Musculoskeletal injuries (MSI) are a frequent occurrence in lower extremity (LE) dominant sports. The serious and persistent nature of these MSI affects an athlete's ability to compete, compromises their health, and has long-term impacts on their wellbeing and ability to maintain an active lifestyle. The purpose of this study was to identify the incidence of LE MSI in athletes, describe the musculoskeletal characteristics of the LE, and identify the association between musculoskeletal characteristics of the LE and the rate of LE MSI. A total of 131 NCAA Division I athletes participating in LE dominant sports at the University of Pittsburgh participated in this study (48 soccer athletes, 43 football athletes, 16 volleyball athletes, 24 basketball athletes). Each subject completed an assessment of LE musculoskeletal characteristics including, range of motion, flexibility, isometric strength, as well as static and dynamic postural stability. Descriptive statistics were calculated for all variables and used to describe musculoskeletal characteristics of the LE in athletes. Data was tested for normality utilizing a Shapiro Wilk test. Statistical significance was set *a priori* at alpha = 0.05, two-sided. Injury incidence rate, injury incidence rate ratios, and corresponding 95% confidence intervals were calculated in order to describe the incidence of LE MSI. Separate simple Poison regression analysis were conducted to assess the association between the predictor variables and LE MSI rates in athletes. Football demonstrated the highest rate of LE MSI, followed by women's soccer and men's soccer, as well

as women's basketball and men's basketball. Women's volleyball had the lowest rate of LE MSI. Range of motion, flexibility, isometric strength, and eye-closed static balance were determined to be modifiable risk factors for LE MSI in all sport types, excluding men's soccer. Each sport type displayed a different profile of modifiable risk factors for LE MSI. Therefore, it is important that clinicians focus on sport type specific modifiable risk factors for LE MSI. By targeting the specific differences in modifiable risk factors for LE MSI identified in the present study, clinicians can provide more comprehensive and targeted care; potentially decreasing the duration of missed participation and risk of re-injury.

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PREFACE

Completing a PhD and dissertation is not a simple task; it requires dedication, sacrifice, and a team of individuals who are constantly supporting you throughout the process. I have been lucky enough to have an amazing team of individuals who have supported me throughout all of my education and the dissertation process. First, I would like to thank my dissertation committee who were supportive of this project from the start. I would like to specifically thank Mita Lovalekar and Takashi Nagai for acting as my dissertation advisors throughout this process. This process was not easy and their help and support was critical to the successful completion of the project.

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and without them a large amount of data would have been lost. The work they did to support the project was imperative and appreciated.

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1.0 INTRODUCTION

Lower extremity musculoskeletal injury is a serious and persistent concern for athletes who participate in lower extremity dominant sports.[3-5, 28, 29, 31, 47] The complex, high-intensity, multi-directional nature of these sports make the risk of lower extremity musculoskeletal injuries exceedingly greater than sports of a more passive nature. Musculoskeletal characteristics including range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability have all been linked to lower extremity musculoskeletal injury. However, a lack of prospective data proves there is an extensive knowledge gap in understanding the relative contribution of these modifiable risk factors to lower extremity musculoskeletal injury.[72] This confounds the ability to provide effective injury prevention initiatives and post-injury rehabilitation programs. These issues can severely stunt an athlete's short-term playing status, as well as long-term well-being and ability to sustain an active, healthy lifestyle following completion of their athletic career. To address this knowledge gap an examination of the underlying risk factors for lower extremity musculoskeletal injury in addition to musculoskeletal injury surveillance is necessary. This will allow for the identification of each risk factor's specific role in musculoskeletal injury, as well as the potential for modification prior to injury. Establishing modifiable risk factors for lower extremity musculoskeletal injury will promote effective injury prevention initiatives aimed at addressing modifiable risk factors for injury, increasing the likelihood of both short-term and long-term athlete success.

1.1 LOWER EXTREMITY MUSCULOSKELETAL INJURY IN COLLEGIATE ATHLETES

Lower extremity musculoskeletal injury is a significant and consequential part of all lower extremity dominant sports.[47] However, the demands of each sport are different, leading to differences in type, location, and severity of injury.[47] It is important to understand the epidemiology of lower extremity musculoskeletal injury in each sport individually in order to understand how to effectively treat as well as understand the long-term impact of injury. Examining each lower extremity dominant sport individually leads to focused, evidence driven injury prevention initiatives, addressing the injuries specific to each sport. This provides more effective prevention and treatment options for lower extremity musculoskeletal injury. Participation in a lower extremity dominant sport increases an athlete's likelihood of sustaining a lower extremity musculoskeletal injury compared to participation in an upper extremity dominant sport.[47] In order to address this increased risk of lower extremity musculoskeletal injury, this study will only focus on lower extremity dominant sports. By narrowing the population to just athletes participating in lower extremity sports, the demands the athletes face are similar. These demands would include running and jumping in lower extremity dominant sports, whereas in upper extremity dominant sports these demands would include throwing or repetitive overhead motion. Although all lower extremity dominant sports will be discussed in this section, the focus of this study will be limited to soccer, football, volleyball, and basketball. Data for this study were obtained from NCAA Division I athletes participating in lower extremity dominant sports at the University of Pittsburgh. The reason for focusing on these sports is that the University of Pittsburgh Athletic Department does not field varsity teams for lacrosse, ice hockey, or field hockey. Therefore, the sample for this study will include athletes who participate in soccer, football, volleyball, or basketball.

The Public Health Model is a science-based approach to prevention of diseases and injuries, including musculoskeletal injury.[60] The model is a four step system rooted in a broad range of disciplines, including medicine, epidemiology, sociology, psychology, criminology, education and economics.[60] The first step of the process is defining and monitoring the problem.[60] This includes understanding the who, what, when, where and how of the problem.[60] The current study will focus on defining and monitoring lower extremity musculoskeletal injuries in NCAA Division I athletes participating in lower extremity dominant sports. The second step of the process is identifying the risk and protective factors.[60] The current study will include understanding the modifiable risk factors associated with lower extremity musculoskeletal injury.[60] The third and fourth steps of this model include developing and testing prevention strategies and assuring widespread adoption of these prevention strategies.[60] Although, the third and fourth steps are important, this study will focus on the first two steps.[60] By focusing on injury surveillance and risk factor identification, a strong foundation based in scientific evidence can guide the development and implementation of effective lower extremity musculoskeletal injury prevention strategies.[60]

Information on injuries involving NCAA athletes participating in lower extremity dominant sports is now readily available due to the NCAA Injury Surveillance System. The NCAA Injury Surveillance System has been put in place to support the cause of injury tracking in college-age athletes.[27] Sustaining an injury is an inherent risk of participating in a sport; understanding the epidemiology helps to minimize this risk.[27] Injury and exposure data has been collected from a total of 17 sports during the 1988-1989 through 2003-2004 athletic seasons.[27]

An injury must meet the following criteria defined by the NCAA Injury Surveillance System to be counted as a reportable injury: 1) injury occurred as a result of participation in an organized intercollegiate practice or contest, 2) injury required medical attention by a team certified athletic trainer or physician, and 3) injury resulted in restriction of the athlete's participation or performance for one or more days beyond the day of injury.[27] The NCAA Injury Surveillance System defines athlete-exposures as a combination of both games and practices.[27]

1.1.1 Soccer

According to the NCAA Injury Surveillance System, men's soccer has an overall injury rate of 7.7 injuries per 1,000 athlete-exposures, while women's soccer has an overall injury rate of 7.3 injuries per 1,000 athlete-exposures.[3, 31] The injury rate during game play for men's soccer has been reported as 18.75 injuries per 1,000 athlete-exposures and the injury rate during practice has been reported as 4.34 injuries per 1,000 athlete-exposures (rate ratio = 4.3, 95% CI = 4.2, 4.5). The injury rate during game play for women's soccer has been reported as 16.4 injuries per 1,000 athlete-exposures and the injury rate during practice has been reported as 5.2 injuries per 1,000 athlete-exposures (rate ratio = 3.2, 95% CI = 3.1, 3.4). The most common type of injury suffered by men's soccer athletes is muscle strain (25.8%) with ligament sprains being the second most common injury (25.3%).[3] The most common injury suffered by women's soccer athletes is ligament sprain (25.7%) followed by muscle strain (21.5%).[31] Both men's and women's soccer athletes share the most common injury, ligament sprain of the lateral ankle (Men: 12.2%, Women 12.8%).[3, 31] Hamstring strains are the second most common injury in men's soccer (7.5%).[3] Although the second most common injury in women's soccer is concussion, quadriceps strains are comparable to the amount of hamstring strains in men's soccer, accounting for 7.0% of all injuries.[31]

1.1.2 Football

The NCAA Injury Surveillance System illustrated an overall injury rate in collegiate football of 8.1 injuries per 1,000 athlete-exposures.[28] The injury rate for game play has been reported as 35.90 injuries per 1,000 athlete-exposures and the injury rate during practices has been reported as 3.80 injuries during 1,000 athlete-exposures (rate ratio = 9.4, 95% CI = 9.3, 9.5). Overall, more than 50 percent of all injuries suffered during football participation are at the lower extremity.[28] The most common injury reported in football is ligament sprain, accounting for more than 30 percent of all injuries reported.[28] The most common types of ligament sprains occur to the lateral ankle ligaments and the medial collateral ligament of the knee.[28] Although the ankle accounts for a number of the reported ligament sprains the knee is the most common location of injury (17.1%); following knee injury a median of seven days is lost from participation in football overall.[28] The most common mechanism for injury is acute noncontact, accounting for 24.1 percent of all injuries.[28]

1.1.3 Volleyball

Collegiate volleyball has an overall injury rate of 4.58 injuries per 1,000 athlete-exposures during games and 4.10 injuries per 1,000 athlete-exposures during practices according to the NCAA Injury Surveillance System (rate ratio = 1.1, 95% CI = 1.0, 1.2).[5] During the 16-year data collection period, the NCAA Injury Surveillance System reported 2,216 injuries during 50,000 games and 4,725 injuries during 90,000 practices.[5] Ligament sprains are the most common type of injury, accounting for 28.2 percent of all injuries.[5] Muscle strains are the second most common type of injury, accounting for 21.7 percent of all injuries, followed by tendinosis, making up 7.5 percent of all injuries.[5] The most common injury suffered during volleyball participation is ligament sprain of the lateral ankle (15.6%).[5] Quadriceps muscle strains account for 4.0 percent of all injuries suffered during volleyball participation, followed closely by abdominal strains making up 3.0 percent of all injuries.[5] ACL sprains account for just 0.6 percent of all injuries during volleyball participation.[5] The most common mechanism of injury during volleyball participation is acute non-contact (39.1%).[5]

1.1.4 Basketball

The NCAA Injury Surveillance System has identified an overall injury rate for men's basketball of 9.9 injuries per 1,000 athlete-exposures during game play while the overall injury rate is 4.3 injuries per 1,000 athlete-exposures during practice (rate ratio = 2.3, 95% CI = 2.2, 2.4).[29] Women's basketball has a game overall injury rate of 7.68 injuries per 1,000 athlete-exposures and an injury rate of 3.99 injuries per 1,000 athlete-exposures during practice (rate ratio = 1.9, 95% CI = 1.9, 2.0).[4] In both men's and women's basketball more than 60% of all injuries occurring during practice and game play are at the lower extremity.[4, 29] During game play, men's basketball athletes suffered ankle ligament sprains the most (26.2%), followed by knee internal derangements accounting for the second most common injury suffered (7.4%).[29] During game play, women's basketball athletes sustain ankle ligaments sprains the most (24.6%) followed by knee internal derangements accounting for 15.9% of all injuries.[4]

1.1.5 Field Hockey

Game injury rates for collegiate field hockey have been reported by the NCAA Injury Surveillance System as 7.87 injuries per 1,000 athlete-exposures; more than 40% of these injuries are to the lower extremity.[30] Practice injury rates are 3.70 injuries for 1,000 athlete-exposures at the same level of field hockey; more than 60% of these injuries are to the lower extremity (rate ratio = 2.1, 95% CI = 2.0, 2.3).[30] Over the 15-year period of data collection for the NCAA Injury Surveillance System 1,220 injuries were collected during 10,358 games and 2,066 injuries were collected from 26,740 practices.[30] During game play the most common type of injury was ankle ligament sprain (13.7%), followed by knee internal derangement (10.2%).[30] During practice 26.9% of all injuries were upper leg muscle strains, followed by ankle ligament sprains (15.0%), pelvis-hip muscle strains (9.9%), and knee internal derangements (7.8%).[30]

1.1.6 Ice Hockey

Collegiate men's ice hockey has a game injury rate of 16.27 injuries per 1,000 athlete-exposures and a practice injury rate of 1.96 injuries per 1,000 athlete-exposures (rate ratio = 8.3, 95% CI = 7.9, 8.8).[2] Collegiate women's ice hockey has an injury rate of 12.6 injuries per 1,000 athlete-exposures during game play and 2.5 injuries per 1,000 athlete-exposures during practice situations (rate ratio = 5.0, 95% CI = 4.2, 6.1).[1] 34.3% of all game play injuries and 35.9% of all practice injuries occur at the lower extremity in men's ice hockey.[2] Over the 16-year period of data collection with men's ice hockey, the NCAA Injury Surveillance System reported 4,673 injuries during 14,000 games and 1,966 injuries during 38,000 practices.[2] In women's ice hockey, 31.8% of all game injuries and 31.1% of all practice injuries are to the lower extremity.[1]

Over the 4-year period of data collection for women's ice hockey, the NCAA Injury Surveillance System reported 264 injuries during 1,100 games and 167 injuries during 3,200 practices.[1] In game play the most common type of injury is knee internal derangements, accounting for 13.5% of all injuries in men's ice hockey.[2] During women's ice hockey, game play the second most common injury following concussion is knee internal derangement (12.9%).[1] In men's ice hockey practice situations pelvis and hip muscle strains account for 13.1% of all injuries, second most common is knee internal derangements (10.1%), followed by ankle ligament sprains (5.5%).[2] The most common women's ice hockey injury during practice situations was concussion, followed by pelvis or hip muscle-tendon strains (12.0%), and foot contusion (7.2%).[1]

1.1.7 Lacrosse

Collegiate men's lacrosse has a game injury rate of 12.58 injuries per 1,000 athlete-exposures, while the practice injury rate is 3.24 injuries per 1,000 athlete-exposures according to the NCAA Injury Surveillance System (rate ratio = 3.9, 95% CI = 3.7, 4.1).[32] Over the 16-year period of data collection for the NCAA Injury Surveillance System, 1,921 injuries were collected during 6,800 games and 2,924 injuries were collected during 29,000 practices. 48.1% of all game injuries and 58.7% of all practice injuries occur at the lower extremity.[32] In game play the most common type of injury is ankle ligament sprain (11.3%), followed by knee internal derangements (9.1%).[32] In practice the most common type of injury is ankle ligament sprain (16.4%), followed by upper leg muscle-tendon strains (11.4%), and knee internal derangements (7.1%).[32]

1.2 RISK FACTORS FOR LOWER EXTREMITY MUSCULOSKELETAL INJURY

The identification of potentially modifiable risk factors for lower extremity musculoskeletal injury is guided by previous research. This previous research is based on comparisons of populations of injured athletes vs. uninjured athletes.[72] Risk factors for lower extremity musculoskeletal injury have been previously identified with these studies.[72] However, the evidence for these risk factors has not been studied on a wide variety of sports.[72] Other issues with these studies include a lack of focus on the modifiable nature of these risk factors.[72] If a risk factor is not modifiable, the usefulness of measuring the risk factors is unknown because an intervention will have no direct effect on the risk factor. Sex, previous injury, and limb dominance are non-modifiable risk factors for lower extremity musculoskeletal injury.[72] Although an intervention cannot change these risk factors, they may compound the negative impact that modifiable risk factors have on lower extremity musculoskeletal injury. The identification of non-modifiable intrinsic risk factors can assist in the identification of populations that should be receiving injury prevention initiatives.[72] Modifiable risk factors for lower extremity musculoskeletal injury include body size, flexibility, strength, and postural stability.[72] Regardless of the modifiable nature, the more risk factors identified in athletes prior to injury, the more effective intervention and clinical care can be. The focus of this study will be the intrinsic risk factors for musculoskeletal injury; each of the risk factors mentioned in this section are intrinsic in nature. Extrinsic risk factors will not be included in this study because this study is focused on human optimization. Extrinsic risk factors include training parameters, environmental conditions, and equipment. Changes to extrinsic risk factors are typically a product of engineering or rules and regulations set forth by an overseeing organization, such as the NCAA. Trends of musculoskeletal injury rates during game play indicate that over the 16-

year collection period of the NCAA Injury Surveillance System, the rate of musculoskeletal injury has decreased in recent years, although this is not statistically significant.[47] This decrease in the rate of musculoskeletal injury may be attributed to modification of NCAA policy and procedures.[47] Although not the focus of this study, changes in the rules and regulations of sport are effective in reducing the rate of musculoskeletal injury.[47]

1.2.1 Sex (Non-modifiable)

Sex, although non-modifiable, is a well-documented intrinsic risk factor for lower extremity musculoskeletal injury at both the knee and ankle in athletes participating in lower extremity dominant sports.[42, 49, 70, 73, 103] A strong link between female sex and knee injuries, specifically ACL injuries, has been identified over various ages, sports, and levels of competition. Female collegiate soccer athletes have demonstrated a likelihood of ACL injury between seven and nine times greater than male soccer athletes under the same conditions.[42, 73] Basketball athletes have demonstrated a significant risk of lower extremity musculoskeletal injury regardless of sex due to the constant jumping and cutting associated with the sport. Similar to soccer athletes, compared to their male counterpart female basketball athletes suffer from 60% more injuries than male basketball athletes at the professional level. The dynamic nature of basketball leads to more injuries primarily at the knee and thigh. In high school and college basketball, female athletes have been identified as being at greater risk for grade one ankle sprains compared to male athletes competing at the same level.[49] The identification of sex as an intrinsic risk factor for lower extremity musculoskeletal injury is important, but as a non-modifiable risk factor for injury, it lacks ability to be changed through intervention.

1.2.2 Limb Dominance (Non-modifiable)

Limb dominance is an important intrinsic risk factor for lower extremity musculoskeletal injury with strong links to increased risk of lower extremity musculoskeletal injury in athletes participating in lower extremity dominant sports.[12, 24, 35, 76] The nature of lower extremity dominant sports including, soccer, football, volleyball, and basketball, is heavily reliant on movements of the dominant leg including kicking, pushing off, jumping, and landing. All of these tasks are generally linked to lower extremity musculoskeletal injury due to the nature of the tasks being dynamic and multi-planar. Athletes who are left leg dominant participating in soccer, field hockey, and lacrosse have demonstrated an increase likelihood of suffering an ankle sprain compared to athletes of the same sport who are right leg dominant.[12] In soccer athletes, more ankle sprains occur on the dominant leg in comparison to the non-dominant leg.[35] This same injury risk is present in strains of the quadriceps muscle which occur more often in the dominant lower extremity than the non-dominant lower extremity in soccer athletes (RR = 2.13, 95% CI = 1.59 to 2.86).[76]

1.2.3 Previous Lower Extremity Musculoskeletal Injury (Non-modifiable)

One of the most significant intrinsic risk factors for lower extremity musculoskeletal injury is previous lower extremity musculoskeletal injury and lack of adequate rehabilitation following lower extremity musculoskeletal injury in athletes participating in all types of sports.[10, 11, 67, 72, 95] Lower extremity musculoskeletal injury significantly compromises the anatomical structures of the lower extremity, including both the static and dynamic stabilizers surrounding the joints distal and proximal to the injured joint in addition to the injured joint.[72] A lack of proper and adequate rehabilitation for these lower extremity musculoskeletal injuries prevents the restoration of the static and dynamic stabilizers to their original form lending to significant damage of the integrity of these structures.[72] This puts athletes at increased risk of re-injury. The ankle and knee joints demonstrate the highest risk for re-injury following previous joint injury, but re-injury is also seen at the muscles that surround and stabilize these two joints. In a population of Australian football athletes, a lower extremity musculoskeletal injury placed the athlete at significant risk for re-injury of the same type.[76] Specifically, the chance for re-injury has been demonstrated in muscles strains in the same anatomical location within eight weeks of initial injury.[76] The most significant chance for re-injury is at the hamstring (RR = 6.33), quadriceps (RR = 15.61), and gastrocnemius (8.94). Injury risk is still present following the eight weeks, although the risk is decreased.[76] The threat of muscle strain and subsequent re-injury is most significant in the hamstring (RR = 2.42), quadriceps (RR = 3.67), and gastrocnemius muscles (RR = 4.28) after the 8-week time frame.[76] Much of the link between lower extremity musculoskeletal injury and the risk of re-injury is grounded in a foundation of proprioceptive deficits (functional instability), muscle strength impairments or imbalances, persistent ligamentous laxity (mechanical instability, diminished muscle flexibility and joint movement, and the presence of localized scar tissue which produces discomfort within the compromised muscle or joint structures.[72] With proper identification of these foundational elements prior to lower extremity musculoskeletal injury, successful intervention may be possible, preventing the initial lower extremity musculoskeletal injury and reducing risk of re-injury.

1.2.4 Body Size (Modifiable)

The Body Mass Index has been previously linked to lower extremity musculoskeletal injury in athletes participating in all types of sports and military recruits. These links are most prominent at the extreme ends of Body Mass Index, defined as low and high Body Mass Index categories outside of the normal range..[9, 54, 71, 76] Male military recruits at extreme ends of Body Mass Index demonstrate an increase in incidence of all lower extremity musculoskeletal injuries three times greater than the incidence associated with male athletes who are in the moderate range of Body Mass Index.[54] Male military recruits in the higher ranges of Body Mass Index have demonstrated an incidence of all lower extremity musculoskeletal injuries two times greater than male athletes who are in the remaining ranges of the Body Mass Index.[54] In addition, an overall increase in body fat and height have been identified as risk factors for lower extremity musculoskeletal injury in both male and female athletic populations.[16, 48] Shorter height in female athletes has been previously linked to lower extremity musculoskeletal injury. It is hypothesized that this link is due to the shift in how overall body mass is carried compared to taller female athletes.[54] A more specific link between shorter height and quadriceps muscle injury in Australian football athletes has also been identified (RR = 1.48).[76]

1.2.5 Flexibility (Modifiable)

Flexibility describes numerous unique issues surrounding joint laxity and muscle stiffness. Although these issues all fall under the umbrella of flexibility, each level and gradation of flexibility effects risk of lower extremity musculoskeletal injury differently. Generalized joint laxity is the most common and all encompassing, but its association with risk of lower extremity musculoskeletal injury is unclear.[77, 94] In a prospective study of female soccer athletes, those who demonstrated greater generalized joint laxity were five times more likely to sustain an injury compared to those athletes who demonstrated less generalized joint laxity.[77] Similar studies have reiterated these results, with athletes who demonstrate increased generalized joint laxity having a three times greater risk of traumatic leg injury than athletes who demonstrate decreased generalized joint laxity (95% CI = 1.19 to 8.01).[94] A strong association between generalized joint laxity and increased risk for specific lower extremity musculoskeletal injuries, specifically acute injuries exists, but there is no demonstrated link between generalized joint laxity and overuse leg injuries.[72]

Joint laxity at the knee and ankle, has demonstrated a strong link to risk of lower extremity musculoskeletal injury in previous studies in athletes participating in lower extremity dominant sports.[6, 16, 24, 35, 39] At the knee, athletes who demonstrate increased medial joint laxity have a significant increase in knee injuries.[35] In a population of male soccer athletes, increased knee laxity diagnosed during varus/valgus and anterior/posterior clinical examinations were proven to be at significantly increased risk of lower extremity musculoskeletal injury.[24] A population of soccer athletes who exhibited increased laxity score at the knee as yielded during an anterior draw test, also demonstrated a significant risk of musculoskeletal injury at both the knee and ankle.[6]

Muscle tightness has been previously linked to increased risk of musculoskeletal injury in both male and female athletes participating in lower extremity dominant sports, including soccer and basketball. Increased iliopsoas tightness has been linked to overuse lower extremity injuries in a population of male soccer athletes.[58] General stretching prior to participation in sport has also been associated with lower extremity musculoskeletal injury.[67] In a population of elite and recreationally active basketball athletes, athletes who did not stretch during their warm up were at a significantly increased risk of injury when compared to those athletes who did stretch during their warm up (OR = 2.62, 95% CI = 1.01 to 12.68).[67]

Range of motion has been associated with muscle tightness and generalized joint laxity; both significantly influence the amount of range of motion allowed by a joint. Range of motion, in its own right, has been previously associated with ankle injury and general lower extremity injury.[16, 55, 94] Both extremes of range of motion have been associated with risk of lower extremity musculoskeletal injury. Knee hyperextension greater than ten degrees has been demonstrated as a risk factor for lower extremity musculoskeletal injury in a population of female soccer athletes (OR = 2.50, 95% CI = 1.11 to 5.61).[94] Additionally, the same population of athletes demonstrated no links between increases and decreases in ankle dorsiflexion range of motion and hamstring flexibility and risk of lower extremity musculoskeletal injury.[94] In opposition, side to side differences in ankle dorsiflexion range of motion (OR = 7.06) and hamstring (OR = 3.56) flexibility have been linked to increased risk of overuse leg injury.[94]

1.2.6 Strength (Modifiable)

A highly modifiable intrinsic risk factor for lower extremity musculoskeletal injury is strength. Both overall muscle strength and strength imbalances in muscles acting as agonist antagonist pairs are important risk factors in athletes participating in all types of sports.[12, 35, 94] The link between strength as an intrinsic risk factor for lower extremity musculoskeletal injury has been demonstrated at the ankle, knee, as well as for overuse injuries of the leg.[12, 35, 94] Previous research in a population of college age athletes attributes ankle sprains to imbalances in ankle strength.[12] Athletes who demonstrated lower ratios of dorsiflexion to plantarflexion (0.373 in the injured group vs. 0.3488 in the uninjured group) along with higher ratios of eversion to inversion strength (1.0 in the injured group vs. 0.8 in the uninjured group) suffered from ankle injuries compared to those who did not demonstrate these musculoskeletal characteristics.[12] Hamstring to quadriceps strength ratio is also a significant factor in injury of the lower extremity.[94] A decreased ratio of hamstring to quadriceps strength has been demonstrated as a risk factor for traumatic leg injury while the opposite, an increased hamstring to quadriceps ratio, has been demonstrated as a risk factor for overuse leg injury in a population of female soccer athletes (OR = 1.13).[94] In a population of male soccer athletes, significantly reduced quadriceps strength was measured in the injured leg compared to the non-injured leg in athletes who had previously suffered a non-contact knee injury.[35]

1.2.7 Postural Stability (Modifiable)

Postural stability has been identified as an intrinsic risk factor for lower extremity musculoskeletal injury in athletes participating in lower extremity dominant sports.[66, 94, 96] Diminished postural stability is associated with altered neuromuscular control strategies, increased intersegmental joint forces, and increased forces developed about the articular, ligamentous, and muscular structures of the lower extremity.[72] All of these altered musculoskeletal characteristics are strong contributors to lower extremity musculoskeletal injury. Increased postural sway, movement away from the center of mass, measured by the NeuroCom Balance Master, in a population of 210 high school aged basketball athletes is linked to ankle sprains. A seven times greater risk of lower extremity musculoskeletal injury has been demonstrated in athletes with diminished postural stability compared to athletes with normal postural stability.[66] The same risk of injury associated with increased postural sway has been demonstrated in male soccer athletes; increased postural sway, measured by a force plate, increases the risk of ankle injury in athletes with decreased postural stability compared to athletes with normal postural stability.[96] Out of the 29 athletes with increased postural sway, 12 developed an ankle sprain.[96] Eleven of the 98 athletes with normal postural sway suffered an ankle sprain.[96] In a population of female soccer athletes, increased postural sway and diminished postural stability, measured by the Kinesthetic Ability Trainer 2000, has been linked to increased risk of sustaining a leg injury (OR = 0.31).[94]

1.2.8 Fatigue and Deconditioning (Modifiable)

Another significant risk factor for lower extremity musculoskeletal injury is fatigue. Fatigue is a regularly occurring obstacle as well as an unfortunate consequence of athletic competition. Fatigue is related to the intensity and duration of participation; fatigue typically sets in closer to the end of a practice or game or the end of a competitive season.[18, 62] Although fatigue in itself is a risk factor for lower extremity injury, in the context of athletic competition fatigue is unavoidable. This means that the focus must shift from fatigue as a risk factor itself to how fatigue affects previously identified risk factors for lower extremity musculoskeletal injury, which can be modified with success.

Understanding the impact of fatigue on postural stability during periods of two-legged stance and simplistic movement is paramount in understanding how fatigue will impact athletes during dynamic athletic competition. Simple two-legged stance tasks require the synchronized functioning of multiple sensory systems as well as motor components of the nervous system.[64] Correct and accurate ankle proprioception is essential to the stabilization of the body as the most distal portion of the kinetic chain; the most basic of organization and pre-planning of motor actions occurs at the ankle.[25] Proper ankle proprioception requires only low levels of muscle force, necessary for stabilization of the center of mass over a quiet uninterrupted base of support.[33, 88] With any minor perturbation, proper ankle proprioception should counteract the extreme movements of the center of mass away from the equilibrium. [33, 88 33, 88 33, 88 33, 88 33, 88 33, 88 33, 88 33, 88 33, 88 33, 88] The sensory motor system and the proprioceptive capabilities of the ankle alter muscle activity concurrently in order to maintain the joint stability and more proximally the functional stability of the entire kinetic chain.[25]

Deconditioning also significantly impacts an athlete's risk of lower extremity musculoskeletal injury.[72] Deconditioning and decreased levels of aerobic fitness lead to altered muscular recruitment patterns.[72] When an athlete experiences altered muscular recruitment patterns the forces that act on the articular, ligamentous, and muscular structures are significantly impacted, adversely impacting the distribution of forces.[72] Alterations in the distribution of forces surrounding the joints of the lower extremity increases an athlete's risk of lower extremity musculoskeletal injury.[72] Male soccer athletes who demonstrated poor physical conditioning and subsequently suffered from a musculoskeletal injury demonstrated slower reaction times following a 12-minute run compared to athletes who did not suffer a musculoskeletal injury.[24] Male and female military recruits who performed less pushups and demonstrated slower run times had a higher likelihood of suffering a musculoskeletal injury.[57] A similar risk of musculoskeletal injury has been demonstrated in military recruits who had slower one mile run times compared to their peers.[54]

1.3 LOWER EXTREMITY MUSCULOSKELETAL INJURY SURVELLIANCE

Despite attempts to measure the magnitude and scope of lower extremity musculoskeletal injuries and subsequently initiate injury prevention initiatives to mitigate these injuries, athletes are still at grave risk of suffering these injuries. The frequent occurrence of lower extremity musculoskeletal injuries and the harmful impact they have on both the short-term and long-term well-being of the athlete increases the need to understand why these injuries persist despite previous attempts to understand them. Musculoskeletal characteristics including range of motion, flexibility, and strength have previously been evaluated in athletes.[72] However, there is a lack of injury surveillance following evaluation of these musculoskeletal characteristics. By including all of these aspects in the injury surveillance process, the evidence for effective injury prevention and treatment increases. Previous attempts at the identification of modifiable risk factors for lower extremity musculoskeletal injury have yielded results indicating further research is necessary.[72] Understanding the modifiable risk factors for lower extremity musculoskeletal injury allows for primary prevention of injury, mitigating the future implications of these injuries.

1.4 DEFINITION OF THE PROBLEM

Musculoskeletal injuries are a frequent occurrence in lower extremity dominant sports. The serious and persistent nature of these musculoskeletal injuries affects an athlete's ability to compete, compromises their health, and can have a long-term impact on their wellbeing and ability to maintain an active lifestyle. The prevention of these musculoskeletal injuries requires an examination of the scope and magnitude of the problem. This would include the identification of modifiable intrinsic risk factors for musculoskeletal injury. Musculoskeletal characteristics, including range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability are theorized to be modifiable intrinsic risk factors for lower extremity musculoskeletal injury.

1.5 PURPOSE

This study includes an evaluation of lower extremity musculoskeletal injury and the modifiable intrinsic risk factors for these injuries in NCAA Division I athletes participating in lower extremity dominant sports at the University of Pittsburgh. The public health model was used as the model for the design of this study. One purpose of this study was to identify the incidence of lower extremity musculoskeletal injury in NCAA Division I athletes participating in lower extremity dominant sports at the University of Pittsburgh. The second purpose of this study was to describe the musculoskeletal characteristics of the lower extremity, including range of motion, flexibility, strength, and postural stability in NCAA Division I athletes participating in lower extremity dominant sports at the University of Pittsburgh. An evaluation of the association between musculoskeletal characteristics of the lower extremity, including range of motion, flexibility, strength, and postural stability, and the rate of lower extremity musculoskeletal injury in NCAA Division I athletes at the University of Pittsburgh was also included in this study.

1.6 SPECIFIC AIMS AND HYPOTHESIS

Specific Aim 1: To describe musculoskeletal characteristics of the lower extremity including range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability in NCAA Division I University of Pittsburgh male and female athletes participating in lower extremity dominant sports.

Specific Aim 2: To identify the incidence of lower extremity musculoskeletal injury in NCAA Division I University of Pittsburgh male and female athletes participating in lower extremity dominant sports.

Specific Aim 3: To evaluate the association between lower extremity musculoskeletal characteristics including range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability and the rate of lower extremity musculoskeletal injury in NCAA Division I University of Pittsburgh male and female athletes.

> *Hypothesis 3a*: The rate of lower extremity musculoskeletal injury will be higher among NCAA Division I University of Pittsburgh male and female athletes who demonstrate decreased lower extremity range of motion, flexibility, and isometric strength, as well as deficits in static and dynamic postural stability compared to NCAA Division I University of Pittsburgh male and female athletes who do not demonstrate decreases in these musculoskeletal characteristics.

1.7 STUDY SIGNIFICANCE

The results of this study include a description of the burden of lower extremity musculoskeletal injury in NCAA Division I athletes participating in lower extremity dominant sports at the University of Pittsburgh. The relative distribution of lower extremity musculoskeletal injury was identified according to sport, location, and type. The identification of modifiable intrinsic risk factors for these lower extremity musculoskeletal injuries will inform clinicians on appropriate injury prevention strategies. If significant differences in these modifiable intrinsic risk factors exist between athletes who sustain a musculoskeletal injury and those who do not, injury prevention initiatives can be developed to target the identified risk factors for injury. By targeting these specific differences, clinicians may be able to provide more comprehensive care for lower extremity musculoskeletal injuries, potentially decreasing the duration of missed participation and risk of re-injury. These results may provide information that can be employed for the improvement of overall musculoskeletal heath, longevity of an athlete's career, and success of an athlete living a healthy lifestyle following the end of their athletic career. Clinicians, coaches, and policy makers can all benefit from targeted strategies for prevention of lower extremity musculoskeletal injuries, focused on modifiable intrinsic risk factors.

2.0 REVIEW OF LITERATURE

This chapter will provide a review of the literature about the descriptive epidemiology of lower extremity musculoskeletal injuries in collegiate athletes and the intrinsic risk factors associated with these injuries. The first section of this literature review will provide an in depth overview of the descriptive epidemiology of lower extremity musculoskeletal injuries in NCAA collegiate athletes. A discussion of the intrinsic risk factors for lower extremity musculoskeletal injury will follow the review of the descriptive epidemiology of lower extremity musculoskeletal injury. Current injury surveillance systems will be discussed, focusing on the methodology specific to each surveillance system. Lastly, the methodology of the current study will be presented in a way that compares and contrasts the chosen methodology to similar methodology utilized in other related research studies.

2.1 LOWER EXTREMITY MUSCULOSKELETAL INJURY IN COLLEGIATE ATHLETES

The National Collegiate Athletic Association (NCAA) encompasses more than 375,000 student-athletes who participate in sports that offer a national championship, the minimum criteria to be recognized by the NCAA.[7] The number of athletes participating in NCAA sports is rapidly expanding. Men's sports are gaining athletes at a rate of over 28% per year and women's sports are gaining athletes at a rate of over 120% per year.[27] Data gathered from NCAA participating schools, demonstrates that on average there are 366 athletes per school, making these athletes an important part of these schools.[27] Information on injuries involving NCAA athletes is available through the NCAA Injury Surveillance System. The NCAA Injury Surveillance System has been developed to conduct injury surveillance in collegiate athletes. The overall goal of the NCAA Injury Surveillance System is to collect injury and exposure data from a wide variety of sports in a representative sample of NCAA schools.[27] The secondary goal of the NCAA Injury Surveillance system is to provide each NCAA school with injury information, which may assist them in making informed decisions and lay a foundation for risk management decision making.[27] Sustaining an injury is an inherent risk of participating in sport; understanding the epidemiology is the first step in minimizing this risk.

As a part of the NCAA Injury Surveillance System, injury and exposure data has been collected from a total of 17 sports during the 1988-1989 through 2003-2004 athletic seasons.[27] An injury must meet the following criteria defined by the NCAA Injury Surveillance System to be a reportable injury: 1) injury occurred as a result of participation in an organized intercollegiate practice or contest, 2) injury required medical attention by a team certified athletic trainer or physician, and 3) injury resulted in restriction of the athlete's participation or performance for one or more days beyond the day of injury.[27] The NCAA Injury Surveillance System injury rates are expressed as the number of injuries per 1,000 athlete-exposures.[27] According to the NCAA Injury Surveillance System an athlete exposure is defined as one athlete participating in one practice and/or one competition.[27] During participation in this one practice and/or one competition each athlete is exposed to the possibility of injury without regard to the amount of time associated with that instance of participation.[27] Participation in competition is only counted if the athlete has playing time during the duration of the competition.[27] Any games played within the team are counted as practices as opposed to competitions for the purposes of exposure tracking.[27]

Across all 17 sports surveyed by the NCAA Injury Surveillance System, more than 50% of all musculoskeletal injuries occurred at the lower extremity; a majority of these injuries occurred at the knee and ankle.[47] With a majority of these lower extremity injuries occurring at the knee and ankle in this population of athletes, there is an increased emphasis on injury prevention and education specific to knee and ankle injuries.[47] Anterior cruciate ligament (ACL) injuries have been the focus of injury prevention initiatives in more recent research and clinical care.[47] However, with increased focus of injury prevention on ACL injuries, there is decreased focus on more broad, general lower extremity musculoskeletal injury prevention. Focusing on more broad, general lower extremity musculoskeletal injury prevention will require an extensive examination of the risk factors for general lower extremity musculoskeletal injury, as opposed to specific injuries at the knee and ankle. By identifying risk factors for broad, general lower extremity musculoskeletal injury a reduction in occurance is possible, as well as a vast reduction in the medical costs associated with these injuries.[47] Specific lower extremity musculoskeletal injuries at the knee and ankle, including ACL injuries, are relatively rare compared to other lower extremity musculoskeletal injuries.[47] With these injuries having a relatively low incidence rate research becomes more difficult because it requires large sample sizes and have extended durations for intervention and follow up.[47] By looking more broadly at general lower extremity musculoskeletal injuries these studies have more statistical power because the incidence rate of these injuries is high.[47] These studies can provide strong evidence for the use of injury prevention initiatives in the clinical setting.

14.8% of all injuries reported during the data collection period of the NCAA Injury Surveillance System were ankle ligament sprains.[47] Over a 16-year reporting period, 27,000 ankle ligament injuries were reported; this averages out to approximately 1,700 ankle ligament injuries per year.[47] Ankle ligament injuries accounted for more than one quarter of all injuries in men's and women's basketball, as well as women's volleyball, however spring football and men's basketball had the highest rates of ankle ligament sprains (1.34 per 1000 athlete-exposures and 1.30 per 1000 athlete-exposures, respectively).[47] The second and third most common injuries reported were concussion and ACL injuries.[47] 5,000 ACL injuries were reported over the 16-year period of data collection for the NCAA Injury Surveillance System; averaging out to approximately 313 ACL injuries per year.[47] Football demonstrated the highest number of reported ACL injuries, but women's gymnastics had the highest rate of ACL injuries when averaged across the number of athletes participating in each sport.[47] Three of the four sports with the highest ACL injury rates were women's sports, including gymnastics, basketball, and soccer.[47] Although these ACL injuries are less frequent than ankle ligament sprains, they often get more attention due to the fiscal cost in addition to the significant time loss and treatment requirements.[47] During the reporting period of the NCAA Injury Surveillance System, ACL and concussion rates steadily increased.[47] This is likely due to the notoriety of these injuries and how the awareness of these injuries has increased significantly in recent years.[47] This has led to increased reporting of these specific injuries because of the growing awareness of the signs and symptoms associated with these injuries.

Across the 17 different sports surveyed by the NCAA Injury Surveillance System the most common mechanism of injury is direct player contact. 58.0% of all injuries sustained during game play have been reported as a result of direct player contact, while 41.6% of injuries suffered during practice are a result of direct player contact.[47] The rate of non-contact injuries during game play is 17.7%, while 36.8% of practice injuries are attributed to non-contact mechanisms.[47] Lower extremity dominant sports have an increased rate of direct player contact in contrast to upper extremity dominant sports.[47] During lower extremity dominant sports, player contact is inherent; during football, direct player contact occurs during every play. The low rate of injuries due to direct player contact during practice, in addition to the high rate of non-contact injuries highlights the importance of sport rules and regulation. The interpretation and enforcement of rules and regulations are likely to be significantly different during game play compared to practice. Traditionally, to avoid athlete injury, excessive direct player contact is controlled during practice. During game play, the likelihood of becoming injured due to direct player contact is increased, likely due to the intensity of the playing situation. Sports that frown upon direct player contact, including soccer and volleyball, still demonstrate that a majority of injuries during game play are a result of direct player contact.[47] Compared to direct player contact injuries, the most common non-contact injuries that occur during practice are muscle strains and joint sprains.[47] These injuries, unlike direct player contact injuries, cannot be mitigated through enforcement of rules and regulations.[47] Thus, these non-contact injuries should be the focus of risk factor identification and subsequently injury prevention initiatives because they are more amenable to risk factor modification prior to injury.

2.1.1 Soccer

Men's and women's collegiate soccer share similar demands, making the injury mechanism profile for each sport similar. The three primary mechanism of injury for both men's and women's soccer are: 1) direct player contact, 2) other contact (EX: balls, goals, ground), and 3) no contact. 61% of game injuries in men's soccer are attributed to direct player contact, while 54% of game play injuries in women's soccer are attributed to direct player contact.[3, 31, 47] Other injuries associated with game play in women's soccer have been attributed to other contact 22.0% and no contact 22.0%.[31] During practice the primary mechanism of injury for both men's and women's soccer is no contact.[3, 31] In men's soccer specifically, 47.0% of all injuries during practice result from non-contact mechanisms.[3] Receiving and performing slide tackles during soccer play is a unique aspect of the game, in men's soccer particularly, 16% of all game play injuries attribute the mechanism to attempting or receiving a slide tackle.[3] ACL injuries are of concern for male and female soccer athletes but previous research has demonstrated that these injuries might be more concerning for the female soccer population.[3, 31] ACL injuries in male soccer athletes during game play are attributed to direct player contact 46.2% of the time, while non-contact mechanism account for 35.6% of all ACL injuries.[3] During game play in women's soccer 35.6% of all ACL injuries are attributed to direct player contact while 52.7% are attributed to non-contact mechanism.[31] The opposite is true of women's soccer practice where 19.5% of ACL injuries are attributed to direct player contact and 64.6% are attributed to non-contact mechanism.[31]

Men's soccer has demonstrated an injury rate four times higher during game play in comparison to practice.[3] During game play the injury rate was 18.75 injuries per 1,000 athlete-exposures, while during practice the injury rate was 4.34 injuries per 1,000 athlete-exposures.[3] Over the 15-year period in which the NCAA Injury Surveillance System collected data on men's soccer, 6,693 total injuries were reported.[3] These injuries were spread across different times during the soccer season, a majority of which occurred during pre-season practice.[3] Pre-season practice placed athletes at a three times higher injury risk than competitive season practice (7.98

injuries per 1,000 athlete-exposures vs. 2.43 injuries per 1,000 athlete-exposures; $p < 0.01$) or post-season practice (7.98 injuries per 1,000 athlete-exposures vs. 1.62 injuries per 1,000 athlete-exposures; $p < 0.01$).[3] Similar patterns were noted during game play, where competitive season injury rates were significantly higher than post-season injury rates (18.91 injuries per 1,000 athlete-exposures vs. 14.58 injuries per 1,000 athlete-exposures; $p < 0.01$).[3] Being that soccer is primarily a lower extremity dominant sport, it is not surprising that at least two thirds of the injuries that occur during men's soccer are to the lower extremity.[3] 28.0% of all injuries that occurred during game play were a combination of ankle ligament sprains and knee internal derangement.[3] Practices were slightly different than game play, with ankle ligament sprains and upper leg muscle strains totaling 34.0% of all injuries.[3] Interestingly, game play placed men's soccer athletes at an increased risk for a significant amount of lower extremity injuries.[3] Men's soccer athletes participating in games were at 4 times the likelihood of suffering an ankle ligament sprain (3.19 injuries per 1,000 athlete-exposures vs. 0.76 injuries per 1,000 athlete-exposures) and six times the likelihood of suffering a knee internal derangement injury compared to practice situations (2.07 injuries per 1,000 athlete-exposures vs. 0.33 injuries per 1,000 athlete-exposures).[3] It is well known that the leading risk factor for ankle ligament sprain is prior incidence of ankle ligament sprain; in men's soccer this is very apparent with 24% of all ankle ligament sprains being recurrent sprains.[3]

Women's soccer is very similar to men's soccer when comparing injury rates. Over the 15-year period in which women's soccer was surveyed by the NCAA Injury Surveillance System, the injury rates during game play were three times higher than the injury rate during practice.[31] Game injury rates were 16.4 injuries per 1,000 athlete-exposures, while practice injury rates were 5.2 injuries per 1,000 athlete-exposures.[31] 5,373 injures were recorded over the survey period of the NCAA Injury Surveillance System for women's soccer.[31] Pre-season injury rates were higher than competitive season injury rates (19.65 injuries per 1,000 athlete-exposures vs. 16.56 injuries per 1,000 athlete-exposures; $p = 0.01$), while competitive season injury rates were higher than post season for games (16.56 injuries per 1,000 athlete-exposures vs. 11.67 injuries per 1,000 athlete-exposures; $p < 0.01$).[31] For practices, the same trend was noted with pre-season injury rates being the highest ($p < 0.01$).[31] Approximately 70% of all injuries recorded in women's soccer occurred at the lower extremity.[31] In game play 18.3% of all injuries were ankle ligament sprains, while knee internal derangements accounted for 15.9% of all injuries.[31] In practices, a different trend was noted with upper leg muscle-tendon strains accounting for 21.3% of injuries and ankle ligament sprains accounting for 15.3% of injuries.[31] Women's soccer athletes were six times more likely to sustain a knee internal derangement in game play than in practice (2.61 injuries per 1,000 athlete-exposures vs. 0.4 injuries per 1,000 athlete-exposures), as well as being four times more likely to sustain an ankle ligament sprain in game play than in practice (3.01 injuries per 1,000 athlete-exposures vs. 0.80 injuries per 1,000 athlete-exposures).[31] Women's soccer athletes were equally as likely to suffer an upper leg muscle-tendon strain in game play or practice (1.14 injuries per 1,000 athlete-exposures vs. 1.11 injuries per 1,000 athlete-exposures).[31]

2.1.2 Football

Collegiate football athletes have demonstrated three primary mechanisms for injury: 1) direct player contact, 2) other contact (EX: balls, blocking dummies, ground), and 3) no contact.[28, 47] Collegiate football encompasses a number of different practice and game seasons, including the competitive fall practice and game season as well as a less competitive spring practice and game season.[28, 47] During fall practices direct player contact accounts for 56.5% of all injuries, while during fall games direct player contact accounts for 77.9% of all injuries.[28, 47] Non-contact mechanisms account for 28.8% of all injuries during fall game play and 8.9% of all injuries during practice play.[28, 47] Non-contact mechanisms for injury account for the second highest mechanism of injury during all season of collegiate football.[28, 47]

Football has the highest injury rates out of all lower extremity dominant sports. Game injury rates have been reported as being nine times higher than practice injury rates (35.90 injuries per 1,000 athlete-exposures and 3.80 injuries per 1,000 athlete-exposures, respectively).[28] During the NCAA Injury Surveillance System 16 year reporting period, 42,355 total injuries were reported during football play.[28] The fall competitive football season game and practice injury rates did not differ significantly.[28] Fall pre-season practice injury rates were more than three times higher than competitive season practice or post-season practice injury rates (36.11 injuries per 1,000 athlete-exposures vs. 23.71 injuries per 1,000 athlete-exposures; $p < 0.01$).[28] Competitive season game injury rates were 50% higher than post-season game injury rates. Like all other lower extremity dominant sports, a majority of all reported injuries were to the lower extremity; in the case of football, 50% of all reported injuries were to the lower extremity.[28] During competitive season games, 17.8% of all injuries were knee internal derangements, while ankle ligament sprains accounted for 15.8% of all injuries.[28] In competitive season practices, knee internal derangements accounted for 12.0% of all injuries, ankle ligament sprains accounted for 11.8% of all injuries, and upper leg muscle-ligament strains accounted for 10.7% of all injuries.[28]

2.1.3 Volleyball

The primary mechanisms of injury in collegiate volleyball are identical to that of both football and soccer. Volleyball game play demonstrates an equal distribution of injuries across the three primary mechanisms of injury with other contact accounting for 35.4%, direct player contact accounting for 30.4%, and no contact accounting for 32.7% of all injuries.[5, 47] The mechanism of injury has a larger spread during practice with 54.0% attributing the mechanism of injury to no contact, 27.0% attributing the mechanism of injury to other contact, and 15.0% attributing the mechanism of injury to direct player contact.[5, 47]

Women's volleyball follows similar trends to all other lower extremity dominant sports, with a majority of injuries occurring during game play as opposed to practice.[5] Game injury rates were just slightly higher during volleyball, with an injury rate of 4.58 injuries per 1,000 athlete-exposures while practice injury rates have been reported as 4.10 injuries per 1,000 athlete-exposures.[5] More than 2,216 injuries were reported in women's volleyball over the 16 year reporting period of the NCAA Injury Surveillance System.[5] Pre-season injury rates were two times higher than competitive season injury rates for practices (6.19 injuries per 1,000 athlete-exposures vs. 2.82 injuries per 1,000 athlete-exposures; $p < 0.01$), while competitive season injury rates were higher than post-season injury rates (4.52 injuries per 1,000 athlete-exposures vs. 2.67 injuries per 1,000 athlete-exposures; $p < 0.01$).[5] More than 55% of all injuries in women's volleyball have been reported as injuries to the lower extremity.[5] Ankle ligament sprains accounted for 44.1% of all injuries, while knee internal derangements accounted for 14.1% of all injuries reported during game play.[5] During practice, the injuries were similar with ankle ligament sprains accounting for 29.4% of all injuries and upper leg muscle-tendon strains accounting for 12.3% of all injuries.[5] Athletes were twice as likely to sustain knee internal derangements in game play compared to practice (1.44 injuries per 1,000 athlete-exposures vs. 0.83 injuries per 1,000 athlete-exposures). The same results were demonstrated for knee internal derangements (0.46 injuries per 1,000 athlete-exposures vs. 0.22 injuries per 1,000 athlete exposures).[5]

2.1.4 Basketball

The primary mechanisms for injuries in women's basketball are player contact, other contact (balls, standard, floor), and no contact in both games and practices.[4, 29, 47] Most of the game injuries, 46%, resulted from player contact.[4, 29, 47] All remaining game injuries were approximately evenly distributed between contact with 29% of injuries and other contact with 24% of injuries.[4, 29, 47] A majority of all practice injuries, 47%, were no contact. Men's basketball has a primary mechanism of player contact, other contact (balls, standards, ground), and no contact in both games and practices.[4, 29, 47] Most games and practices injuries, 52.3% and 43.6%, respectively, resulted from player contact.[4, 29, 47] The remaining game injuries were equally distributed between no contact at 22.3% and other contact at 24.3%. No contact was the second highest injury mechanism in practices at 36.3%.[4, 29, 47]

Men's basketball demonstrates an injury rate two times higher in game play compared to practice situations; game play has a reported injury rate of 9.9 injuries per 1,000 athlete-exposures, while practice has an injury rate of 4.3 injuries per 1,000 athlete-exposures.[29] Over the entirety of the NCAA Injury Surveillance System data collection period, 16 years, a total of 4,211 injuries were reported as a result of men's basketball participation.[29] One of the major factors that plays into the risk of injury for men's basketball athletes is timing during the season.[29] Pre-season injury rates tend to be three times higher than injury rates during the competitive season (7.5 injuries per 1,000 athlete-exposures vs. 2.8 injuries per 1,000 athlete-exposures; $p < 0.01$).[29] In contrast practice injury rates have been reported as being higher during the competitive season compared to the post-season (2.8 injuries per 1,000 athlete-exposures vs. 1.5 injuries per 1,000 athlete-exposures; $p < 0.01$).[29] This trend has also been noted during game play (10.1 injuries per 1,000 athlete-exposures vs. 6.4 injuries per 1,000 athlete-exposures). Of all injuries reported during men's basketball 60% are injuries occurring at the lower extremity.[29] In game play, ankle ligament sprains account for a majority of reported injuries (26.2%), while knee internal derangements followed second, accounting for 7.4%.[29] Patellar injuries and upper leg contusions account for the third and fourth most common injuries during game situations, 3.9% and 2.4%, respectively.[29] The same trend has been noted during practice with ankle ligament sprains accounting for 26.8% of injuries reported, followed by knee internal derangements and patellar injuries (6.2% and 3.7%, respectively).[29] Game play presents athletes with a higher likelihood of lower extremity injury compared to practice situations. In game play athletes are 2 times more likely to sustain an ankle ligament sprain (2.33 injuries per 1,000 athlete-exposures vs. 1.06 injuries per 1,000 athlete-exposures) or knee internal derangement (0.66 injuries per 1,000 athlete-exposures vs. 0.25 injuries per 1,000 athlete exposures) compared to practice.[29]

Women's basketball follows similar trends to men's basketball in that the injury rate during game play is two times higher than that of practice. The game injury rate for women's basketball is 7.68 injuries per 1,000 athlete-exposures while the practice injury rate is 3.99 injuries per 1,000 athlete-exposures.[4] Over the 16-year period that the NCAA Injury Surveillance System was collecting data, 3,556 injuries were collected in women's basketball.[4] Pre-season practice injury rates were consistently higher than that of competitive season injury rates (6.75

injuries per 1,000 athlete exposures compared to 2.84 injuries per 1,000 athlete exposures).[4] Competitive season games demonstrated an increased injury rate at 7.74 injuries per 1,000 athlete exposures compared to post-season injury rates at 5.52 injuries per 1,000 athlete exposures.[4] Of all injuries reported in women's basketball, more than 60% occurred at the lower extremity.[4] The most common type and location of injury during women's basketball was ankle ligament sprains, accounting for 24.6% of all injuries, followed by knee internal derangements at 15.9% of all injuries.[4] As with many of the other lower extremity dominant sports, 30% of all ankle ligament sprains are re-injuries, a common issue surrounding ankle ligament sprains.[4]

2.1.5 Field Hockey

The primary mechanisms of injury in women's field hockey is direct player contact, other contact (balls, sticks, ground), and no contact.[30] During game play, 60% of all injuries are a result of other contact. This means that the injury was a result of contact with either a stick or ball.[30] 26.0% of injuries during game play are a result of no contact, while 13% of all injuries are a result of direct player contact.[30] During practice, approximately 64% of all injuries are a result of non-contact mechanisms.[30]

During women's field hockey participation, injury rates associated with game play are twice as high as injury rates associated with practice (7.87 injuries per 1,000 athlete-exposures vs. 3.70 injuries per 1,000 athlete-exposures).[30] Game injury rates do not differ based on timing of the season (pre-season, competitive season, post-season) ($p = 0.34$).[30] However, practice injury rates during the pre-season are three times higher than during the competitive season (6.37 injuries per 1,000 athlete-exposures vs. 2.21 injuries per 1,000 athlete-exposures; $p < 0.01$).[30] Pre-season practice injury rates are almost four times higher than post-season practice injury rates (6.37 injuries per 1,000 athlete-exposures vs. 1.63 injuries per 1,000 athlete-exposures; $p < 0.01$).[30] Of all game injuries, 40.0% occur at the lower extremity, while 60.0% of all practice injuries occur at the lower extremity.[30] During game play, 13.7% of all injuries associated with women's field hockey are ankle ligament sprains, while knee internal derangements account for 10.2% of all injuries.[30] 26.9% of all practice injuries suffered during women's field hockey are upper leg muscle strains, ankle ligament sprains account for 15.0% of all injuries, and pelvis-hip muscle strains account for 9.9% of all injuries.[30] The risk of sustaining a knee internal derangement and/or ankle ligament sprain is greater during game play compared to practice.[30] Game rates of knee internal derangements are three times greater than practice rates (0.57 injuries per 1,000 athlete-exposures vs. 0.20 injuries per 1,000 athlete-exposures).[30] Ankle ligament sprains are twice as likely during game play compared to practice (0.76 injuries per 1,000 athlete-exposures vs. 0.37 injuries per 1,000 athlete-exposures).[30]

2.1.6 Ice Hockey

The primary mechanisms of injury for both men's and women's ice hockey are the same, direct player contact, other contact (pucks, boards, ice), and no contact.[1, 2] During game play, half of all injuries that occur are a result of direct player contact while participating in men's ice hockey.[2] 40.0% of the other injuries that occur during men's hockey game play are a result of other contact with either the boards, a stick, or the puck.[2] In women's ice hockey, a majority of the game injuries (48.1%) are a result of direct player contact.[1] 40.9% of all other women's ice hockey game injuries are a result of other contact.[1] During men's ice hockey, the injuries that occur during practice are equally distributed between direct player contact, other contact, and non-contact mechanisms.[2] In women's ice hockey, the primary mechanisms of injury during practice is non-contact and other contact.[1]

The injury rate during game play for men's ice hockey is 16.27 injuries per 1,000 athlete-exposures, while the practice injury rate is 1.96 injuries per 1,000 athlete-exposures.[2] The injury rate during game play for men's ice hockey is eight times greater than during practice.[2] Pre-season practice injury rates are two times greater than competitive season practice injury rates (5.05 injuries per 1,000 athlete-exposures vs. 1.94 injuries per 1,000 athlete-exposures; $p < 0.01$).[2] Competitive season game injury rates are just slightly higher than post-season game injury rates during participation in men's ice hockey (16.27 injuries per 1,000 athlete-exposures vs. 11.91 injuries per 1,000 athlete-exposures; $p < 0.01$).[2] 34.3% of all game injuries occur at the lower extremity, while 35.9% of all injuries during practice occur at the lower extremity.[2] In men's ice hockey game play, 13.5% of all injuries are knee internal derangements.[2] During practice, 13.1% of all injuries are pelvis and hip muscle strains, followed by knee internal derangements accounting for 10.1% of all injuries, and ankle ligament sprains accounting for 5.5% of all injuries.[2] The likelihood of suffering a knee internal derangement during men's ice hockey is 11 times more likely in game play than at practice (2.20 injuries per 1,000 athlete-exposures vs. 0.20 injuries per 1,000 athlete-exposures).[2] The risk of suffering a pelvis or hip muscle strain is three times greater in men's ice hockey game play than practice (0.73 injuries per 1,000 athlete-exposures vs. 0.26 injuries per 1,000 athlete-exposures).[2]

Women's ice hockey has a game injury rate of 12.6 injuries per 1,000 athlete-exposures.[1] The practice injury rate for women's ice hockey is 2.5 injuries per 1,000 athlete-exposures.[1] The rate of injury during game play is on average five times greater than the rate of injury during practice ($p < 0.01$).[1] Pre-season women's ice hockey practice injury rates are two times greater than competitive season practice injury rates (4.2 injuries per 1,000 athlete-exposures vs. 2.3 injuries per 1,000 athlete-exposures; $p < 0.01$).[1] There are no differences noted in injury rates between different times of the season (pre-season, competitive season, post-season) for game play.[1] Lower extremity injuries account for 31.8% of all game injuries and 31.1% of all practice injuries during participation in women's ice hockey.[1] In game play, knee internal derangements account for 12.9% of all injuries.[1] During practice, 12.0% of all injuries are pelvis or hip muscle-tendon strains, while foot contusions account for 7.2% of all injuries.[1] Women's ice hockey game play has an 11 times greater risk of knee internal derangement during game play compared to practice (1.63 injuries per 1,000 athlete-exposures vs. 0.15 injuries per 1,000 athlete-exposures).[1]

2.1.7 Lacrosse

The primary mechanisms of injury for men's lacrosse are similar to those of football, which has similar sport demands; direct player contact, other contact (balls, sticks, ground), and no contact.[32] During game play, 45.9% of all men's lacrosse injuries are a result of direct player contact.[32] The remainder of the injuries associated with men's lacrosse, occurring during game play, are a result of other contact, specifically contact with a stick, or non-contact mechanisms.[32] The primary mechanism of injury during practice is non-contact mechanism, accounting for 50.0% of all injuries.[32]

The overall injury rate for men's lacrosse is 12.58 injuries per 1,000 athlete-exposures during game play and 3.24 injuries per 1,000 athlete-exposures during practice.[32] The game play injury rate for men's lacrosse is almost four times greater than the practice injury rate.[32] Over the course of the data collection period for the NCAA Injury Surveillance System pre-season practice injury rate were two times greater than competitive season practice injury rates (4.84 injuries per 1,000 athlete-exposures vs. 1.99 injuries per 1,000 athlete-exposures; $p = 0.01$).[32] Injury rates during competitive season games are two times greater than injury rates during post-season games (12.60 injuries per 1,000 athlete-exposures vs. 7.54 injuries per 1,000 athlete-exposures; $p < 0.01$).[32] Lower extremity injuries account for 48.1% of all game injuries and 58.7% of all practice injuries during participation in men's lacrosse.[32] During game play a majority of these injuries are ankle ligament sprains (11.3%), followed by knee internal derangements (9.1%). 16.4% of all practice injuries during men's lacrosse participation are ankle ligament sprains, followed by upper leg muscle-tendon strains (11.4%), and knee internal derangements accounting for 7.1% of all injuries.[32] During men's lacrosse participation, knee internal derangements are five times more common in game play than practice (1.14 injuries per 1,000 athlete-exposures vs. 0.23 injuries per 1,000 athlete-exposures).[32] Game play ankle ligament sprain rates are three times higher in game play compared to practice (1.43 injuries per 1,000 athlete-exposures vs. 0.53 injuries per 1,000 athlete-exposures).[32]

2.2 RISK FACTORS FOR LOWER EXTREMITY MUSCULOSKELETAL INJURY

2.2.1 Sex (Non-modifiable)

Sex is a well-documented risk factor for lower extremity musculoskeletal injury.[72] Female athletes have demonstrated an increased risk of lower extremity musculoskeletal injury, specifically ACL sprain, compared to male athletes.[72] Female handball athletes have demonstrated a five times greater risk of suffering an ACL injury compared to male handball athletes.[73] A relative risk of 2.44 has been demonstrated in female military recruits participating in intercollegiate sports, coed intramural sports, and military training compared to male military recruits.[42] Collegiate female soccer athletes have demonstrated a nine times greater risk of sustaining an ACL tear compared to collegiate male soccer athletes.[42] Although this is true in soccer athletes, the same risk of ACL tear is not present in female basketball and rugby athletes.[42] Coed intramural college soccer demonstrates similar risk of ACL tear with female athletes having a seven times greater risk of injury compared to male athletes.[42] The relative risk of ACL injury within military training for females is 9.74 compared to males.[42]

Sex also has links to other injuries, although these links are less understood.[72] Female athletes participating in professional basketball suffer 60% more knee and thigh injuries than male athletes participating in professional basketball.[103] In a population of youth soccer athletes, females demonstrate a greater overall injury incidence compared to males.[9] The overall injury incidence for female youth athletes is 10.6 injuries per 1,000 hours of exposure, compared to the overall injury incidence for male athletes which is 7.3 injuries per 1,000 hours of exposure.[9] In military recruits, the incidence of all injuries in women was two times greater than in men participating in basic combat training.[57] In this instance, the risk of all injuries for women was 1.16 injuries per 1,000 person days of exposure, compared to the risk of all injuries for men at 0.56 injuries per 1,000 person days of exposure.[57] In a similar population of military recruits, it has been determined that the relative risk of injury for women is 2.1 (CI = 1.78 to 2.5).[13] Female high school and collegiate basketball athletes also demonstrate a greater risk of musculoskeletal injury compared to male high school and collegiate basketball athletes.[49] Female basketball athletes demonstrated a relative risk of 1.26 (RR = 1.00 for male basketball athletes) of sustaining a grade I ankle sprain compared to male basketball athletes.[49]

2.2.2 Limb Dominance (Non-modifiable)

Limb dominance has been demonstrated to be associated with the risk of musculoskeletal injury in certain sports. Typically, the sports that involve kicking, pushing off, jumping, and/or landing.[12] The reason limb dominance is important is because these movements predominantly occur on the dominant leg as opposed to the non-dominant leg.[12] College athletes have demonstrated an increased risk of musculoskeletal injury when they are right leg dominant as opposed to left leg dominant participating in soccer, field hockey, and lacrosse.[12] These right leg dominant athletes have an increased risk of ankle injury compared to the left leg dominant athletes.[12] In male soccer athletes more ankle injuries occur in the dominant leg compared to the non-dominant leg (92.3%).[35] Male soccer athletes also suffer more contact knee injuries in the dominant knee compared to the non-dominant knee.[24] The risk of sustaining a quadriceps strain in the dominant leg of a netball athlete is higher than in the non-dominant leg of a netball athlete.[76] The relative risk of sustaining a quadriceps strain in the dominant leg is 2.13 (95% CI = 1.59 to 2.86) in female netball players.[76]

There is evidence that limb dominance affects side-to-side differences, including flexibility, strength, and dynamic tasks like jump landing.[20, 36] These differences are attributed to the greater demand that athletes place on their dominant limb compared to their non-dominant limb. [16, 28] Limb dominance is often linked to lower extremity kinematics during jump landing tasks. [16, 28] The demand that the dominant limb must meet often increases the frequency and magnitude of the moments at the knee and ankle, subsequently increasing the risk of injury.[15, 19] During tasks that require increased shock absorption and force production, such as jump landing or running, limb dominance negatively affects the dominant limb compared to the non-dominant limb. [17] The dominant limb often experiences increased forces compared to the non-dominant limb, placing the dominant limb at increased risk of injury compared to the non-dominant limb. [17]

2.2.3 Previous Lower Extremity Musculoskeletal Injury (Non-modifiable)

The evidence that previous lower extremity musculoskeletal injury increases the risk of suffering another lower extremity musculoskeletal injury is strong.[72] Injury at the knee and ankle are common after suffering an injury that is followed by inadequate rehabilitation, compromising the neuroreceptors that innervate the joints.[16] In a population of Australian football athletes, those athletes with a history of lower extremity muscle strain sustained a second strain within eight weeks of the first injury.[76] The risk of re-injury at the hamstring is 6.33, at the quadriceps it is 15.61, and at the calf it is 8.94.[76] This risk also occurs beyond the eight-week time frame with the risk of hamstring strain being 2.42, the risk of quadriceps strain being 3.67, and the risk of calf strain being 4.28.[76]

The reason re-injury is common in athletes is that inadequate rehabilitation leads to compromised neuromuscular characteristics in the lower extremity.[72] These compromised neuromuscular characteristics include proprioceptive defects (functional instability), muscle strength impairment and imbalances, persistent ligamentous laxity (mechanical instability), diminished muscle flexibility and joint movement, and localized scar tissue which leads to constant discomfort.[72] Inadequate rehabilitation and the presence of these negative neuromuscular characteristics have been linked to lower extremity musculoskeletal injury.[72] In a population of male soccer athletes who had inadequate rehabilitation following injury the risk of re-injury was greater than those who had proper rehabilitation.[34] Within 2 months of initial injury 32 out of 124 athletes (25.8%) suffered a minor injury.[34] 13 of these 32 athletes (10.5%) suffered an injury of the same type and location as the initial injury. In Australian football athletes, the risk of ACL injury in those who had previously sustained an ACL injury and were not physically ready to return to the former level of competition in a 12-month period was 4.44 injuries per 1,000 athlete exposures (CI = 2.46 to 8.01).[75]

2.2.4 Body Size (Modifiable)

Body size has been theorized to be a modifiable risk factor for lower extremity musculoskeletal injury.[9, 54, 71, 76] Significant risk of lower extremity musculoskeletal injury has also been attributed to the Body Mass Index, total body mass, body fat percentage, lean muscle mass, Quetelet index, mass moment of inertia (weight x height^2), and height.[9, 16, 48, 54, 71, 76] These variables are all theorized to produce increases in forces that the articular, ligamentous, and muscular structures must resist. The extreme ends of the Body Mass Index, outside of the healthy range, have demonstrated increased risk of lower extremity musculoskeletal injury.[54] Male military recruits at the extreme ends of the Body Mass Index, above and below the healthy range, demonstrate an increased incidence of lower extremity musculoskeletal injuries three times greater than male military recruits who fall within the healthy range (middle 50%) of the Body Mass Index.[54] Those military recruits who fall in the overweight and obese range of the Body Mass Index demonstrate an incidence in lower extremity musculoskeletal injuries two times greater than military recruits within the remaining ranges of the Body Mass Index.[54]

This same risk of lower extremity musculoskeletal injury has been demonstrated with overall increases in body fat percentages.[54] Both the Body Mass Index and calculations of body fat percentage are dependent on height, but height alone has also been linked to additional risk of lower extremity musculoskeletal injury. Increased total body mass is a desirable trait for participation in sports such as football, more specifically the football linemen (offensive or defensive).[41] Success as a lineman is directly related to having an increased body size, although this does not mean excessive body fat percentages.[41] Increased body fat percentages have been linked to lower physical activity levels, agility, and flexibility.[41] Each of these performance indicators, if negatively affected by increased body fat percentages can negatively affect athletic performance.[41] Increased body fat percentages also increase joint loading, which has been linked to decreased physical activity levels.[41] Youth football athletes at heavier weights have more musculoskeletal injuries than youth football athletes at normal weights.[41] Higher levels of both body fat and Body Mass Index are associated with increased risk of musculoskeletal injury in youth football lineman.[41]

Height affects the position of body mass and body fat on an individual's body, leading to changes in center of mass and subsequently an individual's postural stability.[54] Female military recruits of shorter height have demonstrated a more significant risk of sustaining a lower extremity musculoskeletal injury compared to female military recruits of taller height.[54] Male youth soccer athletes have an increased incidence of injury when the athletes are taller than 165 cm. Shorter height, less than 182 cm, in Australian football athletes has also been associated with quadriceps muscle injury (RR = 1.48).[76] Male military recruits who demonstrate a larger mass moment of inertia have a significantly increased risk of sustaining a lateral ankle sprain compared to male military recruits who do not demonstrate this mass moment of inertia.[71]

2.2.5 Flexibility (Modifiable)

Flexibility generally describes a number of unique issues surrounding joint laxity and muscle stiffness. The varying gradation of flexibility significantly affect risk of lower extremity musculoskeletal injury. Generalized joint laxity is the most commonly referred to gradation of flexibility. Prospective data describing a population of women's soccer athletes illustrated athletes who demonstrated greater generalized joint laxity were five times more likely to sustain an injury compared to athletes who demonstrated less generalized joint laxity.[77] A similar population demonstrated that athletes with increased generalized joint laxity were at three times greater risk of traumatic lower leg musculoskeletal injury than athletes with decreased generalized joint laxity.[94] Beyond generalized joint laxity, more localized joint laxity may occur at specific joints. Joint laxity associated with the ankle is typically diagnosed with an anterior drawer or talar tilt test.[6] Increased ankle joint laxity as assessed by either of these tests has been associated with increased risk of injury in a comparison of athletes who demonstrate this specific joint laxity pattern compared to those who do not.[6] At the knee joint laxity has been associated with lower extremity musculoskeletal injury.[35] Athletes who demonstrate increased medial joint laxity have exhibited a significant increase in knee injuries compared to those who do not demonstrate these characteristics.[35] Knee joint laxity diagnosed during varus/valgus and anterior/posterior clinical examination in male soccer athletes has been associated with a significant risk of lower extremity musculoskeletal injury.[24] A similar population has demonstrated a significant risk of musculoskeletal injury at both the knee and ankle when clinical tests of laxity, including the anterior draw test, demonstrate increased laxity.[6]

Other components of flexibility, beyond generalized joint laxity and specific joint laxity, include muscle tightness and range of motion.[16, 54, 58, 67, 94] Both muscle tightness and range of motion have previously been associated with risk of lower extremity musculoskeletal injury.[16, 54, 58, 67, 94] Increased iliopsoas tightness has been linked to overuse lower extremity injuries in male soccer athletes.[58] General stretching, a modality utilized to decrease muscle tightness, prior to participation in sport has been linked to changes in lower extremity musculoskeletal injury risk.[67] In a population of elite and recreationally active basketball athletes, athletes who did not stretch during their warm up were at significantly increased risk of lower extremity musculoskeletal injury compared to athletes who did stretch during their warm up.[67] Range of motion is impacted by both joint laxity and muscle tightness.[94] Range of motion has been previously linked to both ankle injury and general lower extremity musculoskeletal injury. In a population of female soccer athletes, knee hyperextension beyond ten degrees has been demonstrated as a risk factor for lower extremity musculoskeletal injury. Side to side differences in ankle dorsiflexion range of motion and hamstring flexibility have links to risk of overuse lower leg injuries.[94]

More specifically tightness of the soft tissues surrounding the lower extremity has a significant impact on risk of lower extremity musculoskeletal injury.[81] Patellofemoral pain syndrome has been previously linked to tightness of the gastrocnemius, quadriceps, and hamstring muscles, in addition to the iliotibial band and tensor fasciae latae.[53, 59, 63, 93] Issues surrounding tightness in any of these musculoskeletal structures causes maltracking of the patella, which is a main component of patellofemoral pain syndrome.[81] At the quadriceps, limited flexibility, has been demonstrated as being associated with poor biomechanical outcomes, including pulling the patella superiorly.[93] With the patella being pulled superiorly there is an increase in the compression of the patellofemoral joint during both static and dynamic movements.[93] At the ankle, when flexibility is lacking in the gastrocnemius, soleus muscle complex there is limited ankle dorsiflexion mobility.[81] During dynamic movements such as gait, this lack of dorsiflexion mobility results in excessive subtalar joint pronation and tibial internal rotation.[59] The reason these two compensations occur during dynamic movements, such as gait, is because they allow for increased range of motion during the terminal stance phase of gait.[59]

Although these two compensations may be a way to increase range of motion they also lead to increased femoral internal rotation, as well as an increased Q-angle.[59] Both increased femoral internal rotation and increased Q-angle have been linked to increased stress at the patellofemoral joint.

2.2.6 Strength (Modifiable)

Strength, defined as overall muscle strength and strength ratios, comparing the dominant to non-dominant lower extremity and agonist to antagonist pairs, is a highly modifiable risk factor for lower extremity musculoskeletal injury.[12, 35, 94] Muscle contraction, measured as muscle strength, imbalance of extensor muscles compared to flexor muscle and reaction time may all be linked to risk of lower extremity musculoskeletal injury. Risk of injury, specifically at the ankle and knee, as well as injuries characterized by overuse, has been associated with deficits in overall strength and strength imbalances.[12, 35, 94] Ankle sprains have been attributed to strength imbalances at the ankle joint in college-age athletes.[12] Athletes who demonstrated lower ratios of dorsiflexion to plantarflexion (0.373 vs. 0.348) along with higher ratios of eversion to inversion (1.000 vs. 0.800) strength suffer an increased number of ankle injuries compared to those athletes who did not demonstrate these imbalances.[12] Hamstring to quadriceps strength ratio is also a significant factor in musculoskeletal injury of the lower extremity.[94] A decreased ratio of hamstring to quadriceps strength has been demonstrated as a risk factor for traumatic leg injury (OR = 0.95) while the opposite, an increased hamstring to quadriceps ratio have been demonstrated as a risk factor for overuse leg injury (OR = 1.13) in a population of female soccer athletes.[94] Significantly reduced quadriceps strength in a population of male soccer athletes, has been demonstrated in the injured lower extremity compared to the non-injured lower extremity in athletes who suffered a non-contact knee injury, demonstrating the significance of dominant to non-dominant strength imbalances.[35]

Muscle strength in itself has been demonstrated to be a risk factor for lower extremity musculoskeletal injury, but diminished strength may also affect other risk factors for lower extremity musculoskeletal injury, including dynamic postural stability.[74] Weaknesses at the hip are of specific importance.[77] Hip external rotation and hip adduction are important contributors to pelvic stability and lower extremity boney alignment.[77] Weaknesses in the hip external rotators and hip adductors increase medial femoral rotation, valgus knee moments, and gluteus medius gait.[77] All of these biomechanical abnormalities are detrimental to proper function during both static and dynamic movements as well as increase an athlete’s risk of lower extremity musculoskeletal injury.[81]

2.2.7 Postural Stability (Modifiable)

The motor control system is made up of subcomponents of which the sensorimotor system is one. The sensorimotor system is the integration of the sensory, motor, and central integration and processing components involved in maintaining functional joint stability.[92] Functional joint stability is the process by which homeostasis is maintained at the level of the joint during both static and dynamic movements.[85] In its most simplistic form, the sensorimotor system has been described as the activation of dynamic restraints which maintain functional joint stability.[85] This activation requires the entire motor control system, as opposed to specific individual pathways that are responsible for simplistic input-output actions.[85] When musculoskeletal injury occurs, the sensorimotor system is impacted negatively, drastically changing the function of the sensorimotor system and its ability to maintain functional joint stability effectively.[85] Loss of mechanical stability is associated with musculoskeletal injury; this loss requires compensatory mechanisms to be developed in order to regain pre-injury levels of functional joint stability.[85] The development of compensatory mechanisms suggests that the dynamic restrains are a major factor in maintaining functional joint stability prior to and following musculoskeletal injury. The dynamic restrains necessary for these processes are mediated by neuromuscular control. Neuromuscular control is defined as any aspect surrounding the nervous system control over muscle activation and static and dynamic task performance.[85] Neuromuscular control is responsible for the unconscious activation of these dynamic restrains which maintain and return to functional joint stability.[85] The maintenance of these dynamic restrains is essential to proper function and avoidance of musculoskeletal injury.[85]

Another foundation of functional joint stability is proprioception. Proprioception is defined as contributing to postural control, functional joint stability, and other conscious sensations through afferent information, which arise from internal peripheral areas of the body.[85, 86] All dynamic tasks encompass specific functions allowing the body to prepare, maintain, and restore stability at the level of the body and at the level of the joint.[85, 86] In order for these tasks to be executed correctly, proprioceptive information must be moved from joint and muscle mechanoreceptors to a central repository within the sensorimotor system.[85, 86] Proper joint stability is necessary for lower extremity musculoskeletal injury prevention. Without proper joint stability, the ability for the joint to maintain functional joint stability is compromised, placing the joint in a position of poor and improper functioning. [85, 86] From a clinical injury standpoint, the peripheral mechanoreceptors are the most significant factor in proprioception and subsequently functional joint stability and the sensorimotor system. [80, 81] Peripheral mechanoreceptors are housed in cutaneous, muscular, joint, and ligamentous tissues.[37, 43, 85, 86] Activation of any motor neuron can cause a reaction in the form of a direct response from the peripheral mechanoreceptors through sensory input or reflexes or motor commands descending from motor neurons to peripheral mechanoreceptors.[78, 85, 86]

Postural stability has been identified as bring a significant predictor of lower extremity musculoskeletal injury.[66, 94, 96] Diminished postural stability is associated with altered neuromuscular control strategies, increased intersegmental joint forces, and increased forces developed about the articular, ligamentous, and muscular structures of the lower extremity.[72] Alterations in any of these musculoskeletal characteristics are strong contributors to musculoskeletal injury. Increased postural sway or movement away from the center of mass characterizes poor or diminished postural stability. In a population of high school age basketball athletes, a seven times greater risk of ankle sprain is associated with athletes who demonstrated poor postural stability and increase sway compared to athletes who demonstrate normal postural stability and sway.[66] A similar risk of lower extremity musculoskeletal injury has been demonstrated in male soccer athletes; poor postural stability, increased postural sway, placed athletes at increased risk of injury.[96] Increased risk of general lower leg musculoskeletal injury in female soccer athletes is characterized by diminished postural stability, and increased sway (OR = 0.31).[94]

Performance of lower extremity dominant sports requires proper dynamic balance and control of the lower extremity throughout the duration of both static and dynamic movements. It has been previously assumed that increased postural stability leads to decreased risk of lower extremity musculoskeletal injury.[74] A study on female athletes has demonstrated the opposite. Female athletes who demonstrated decreased postural sway during a single-legged stance task have a higher risk of lower extremity musculoskeletal injury.[94] This may be of importance because it demonstrates that although dynamic postural stability as a whole is important, it is a complex function that is influenced by multiple factors that are all being challenged at once. Because there are so many factors involved, this means one test may not actually look at all the components and may not actually give an accurate picture of lower extremity musculoskeletal injury risk. Proper functional balance and control of the lower extremity are essential for both technical and tactical performance as a soccer player, and one would assume that such attributes contribute to being less prone to injuries.[74] Several studies that have demonstrated that poor dynamic postural stability is a risk factors for lower extremity musculoskeletal injury. In a study of high school basketball athletes, those who had lower levels of dynamic postural stability were at increased risk for lower extremity musculoskeletal injury.[21] More specifically, issues with dynamic postural stability have been shown to be associated with ankle sprain in recreationally active adults.[65] When comparing injured populations to uninjured populations, individuals with a history of chronic ankle instability demonstrate diminished dynamic postural stability in comparison to those who do not have chronic ankle instability.[45, 89] The same holds true for individuals with a history of ACL tear compared to those who do not have a history of ACL tear.[44]

2.2.8 Fatigue and Deconditioning (Modifiable)

Central and peripheral fatigue have a significant impact on the risk of injury during athletic competition. Fatigue is associated with general decrease in performance, but neuromuscular adaptations and the ability to overcome fatigue are dependent on the intensity and duration of athletic competition.[18, 26] A clear example of this is athletes who are injured early in game or practice play are typically playing at a higher level of intensity over a shorter duration than those who become injured later in game or practice play.[18, 26] Approximately 70.0% of all ACL tears are attributed to non-contact mechanisms of injury, which occur toward the later stages of game or practice play when the impact of central and peripheral fatigue is a significant factor.[18, 62] The role of fatigue in biomechanical control is of specific importance, because changes in biomechanical control shift the athlete's movement patterns toward risky movement patterns, increasing risk of lower extremity musculoskeletal injury.[26] Fatigue allows unanticipated stimuli to interrupt otherwise natural movement patterns, pushing them in a direction of stress.[26] Following a fatigue protocol including patterns of repeat vertical jumps and sprints, there was a significant increase in proximal anterior tibial sheer force, knee valgus moment, as well as a decrease in knee flexion angle in collegiate athletes.[23] Additional studies examining the role of fatigue on risk factors for lower extremity musculoskeletal injury in collegiate athletes, demonstrated differences in frontal plane knee kinematics and kinetics.[68] These kinematic and kinetic changes have been attributed to both central and peripheral fatigue.[26]

Localized muscle fatigue, specifically at the lower extremity has previously been demonstrated to result in subsequent loss of stability while attempting to maintain center of mass over the base of support.[52] The control of posture is significantly impacted by the presence and persistence of localized muscle fatigue.[98] In its most simplistic form muscle fatigue is a reduction in the force generating capacity without regard to the task being performed.[17] At a global level, central fatigue, impacting the entire kinetic chain, induces a failure of motor neurons limiting their excitation, all due to overall changes in the nervous system.[38] These overall changes in the excitation levels of the motor neurons is theorized to be caused by changes in intrinsic properties of the motor neuron itself, recurrent and regular inhabition, and dysfunction of the descending motor neurons which work to protect the peripheral level of function.[61, 87, 100] The basic impact of fatigue at the peripheral level of the lower extremity joints is that fatigue forces a failure of the transmission of any and all neural signals, leading to a failure of the muscles to respond to any neural excitation.[17]

Altered landing kinematics have been theorized to be a strong predictor of lower extremity musculoskeletal injury.[18, 62] Altered landing kinematic patterns include changes in knee rotation and knee flexion, each of which have been demonstrated under fatigue situations.[26] In addition, changes in hip flexion and posterior ground reaction forces have also been demonstrated under fatigue situations. Positions of extension, including at the knee and hip during landing are associated with increases in proximal anterior tibial sheer force, a strong predictor of ACL injury due to the load the ACL must bear during landing when these positions are present.[23, 51, 79] This extended position places the hamstring in a mechanical disadvantage due to its inability to contract strongly enough at smaller angles to produce a large posterior force. [13, 30, 43] This posterior force is necessary to counteract the proximal anterior tibial sheer force at the knee.[79] Altered movement patterns following periods of fatigue have also demonstrated increase in knee abduction and internal rotation ankles, increased hip rotation angles, hip internal rotation moments, and decreased knee flexion angles.[23]

2.3 LOWER EXTREMITY MUSCULOSKELETAL INJURY SURVEILLANCE

Prior to developing injury prevention initiatives for lower extremity musculoskeletal injuries in athletes, it is important to understand the descriptive epidemiology of these musculoskeletal injuries, as well as the intrinsic risk factors that are potentially modifiable. Identifying risk factors includes ascertaining the temporal sequence of events, so that a causal association can be proven. Assessment of injuries in an athletic population should be scientifically driven, culturally specific, and population-specific.[91] By formulating research questions in this manner, the relevance to the population is significantly improved, improving the effectiveness of injury prevention initiatives. Furthermore, musculoskeletal injury evaluation should be comprehensive. Traditionally, the focus has been on one type of injury or one joint, but this limits the usefulness of the prospective data collection. A successful prospective identification of injuries will accommodate many injuries and many types of athletes. Lastly, identifying and understanding the unique demands of the athletes, how they must prepare, and the demands they must meet, allows for the optimal injury prevention initiative to be produced.[91]

In order to address the unique demands of athletes and understand how injury prevention initiatives should be designed, injury surveillance should be the first step. Injury surveillance is defined as the systematic and continuous collection, analysis, and interpretation of musculoskeletal injury data which is integrated with both timely and coherent dissemination of results.[82] Following the initial step of injury surveillance should be an understanding of the predictors of injury and optimal performance unique to this population.[91] The injury surveillance portion of the process allows for an understanding of the scope and magnitude of musculoskeletal injuries.[91] Injury surveillance can determine the most common injuries specific to the population of interest.[91] Previous research utilizing injury surveillance systems has demonstrated an increased need for both strategies and injury prevention initiatives focused on common preventable injuries within the unique population of interest.[91] Despite previous attempts to do this in athletic populations, there are still a significant amount of injuries occurring in athletic populations, consistently affecting both the short-term and long-term well-being of the athletes. Predictors of injury and optimal performance include an understanding of modifiable neuromuscular, biomechanical, physiological, musculoskeletal, and nutritional characteristics. Information gathered during the injury surveillance period should include the type of injuries (anatomical location, tissues involved, acute, overuse), where injuries occur, activity performed when injury occurred, and the mechanism of injury.[91] Traditionally, these data are collected by self-report or through chart reviews of existing medical data.[91] Assessing the predictors of injury and optimal performance requires task-specific assessments of musculoskeletal characteristics.[91] This attempts to identify the specific demands of the target population and how these musculoskeletal characteristics specifically affect the unique demands of the athlete and their sport.[91] The true goal of the task and demand analysis is to identify modifiable risk factors that predict injury and performance that can be targeted with specific interventions and injury prevention initiatives.[91]

Task and demand analysis has been completed previously as a part of the University of Pittsburgh Injury Prevention Initiative in combination with clinical knowledge of the investigators conducting testing for the University of Pittsburgh Injury Prevention Initiative. All athletes need a certain level of range of motion, flexibility, strength, and postural stability in order to perform the tasks necessary for successful athletic participation. Athletes participating in lower extremity dominant sports are subjected to repeated running and jumping. This requires increased flexibility and strength for the purposes of acceleration and deceleration, as well as increased levels of postural stability in order to maintain functional joint stability following landings from repeated jumps. Successful completion of these tasks is paramount to athletic performance.

The NCAA Injury Surveillance System was developed for the purpose of collecting injury and exposure data from a representative sample of NCAA institutions, encompassing a variety of sports.[27] 250 different institutions participate annually with data collection being performed by the certified athletic trainers at the institutions.[27] Participation in this program is voluntary and each participating school was only asked to collect data from two sports.[27] The data collection targeted 15% of schools with varsity sports from each NCAA division.[27] This sampling method was chosen because it allows for a representative cross-section of the NCAA institutions that field varsity sports.[27] The data collection period began on the first day of official pre-season practices and terminated on the final day of any post-season competition.[27] Athletic trainers from each of the participating NCAA institutions were instructed on how to submit reportable injuries and exposures. For each reportable injury, the athletic trainers were asked to fill out a form that contained 30-questions related to injury mechanism, site, type of injury, severity, and sport-specific questions.[27] Exposure forms were submitted weekly, the form included the weekly number of practices and competitions, the average number of participants, the season, playing surface, and location of competition.[27] Compliance with all methods was ensured within two weeks of the termination of the sports post-season competition.[27] Compliance was defined as having submitted exposure data for at least 70% of all possible participation weeks.[27] All sports that met this criteria were included in the sample.[27] Each of the participating institutions received a copy of their injury and exposure data, as well as the injury and exposure data for the corresponding NCAA division.[27] The NCAA Injury Surveillance System is the largest ongoing collegiate sports injury database in the world.[27] The data is used by the NCAA sports rules and sports medicine committee to inform rules and regulations, as well as sports medicine care.[27]

The University of Pittsburgh Injury Prevention Initiative was developed in 2010 as a joint initiative between the Neuromuscular Research Laboratory and the University of Pittsburgh, Department of Athletics.[22] The goal of this initiative was to combine the research capabilities, experience, and expertise of the Neuromuscular Research Laboratory with the current level of clinical care provided by the sports medicine staff at the University of Pittsburgh.[22] The idea is to improve the overall health of collegiate athletes, through decreasing the incidence of preventable musculoskeletal injuries.[22] To date the University of Pittsburgh Injury Prevention Initiative has tested over 300 athletes, encompassing six different University of Pittsburgh athletic teams. Like the NCAA Injury Surveillance System, the University of Pittsburgh Injury Prevention Initiative collects musculoskeletal injury data over the duration of each athletic season.[22] In addition, the University of Pittsburgh Injury Prevention Initiative collects pre-season measures of range of motion, flexibility, strength, and postural stability.[22] Collecting these musculoskeletal characteristics plus musculoskeletal injuries makes this initiative unique.[22]

The University of Pittsburgh Injury Prevention Initiative was built from the framework for developing and maintaining an injury surveillance system.[69] The first step in developing and maintaining an injury surveillance system is understanding the conceptual frame work of injury prevention.[69] This step includes defining and developing the typology of preventable musculoskeletal injuries.[69] During the development of the University of Pittsburgh Injury Prevention Initiative it was important that the definitions for both injury and exposure match the NCAA Injury Surveillance System definitions.[27] By utilizing the same definitions for injury and exposure, comparisons can be made across populations. For the University of Pittsburgh Injury Prevention Initiative an injury must meet the following criteria to be reportable: 1) injury occurred as a result of participation in an organized intercollegiate practice or contest, 2) injury required medical attention by a team certified athletic trainer or physician, and 3) injury resulted in restriction of the athlete's participation or performance for one or more days beyond the day of injury.[27] All injury rates for the University of Pittsburgh Injury Prevention Initiative are expressed as the number of injuries per 1,000 athlete-exposures.[27] Athlete exposure is defined as one athlete participating in one practice and/or one competition for the purposes of the University of Pittsburgh Injury Prevention Initiative.[27]

The second step in developing and maintaining an injury surveillance system is assessing injury data sources and describing the injury problem.[69] This step includes the identification of strengths and weakness of injury data sources and the size of the problem.[69] During the development of the University of Pittsburgh Injury Prevention Initiative, the NCAA Injury Surveillance System was used as a template for development of the new surveillance system.[27] The NCAA Injury Surveillance System has been successful at identifying injury incidence among collegiate athletes, for over 25 years.[27] The information gathered includes injury type, location, mechanism, and time loss for each injury.[27] The high injury incidence rates demonstrate a continued need for injury surveillance and subsequent injury prevention initiatives. Although there has been success in identifying the injury incidence in collegiate athletes and identifying the magnitude of the issue, the identification of risk factors for these injuries is missing. The NCAA Injury Surveillance System is lacking any measurement of risk factors prior to injury.[27] This was identified as a weakness prior to the development of the University of Pittsburgh Injury Prevention Initiative. During the development of the University of Pittsburgh Injury Prevention Initiative, investigators included measurement of known risk factors for musculoskeletal injury. This makes the University of Pittsburgh Injury Prevention Initiative unique, differentiating it from the NCAA Injury Surveillance System.[27]

Following identification of the strengths and weaknesses of current injury surveillance systems and understanding the magnitude of the problem, the stakeholders must be identified for the development of a new injury surveillance system.[69] Identifying the stakeholders includes building a coalition to support the injury surveillance system and prevention activities.[69] This step includes identifying the partners to include in a coalition to support the injury surveillance system.[69] The University of Pittsburgh Injury Prevention Initiative was initially developed as a collaboration between the researchers at the Neuromuscular Research Laboratory and the athletic trainers at the University of Pittsburgh.[22] The investment of the University of Pittsburgh Injury Prevention Initiative is with the NCAA Division I athletes at the University of Pittsburgh.[22] The initiative is set up to provide these athletes with information that assists in the mitigation of future musculoskeletal injuries and performance enhancement.[22] Athletes are the largest stakeholder in the University of Pittsburgh Injury Prevention Initiative. The coalition set up to support this initiative is the researchers from the Neuromuscular Research Laboratory, as well as the University of Pittsburgh athletic trainers, team coaches, strength and conditioning coaches, and administration. A partnership between these groups has made it possible for injury surveillance data to be collected over a 5 year time period, benefiting the athletes by promoting both short-term and long-term health and wellbeing.[22]

Developing and maintaining an injury surveillance system requires proper methodology, appropriate for the injury surveillance system being developed.[69] Developing appropriate methodology includes determining events, data elements, type of surveillance, and data collection instruments.[69] The University of Pittsburgh Injury Prevention Initiative was developed using elements of the NCAA Injury Surveillance System as a template.[27] Data collection methods were developed from testing strategies typical of the sports medicine clinical care received by collegiate athletes, including flexibility and range of motion measurements traditionally used in a clinical setting and handheld dynamometry for isometric strength.[22] These measures are both portable and easy to implement.[22] Each test was chosen by examining the mechanisms of common injuries in a population of NCAA Division I collegiate athletes.[22] In order to maintain an appropriate data collection timeframe per athletes, only tests that have been theorized to predict the musculoskeletal injuries that the University of Pittsburgh Injury Prevention Initiative was interested in collecting were included.[22] Previous research was utilized to determine which tests are theorized to predict these specific musculoskeletal injuries.[22]

The University of Pittsburgh Injury Prevention Initiative focuses on collecting only the most common injuries for each sport. For lower extremity dominant sports, including soccer, football, and volleyball, only lower extremity musculoskeletal injuries are collected.[22] The same is true for upper extremity dominant sports, including baseball and softball, where only upper extremity musculoskeletal injuries are collected.[22] By limiting the types of injuries collected, the surveillance system is more focused. How and what musculoskeletal injury data is collected is based on the NCAA Injury Surveillance System.[27] Both surveillances systems collection injury type, mechanisms of injury, injury location, and days missed due to injury. The University of Pittsburgh Injury Prevention Initiative also collects data relative to treatment of each injury. All injury data for both surveillances systems is collected for the duration of one competitive season, beginning the first day of pre-season and ending on the final day of competition (regular competitive season if no championship reached or post-season championship).[22] The athletic trainer assigned to each team reports on all injury data, which is confirmed by an investigator who is a trained clinician (athletic trainer or physical therapist).[22] Both the NCAA Injury Surveillance System and the University of Pittsburgh Injury Prevention Initiative also collect exposure data.[27] For both surveillance systems, exposures are collected as one athlete participating in one practice and/or one competition.[27] Collecting exposures allows for the calculation of injury incidence rate, described as the number of injuries per 1,000 athlete-exposures.[27]

The last steps in developing and maintaining and injury surveillance system are related to the analysis and dissemination of the results.[69] Defining and developing an analysis plan for the surveillance data includes a calculation of the indicators, demographics, and environmental characteristics.[69] Once this analysis plan is put into action the data should inform injury prevention.[69] By identifying the preventable musculoskeletal injuries, interventions can be developed for the groups deemed high-risk and most appropriate to receive the intervention.[69] Maintaining appropriate intervention initiatives requires an evaluation of the both the plan used for injury surveillance and all of the prevention activities.[69] This step is important for future mitigation of injuries and the continued success of injury prevention initiatives.[69] The University of Pittsburgh Injury Prevention Initiative is currently focused on the analysis portion of development and maintenance, with continued data collection, injury prevention initiatives will be developed and implemented as a means to mitigate musculoskeletal injury.[22]

2.4 METHODOLOGICAL CONSIDERATIONS

This methodological consideration section will review methodology previously utilized to evaluate similar parameters compared to those chosen for this study. This section will also provide a rationale for each of the methodologies chosen for this study. A detailed description of the protocol and methodologies specific to this study is provided in chapter 3.

2.4.1 Injury Surveillance and Exposure Tracking

Injury surveillance and exposure tracking for the present study is based on the University of Pittsburgh Injury Prevention Initiative.[22] Lower extremity musculoskeletal injury history was collected utilizing self-report.[22] Each athlete was responsible for disclosing their lower extremity musculoskeletal injury history, spanning the course of their lifetime.[22] Self-report has been utilized successfully by the Neuromuscular Research Laboratory for the purposes of collecting musculoskeletal injury history from Special Operations Forces Operators.[22] Injury surveillance occurred over the course of one athletic season. At the completion of each athletic season, the athletic trainer responsible for the care of teams included in the study will reported on all lower extremity musculoskeletal injuries suffered over the course of the season. These methods for injury surveillance have been utilized by the NCAA Injury Surveillance System with success.[27] By collecting musculoskeletal injury data from each of the athletic trainers responsible for the treatment and care of the teams included in the study, there is an increased likelihood of receiving valid and reliable injury data. Both the University of Pittsburgh Injury Initiative and the NCAA Injury Surveillance System collect musculoskeletal injury data that includes injury type, location, sublocation, mechanism of injury, onset, and time lost.[27] Exposures were collected on a weekly basis, with email surveys sent to each athletic trainer responsible for the care of the teams included in the study. Athlete exposures were collected as either a “yes” or “no” for each potential day of participation for each athlete. If an athlete participated for any amount of time during a potential day of participation it will be counted as a “yes” or one exposure. [27] If an athlete did not participation, for any amount of time during a potential day of participation, it will be counted as a “no” or zero exposure. [27] Athlete exposures are collected in this way as opposed to hours of participation because this method has been proven both reliable and valid through the

NCAA Injury Surveillance System. Collecting hours of athlete participation leads to increased reporting error. [27] These methods have been utilized successfully over the course of five years with the University of Pittsburgh Injury Prevention Initiative.[22]

2.4.2 Range of Motion and Flexibility Assessment

Assessment of lower extremity range of motion and flexibility allows for an establishment of the individual range of motion and flexibility of the muscles of the ankle, knee, and hip. The range of motion and flexibility tests chosen for this study include active ankle joint dorsiflexion mobility, ankle dorsiflexion, straight leg raise, and active knee extension. The range of motion and flexibility tests chosen for this study isolate the specific lower extremity muscles theorized to be related to lower extremity musculoskeletal injury. The flexibility and range of motion tests chosen for this study are also typical of the tests utilized by clinicians when caring for athletes. All lower extremity range of motion and flexibility testing procedures, chosen for this particular study, are based on pre-established procedures. [14, 97] [61, 62, 64] [8, 83] [36, 61, 62, 82, 83] Intra-rater and inter-rater reliability has been conducted within the Neuromuscular Research Laboratory and the ICCs are between 0.51-0.99 with SEMs between 0.97-13.00. The testing positions for each specific lower extremity muscle have been chosen based on previous research that has established that these specific testing positions provide the most valid measurements of lower extremity range of motion and strength. [14, 97] [61, 62, 64] [8, 83] [36, 61, 62, 82, 83]

2.4.3 Isometric Strength Assessment

Assessment of lower extremity isometric strength allows for an establishment of the individual strength of the muscles of the lower extremity including the muscles of the ankle, knee, and hip. The isometric strength tests chosen for this study include, ankle dorsiflexion, ankle plantarflexion, ankle eversion/inversion, knee flexion/extension, hip abduction/adduction, and hip internal/external rotation.[46] Isometric strength is a better choice to isolate these specific muscles when compared to isokinetic strength, because of the inability of isokinetic strength to differentiate between the strength of the individual lower extremity muscles and gross lower extremity strength.[46] Traditionally, the equipment associated with isokinetic strength testing is non-movable, expensive, and requires extensive tester training in order to utilize the equipment appropriately to assess the strength of the lower extremity. Using the handheld dynamometer, which has been chosen for this particular study, allows for the measures of isometric strength to be portable, as well as being more applicable to a clinical assessment of an athlete. The handheld dynamometer, as alluded to earlier, is also a better choice for isolating the lower extremity muscles as opposed to the Biodex which is better for large gross lower extremity movement strength assessment.[46] All lower extremity isometric strength testing procedures, chosen for this particular study, are based on grade five manual muscle testing pre-established procedures.[46] Intra-rater and inter-rater reliability has been conducted within the Neuromuscular Research Laboratory and the ICCs are between 0.20-0.98 with SEMs between 1.53-9.75. The testing positions for each specific lower extremity muscle have been chosen based on previous research that has established that these specific testing positions provide the greatest isometric contraction and isolate the individual lower extremity muscles appropriately.[46]

2.4.4 Postural Stability Assessment

Single leg balance performed on a force plate is a commonly accepted measure of static postural stability.[40] This protocol is both reliable and valid, as well as being sensitive enough to detect the standard deviation of ground reaction forces in three planes (anterior/posterior, medial/lateral, and vertical) during the 10 second trial.[40] This test is performed in a single-leg position (barefooted) under eyes-open and eyes-closed conditions. During the duration of the test the subject is asked to remain as still as possible with non-test leg raised to about the level of the tested ankle without touching the tested limb and while maintaining hands on hips.[40] The static postural stability protocol, chosen for this particular study, has established reliability (ICC = 0.71-0.94; SEM = 0.19-3.40 Newtons).[40]

Several methods have been proposed for use in determining dynamic postural stability, including the Star Excursion Balance Test and Y-Balance Test.[90, 99] Dynamic postural stability as measured by the Dynamic Postural Stability Index is both a reliable and valid measure of dynamic postural stability.[90, 99] The Dynamic Postural Stability Index is a jump task in which the sensitivity and objectivity of the test is strong enough to appropriately calculate three separate component scores in the anterior/posterior, medial/lateral, and vertical directions, as well as a composite score of these three component scores.[90, 99] The jump task associated with the Dynamic Postural Stability Index is an anterior/posterior jump off two-feet, terminating with a single leg balance and subsequent stabilization maintained for a total of five seconds.[90, 99] The jump is normalized to body height in order to standardize across subjects.[90, 99] The dynamic postural stability protocol, chosen for this particular study, has established reliability previously tested within the Neuromuscular Research Laboratory (ICC = 0.86; SEM = 0.01).[90, 99]

3.0 METHODOLOGY

3.1.1 EXPERIMENTAL DESIGN

This study utilized a prospective cohort design. A prospective cohort design was chosen in order to ascertain temporal association between risk factors for lower extremity musculoskeletal injury including range of motion, flexibility, strength, static postural stability, and dynamic postural stability measured at baseline and subsequent lower extremity musculoskeletal injury in NCAA division I male and female athletes at the University of Pittsburgh. The subject flow diagram in Figure 1 illustrates the study design, subject recruitment, enrollment, and procedures.

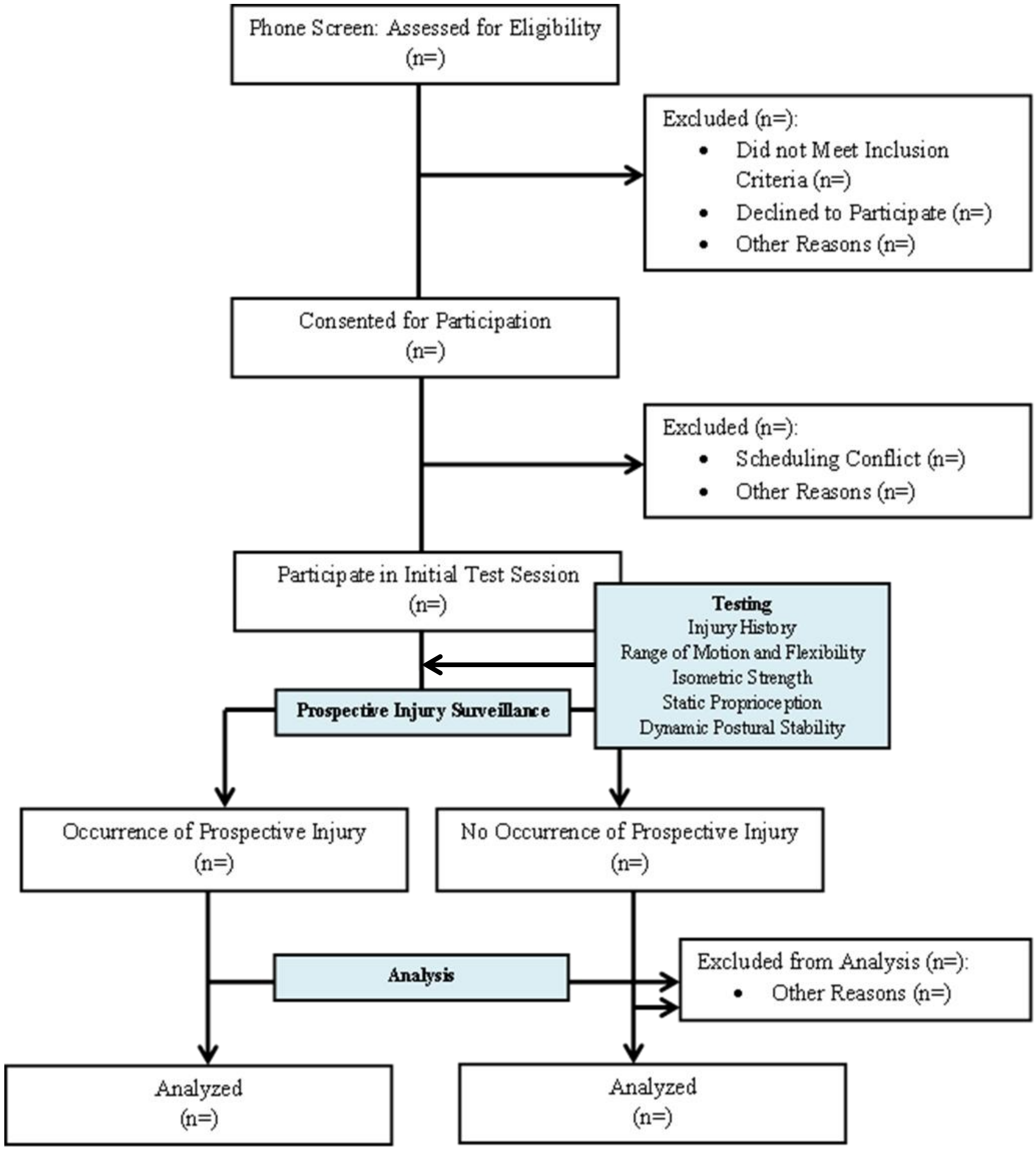

Figure 1. Subject Flow Diagram

3.2 SUBJECT RECRUITMENT

This study was approved by the Institutional Review Board at the University of Pittsburgh prior to initiation of any and all research procedures. All athletes participating in lower extremity dominant sports were recruited from the University of Pittsburgh area and beyond. All interested athletes contacted the Neuromuscular Research Laboratory for further information regarding the details of this study. At that time, interested athletes participated in a phone screen to determine eligibility.

3.3 SUBJECT CHARACTERISTICS

3.3.1 Inclusion Criteria

Athletes were included in the study if they meet the following inclusion criteria:

1) Male or female between the ages of 18-40 years old, inclusive

2) Currently rostered and competing in a lower extremity dominant sport, including soccer, football, volleyball, and/or basketball at the University of Pittsburgh

3) Currently cleared for full physical activity

4) Have not sustained a lower extremity injury in the 4 weeks prior to enrolling in the study

3.3.2 Exclusion Criteria

Athletes were excluded from the study if they do not meet the inclusion criteria specified. Specific exclusion criteria are as follows:

1) Not currently rostered and competing in a lower extremity dominant sport

2) Not currently cleared for full physical activity

3) Having sustained a lower extremity injury in the four weeks prior to enrolling in the study

3.4 POWER ANALYSIS

A Poisson regression on normally distributed independent variable (knee extension strength) with mean = 58.4 and standard deviation = 17.1 using a sample of 93 observations achieves 80% power at a 0.05 significance level to detect a response rate ratio of at least 0.97 due to a one-unit change in the independent variable. The baseline rate is 0.005 and the mean exposure time is 120. To account for data loss and attrition, data on all available 111 subjects will be collected.

3.5 INSTRUMENTATION

3.5.1 Lower Extremity Injury Questionnaire

The lower extremity injury questionnaire documented the self-reported injury history in addition to prospective lower extremity injury for each participating subject.

3.5.2 Stadiometer and Scale

A wall mounted stadiometer (Seca, Hanover, MD) and an electronic scale (Life Measurements Instrument, Concord, CA) was utilized to measure standing height and body weight. Height was measured in centimeters. Body weight was measured in kilograms.

3.5.3 Bod Pod Body Composition Tracking System

The Bod Pod Body Composition Tracking System (Cosmed, Chicago, IL) was utilized to measure body composition, including percent body mass and percent fat free body mass. The Bod Pod utilizes air displacement plethysmography to calculate all body composition percentages through the measurement of body volume.

3.5.4 Goniometer

A universal goniometer (Aircast, Summit, NJ) was utilized to assess lower extremity range of motion and flexibility. For all lower extremity measurements, maximum range of motion and flexibility was measured to the nearest one degree.

3.5.5 Digital Inclinometer

A digital inclinometer (Baseline Evaluation Instruments, White Plains, NY) was utilized to assess lower extremity joint range of motion and flexibility. The digital inclinometer was calibrated according to recommended manufacturer procedures prior to the initiation of any testing procedures. All measures of lower extremity range of motion and flexibility were measured to the nearest one degree.

3.5.6 Handheld Dynamometer

A handheld dynamometer (Lafayette Instrument Co., Lafayette, IN) was utilized to assess isometric muscle force. The manufacture's data, specific to the handheld dynamometer used in this study, states the device was factory calibrated to a sensitivity of 0.1% and a range of 0-500 N. For all measures, peak force was measured in kilograms to the nearest 0.1 kilogram.

3.5.7 Force Plate

A Kistler force plate (Kistler 9286A, Amherst, NY) was utilized to collect ground reaction force data in order to assess both static postural stability and dynamic postural stability. The force plate was calibrated according to manufacturer's recommendations prior to the initiation of any testing procedures. A sampling frequency of 200Hz and 1200Hz was utilized for static postural stability and dynamic postural stability, respectively. All force plate data was passed through an amplifier followed by an analogy digital board (DT3010, Digital Translation, Marlboro, MA) and lastly stored on a personal computer. A custom MATLAB (MathWorks, v7.0.4, Natick, MA) script was utilized to process all ground reaction force data gathered from both the static postural stability and dynamic postural stability tasks.

3.6 OPERATIONAL DEFINITIONS

3.6.1 Lower Extremity Musculoskeletal Injury

For the purposes of this study lower extremity musculoskeletal injury was defined as any occurrence of pain in the lower extremity, acute or chronic, that required medical attention by an athletic trainer, physical therapist, or team physician, in addition to an assessment or diagnosis and treatment. The lower extremity musculoskeletal injury must result in restriction of the athlete's participation beyond the day of injury for one or more days.[56]

3.6.2 Exposure

Exposure was defined as one athlete participating in one practice or one competition, placing the athlete at risk of suffering a lower extremity musculoskeletal injury. For the purposes of this study the amount of time associated with the participation was not collected.

3.6.3 Athletic Season

All risk factors data and injury data was collected over the course of one athletic season. Each athletic season is composed of a pre-season, competitive season, and post-season. Pre-season is defined as any formal team practice or scrimmage that takes place prior to the first competitive season game. The competitive season is defined as all team practices and games that occur following the first competitive season game and end with the last competitive season game. Post-season is defined as all team practices and games that occur following the last competitive season game and end with the last post-season game. If a team does qualify for competition in the post-season, all data collection, including both lower extremity musculoskeletal injury and exposure data, will end with the last competitive season game.

3.7 TESTING PROCEDURES

All subjects reported to the Neuromuscular Research Laboratory in order to complete all testing procedures. Over a period of one test session, each subject was asked to complete a multitude of different tests to assess specific lower extremity musculoskeletal characteristics. These tests included, range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability. Prior to the initiation of any testing procedures subject was guided through the informed consent process. The principal investigator explained all contents of the informed consent and following completion the subject was allowed to questions, to which they were answered to the subjects' complete understanding.

As a part of the University of Pittsburgh Injury Prevention Initiative the author has collected risk factors for lower extremity musculoskeletal injury over the course of four athletic seasons.[22] The risk factors previously measured include, flexibility, range of motion, strength, and dynamic balance.[22] Lower extremity musculoskeletal injuries have been collected for four consecutive athletic seasons.[22] Injuries are collected for the duration of the pre-season, competitive season, and post-season for each respective University of Pittsburgh team.[22] Exposure data, regarding participation in both games and practices, has been recently implemented, with one athletic season of exposures collected.[22] The current study includes all of the previously mentioned procedures with the addition of static postural stability. All data collected was performed during the 2016-2017 athletic seasons.

3.7.1 Injury Surveillance and Exposure Tracking

3.7.1.1 Lower Extremity Injury History

Subjects provided a self-report of all lower extremity injuries sustained over the course of their lifetime. When possible, if the athlete was under the treatment of the athletic training staff during the time of injury, individual medical records maintained by the healthcare provider were reviewed to confirm all lower extremity musculoskeletal injuries. Subjects provided a HIPPA authorization to access their individual medical records to analyze lower extremity musculoskeletal injury history.

3.7.1.2 Lower Extremity Prospective Injury

Subjects provided a self-report of all lower extremity injuries sustain during the competitive season following their initial test session. When possible, if the athlete was under the treatment of the athletic training staff during the time of injury, individual medical records maintained by the healthcare provider were reviewed to confirm all lower extremity musculoskeletal injuries. Subjects provided a HIPPA authorization to access their individual medical records to analyze prospective lower extremity musculoskeletal injury.

3.7.1.3 Exposure Tracking

The athletic trainer associated with each athletic team who participated in this study provided a report of all participation immediately following each athlete's initial test session, ending with the completion of the competitive season, including participation in championship tournaments if applicable. Secure e-mail surveys were sent out over the course of each athletic teams 2016-2017 season to collect participation data. After one failed response, the investigator called the subject to collect participation data. The investigator reviewed all participation data in order to ensure accuracy and completeness. When possible, if the athlete was under the treatment of the athletic training staff during the time period following the initial test session, individual medical records maintained by the healthcare provider were reviewed to confirm all participation. Subjects provided a HIPPA authorization to access their individual medical records to analyze participation. The secure e-mail survey instructed the subject to select "yes" or "no" to participation on the dates listed in the survey. A "yes" was defined as any participation in the athlete's designated sport, including both practice and competition. A "no" was defined as no participation in the athlete's designated sport, including both practice and competition. A "no" was recorded regardless of the reason the subject is not participating, including but not limited to, injury, coach's designation, and/or conflicting schedules. Each instance of participation in practice and/or competition was counted as one exposure; not limited to one exposure per day.

3.7.2 Anthropometrics

3.7.2.1 Height and Weight

A wall-mounted stadiometer (Seca, Hanover, MD) was utilized to capture each subject's height. Height was measured in centimeters. An electronic scale (Life Measurements Instrument, Concord, CA) was utilized to capture body weight. Body weight was taken with minimum clothing (males=spandex shorts; females=spandex+sports bra OR swimsuit). Body weight was recorded in kilograms.

3.7.2.2 Body Composition

The Bod Pod Body Composition Tracking System (Cosmed, Chicago, IL) was utilized to assess body composition. The Bod Pod was calibrated according to manufactures' guidelines and all testing followed the protocol outlined by the manufacturers.

3.7.3 Range of Motion and Flexibility

Table 1. Intra-rater and Inter-rater Reliability of Range of Motion and Flexibility Tests

Range of Motion and Flexibility	Intra-rater Reliability			Inter-rater Reliability		
	ICC	**MDC**	**SEM (º)**	**ICC**	**MDC**	**SEM (º)**
Right Ankle Joint Dorsiflexion Mobility	0.97	2.0	2.02*	0.92	3.4	1.24*
Left Ankle Joint Dorsiflexion Mobility	0.99	1.0	0.97	0.73	7.9	2.86
Right Active Ankle Joint Dorsiflexion	0.95	4.5	4.55	0.68	9.3	3.36
Left Active Ankle Joint Dorsiflexion	0.86	9.0	9.02	0.90	6.4	2.32
Right Active Knee Extension	0.93†	--	--	--	--	--
Left Active Knee Extension	0.93†	--	--	--	--	--
Right Passive Straight Leg Raise	0.76	13.0	13.00	0.51	13.8	4.97
Left Passive Straight Leg Raise	0.83	11.9	11.92	0.86	9.7	3.48

*Indicates SEM in centimeters
†Indicates ICC calculated from different data than remainder of flexibility measurements[8]
SEM calculated as the square root of the mean squared error

Figure 2. Ankle Joint Dorsiflexion Mobility

Ankle joint dorsiflexion mobility was measured through the use of the weight-bearing lunge test.[14, 97] This test demonstrates excellent inter-rater reliability and has been used in previous research successfully.[14] In order to perform the test a tape measure was placed on the ground with the zero point at the point where the wall meets the ground. To perform the test subjects were placed in a lunge position facing the wall. The subject's body weight was supported by outstretching the arms and leaning against the wall. Before the beginning of the test, the back leg was positioned in a place where the subject feels comfortable and is fully supported. The front foot was to remain flat against the floor throughout the entire test and the knee must stay flexed and touching the wall. By simultaneously flexing the knee further and dorsiflexing the ankle, lunging, the subject moved the front foot away from the wall as far as possible. The measurement was taken from the tip of the first toe prior to the point in which the subject heel was going to raise off of the floor or the knee is going to leave the wall. Three measurements were taken on both the dominant and non-dominant lower extremity and subsequently averaged for analysis. Intra-rater and inter-rater reliability for all range of motion and flexibility tests derived from unpublished data from our laboratory are provided in Table 1. Visual representation of this test is provided in Figure 2.

Figure 3. Active Ankle Joint Dorsiflexion

Active ankle joint dorsiflexion was utilized in order assess the length of the gastrocnemius, using an established protocol that has proven to be reliable with similar methods.[80, 81, 84] In order to perform the test subjects were positioned prone on the treatment table with their knees straight and feet hanging off the end of the treatment table. The subjects were asked to dorsiflex their foot, actively, as far as they possibly can while the examiner maintained a neutral position at the subtalar joint throughout the entire test. A goniometer was utilized to measure the angle formed by the line of the lateral midline of the leg, on the line from the head of the fibula to the tip of the lateral malleolus and the lateral midline of the foot, in line with the border of the rear foot (calcaneus). Each of these measurements was completed three times and averaged for data analysis. The measurements was completed on both the dominant and non-dominant lower extremity. Intra-rater and inter-rater reliability for all range of motion and flexibility tests derived from unpublished data from our laboratory are provided in Table 1. Visual representation of this test is provided in Figure 3.

Figure 4. Active Knee Extension

Active knee extension was utilized to assess the length of the hamstring in hip flexion, this protocol has been previously established and has been shown to be reliable.[8, 83] The subject was asked to lay supine on the treatment table with one leg straight and the test leg bent to ninety degrees of hip flexion. One examiner stabilized the femur to prevent any rotation, abduction, or adduction of the hip while the subject actively extended their knee as far as possible. To measure the degree of extension at the knee, a digital inclinometer was utilized and aligned with the lateral midline of the fibula, between the lateral epicondyle of the femur and the lateral malleolus. Three measures was completed and averaged for data analysis. The measurements were completed on both the dominant and non-dominant lower extremity. Intra-rater and inter-rater reliability for all range of motion and flexibility tests derived from unpublished data from our laboratory are provided in Table 1. Visual representation of this test is provided in Figure 4.

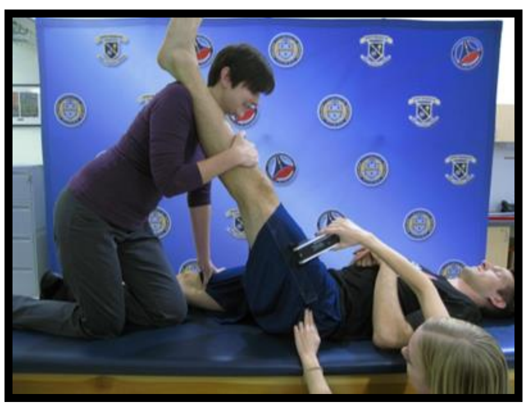

Figure 5. Passive Straight Leg Raise

Passive straight leg raise was utilized to assess the hamstring length, which has been used previously with an established protocol and established reliability.[50, 80, 81, 101, 102] Subjects were asked to lay supine on a treatment table with both leg extended. Subjects were asked to relax as much as possible while the examiner raised the subject's straight leg from the table to the end range of motion ensuring to avoid excessive posterior pelvic tilt, changes in lumbar curve, and the opposite leg raising from the table. The degree of straight leg raise were measured with a digital inclinometer aligned with the lateral midline of the femur between the grater trochanter and the lateral epicondyle of the femur. Three measures were performed on both the dominant and non-dominant lower extremity. The average of these three measures was utilized for data analysis. Intra-rater and inter-rater reliability for all range of motion and flexibility tests derived from unpublished data from our laboratory are provided in Table 1. Visual representation of this test is provided in Figure 5.

3.7.4 Isometric Strength

A handheld dynamometer (Lafayette Instrument Co., Lafayette, IN) was utilized for all isometric strength testing of the lower extremity. All isometric strength testing procedures have been successfully utilized in previous studies based on manual muscle testing procedure instructions developed by Hislop and Montgomery.[46] For all measures of isometric strength, peak force was measured with the dynamometer to the nearest 0.1 kg on both the dominant and non-dominant lower extremity. All testing procedures was carried out by asking the subject to exert as much force as possible against an unmoving resistance, this is otherwise known as a “make test”. One practice trial at 50% of maximum effort was provided for each testing position in order to ensure proper performance of each test. A thirty-second rest period was provided between trials in order to avoid fatigue. The average of three measured trials was utilized for data analysis. Intra-rater and inter-rater reliability for all isometric strength tests are provided in Table 2.[22]

Table 2. Intra-rater and Inter-rater Reliability of Isometric Strength

HHD Isometric Strength	Intra-rater Reliability			Inter-rater Reliability		
	ICC	MDC	SEM (kg/body mass)	ICC	MDC	SEM (kg/body mass)
Right Ankle Dorsiflexion	0.87	14.3	5.17	0.35	15.4	5.54
Left Ankle Dorsiflexion	0.91	11.9	4.29	0.29	18.7	6.75
Right Ankle Plantarflexion	0.98*	8.90*	3.20*	--	--	--
Left Ankle Plantarflexion	0.98*	8.90*	3.20*	--	--	--
Right Ankle Inversion	0.94	9.9	3.57	0.25	16.4	5.93
Left Ankle Inversion	0.91	9.9	3.59	0.34	18.9	6.82
Right Ankle Eversion	0.66	14.7	5.31	0.25	13.0	4.70
Left Ankle Eversion	0.79	11.8	4.25	0.20	13.2	4.76
Right Knee Flexion	0.95	76	2.73	0.66	13.7	4.94
Left Knee Flexion	0.94	7.1	2.56	0.62	13.8	5.00
Right Knee Extension	0.97	15.7	5.65	0.95	27.0	9.75
Left Knee Extension	0.96	22.0	7.94	0.98	16.8	6.05
Right Hip Abduction	0.91	5.1	1.84	0.60	11.0	3.95
Left Hip Abduction	0.84	8.4	3.06	0.91	6.0	2.18
Right Hip Adduction	0.87	6.6	2.38	0.76	7.7	2.79
Left Hip Adduction	0.95	4.2	1.53	0.87	6.0	2.18
Right Hip Internal Rotation	0.60	5.2	1.87	0.48	6.9	2.50
Left Hip Internal Rotation	0.74	5.9	2.12	0.77	6.6	2.40
Right Hip External Rotation	0.71	6.1	2.20	0.77	6.7	2.42
Left Hip External Rotation	0.86	4.4	1.58	0.82	5.9	2.14

* Indicates ICC, MDC, and SEM calculated from different data than remainder of strength measurements
SEM calculated as the square root of the mean squared error

Figure 6. Ankle Dorsiflexion Isometric Strength

Ankle dorsiflexion strength was measured with the subject in upright-seated position while the hips and knees are extended and the foot to be tested is off the end of the table. The examiner stabilized the lower limb of the foot to be tested just proximal to the ankle joint. The handheld dynamometer was placed on the dorsal aspect of the foot just proximal to the metatarsal heads. The examiner passively moved the limb to the starting position, which is in midrange ankle dorsiflexion. Each subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer. Visual representation of this test is provided in Figure 6.

Figure 7. Ankle Plantarflexion Isometric Strength

Ankle plantarflexion strength as measured with the subject in prone position while the hips and knees are extended and the foot to be tested is off the end of the table. The examiner stabilized the lower limb of the foot to be tested just proximal to the ankle joint. The handheld dynamometer was placed on the plantar aspect of the foot just proximal to the metatarsal heads. The examiner passively moved the limb to the starting position, which is in midrange ankle plantarflexion. Each subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer. Visual representation of this test is provided in Figure 7.

Figure 8. Ankle Inversion Isometric Strength

Ankle inversion strength was tested with the subject positioned in the supine position with the hips and knees extended and the foot to be test off the end of the table. The examiner stabilized the lower limb of the foot to be tested just proximal to the ankle joint. The handheld dynamometer was positioned on the medial border of the foot at the midpoint of the shaft of the first metatarsal. The examiner passively moved the limb to the starting position, which is midrange ankle inversion. Each subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer. Visual representation of this test is provided in Figure 8.

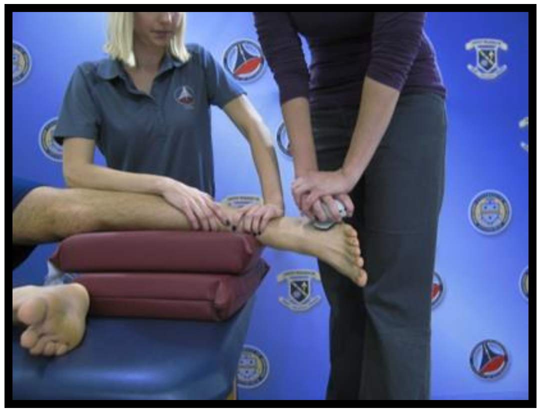

Figure 9. Ankle Eversion Isometric Strength

Ankle eversion strength was tested with the subject positioned in a supine position with the hips and knees extended and the foot to be tested off the end of the table. The examiner stabilized the lower limb to be tested just proximal to the ankle joint. The handheld dynamometer was positioned on the lateral border of the foot at the midpoint of the fifth metatarsal. The examiner passively moved the limb to the starting position, which is midrange ankle eversion. Each subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer. Visual representation of this test is provided in Figure 9.

Figure 10. Knee Flexion Isometric Strength

Knee flexion strength was tested with the subject in a prone position with the leg being tested bent to 45° of knee flexion. This initial test position acted as the starting positon for the test. The handheld dynamometer was placed just distal to the calcaneous of the leg to be tested. The subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer. Visual representation of this test is provided in Figure 10.

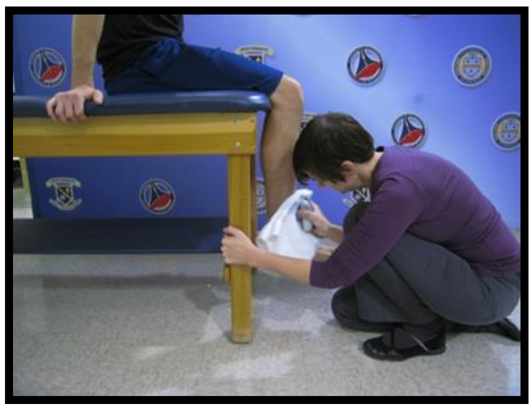

Figure 11. Knee Extension Isometric Strength

Knee extension strength was tested with the subject positioned in an upright-seated position with both the lower legs off the edge of the table. Due to the strength of this muscle, a therapy belt provided resistance during this isometric strength test. The therapy belt was attached to the handheld dynamometer, which was positioned on the most distal aspect of the tibia and anchored to the leg of the treatment table. The subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer. Visual representation of this test is provided in Figure 11.

Figure 12. Hip Abduction Isometric Strength

Hip abduction strength was tested with the subject positioned side lying with the leg to be tested on top. The test leg was supported by a pillow under the lower limb in order to support a neutral spine throughout the duration of the test. The bottom leg was positioned in 90 degrees of knee flexion. The handheld dynamometer was placed just superior to the lateral malleolus. The subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer. Visual representation of this test is provided in Figure 12.

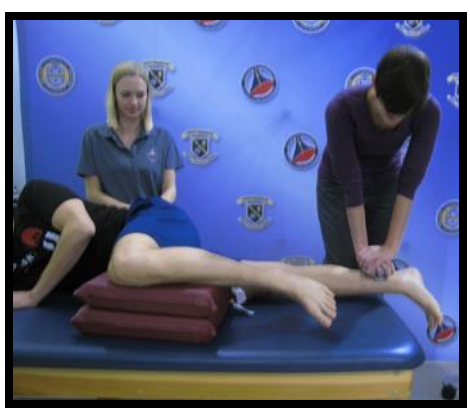

Figure 13. Hip Adduction Isometric Strength

Hip adduction strength was tested with the subject positioned side lying with the leg to be tested on the bottom. The top leg was positioned in 90 degrees of knee flexion with a pillow at the knee in order to support a neutral spine throughout the duration of the test. The handheld dynamometer was placed just superior to the medial malleolus. The subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer. Visual representation is provided in Figure 13.

Figure 14. Hip Internal Rotation Isometric Strength

Hip internal rotation strength was tested with the subject positioned prone on a treatment table with the knee of the test leg flexed to 90 degrees. The examiner passively positioned the test leg into a neutral hip internal-external rotation prior to the initiation of the test. The handheld dynamometer was placed just distal to the lateral malleolus. The subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer. Visual representation is provided in Figure 14.

Figure 15. Hip External Rotation Isometric Strength

Hip external rotation strength was tested with the subject positioned prone on a treatment table with the knee of the test leg flexed to 90 degrees. The examiner passively positioned the test leg into a neutral hip internal-external rotation prior to the initiation of the test. The handheld dynamometer was placed just distal to the medial malleolus. The subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary positon with the handheld dynamometer. Visual representation is provided in Figure 15.

3.7.5 Static Postural Stability

Figure 16. Static Postural Stability

Subjects performed a test of static single-leg postural stability while ground reaction forces were assessed throughout the duration of the test.[40] Subjects performed three trials lasting 10 second each, of a static single-leg postural stability test (barefooted) under eyes-open and eyes-closed conditions. Testing was completed on both the dominant and non-dominant lower extremity. During the duration of the test the subject was asked to remain as still as possible with non-test leg raised to about the level of the tested ankle without touching the tested limb and while maintaining hands on hips. Trials were discarded if the subject touches down outside of the force plate at any time during the duration of the test. All discarded trials were recollected. Data analysis was completed using the standard deviation of ground reaction forces in three planes (anterior/posterior, medial/lateral, and vertical) and the center of pressure in two planes (anterior/posterior and medial/lateral) during the 10-second trial. Reliability and precision of single-leg balance testing was previously established utilizing an identical protocol (ICC = 0.71-0.94; SEM = 0.19-3.40 Newtons).[40] Visual Representation is provided in Figure 16.

3.7.6 Dynamic Postural Stability

Figure 17. Dynamic Proprioception

Subjects was tested on a single-leg jump landing test that previously has been previously utilized demonstrating good inter-session reliability (ICC = 0.86; SEM = 0.01).[90] The single-leg jump landing protocol is a modification of the protocol used by Ross and Wikstrom.[99] The protocol that was used in this study normalizes the jump distance according to body height, whereas Ross and Wikstrom normalized the vertical jump height according to the subjects maximum vertical jump heights.[90,99] The single-leg jump landing test required subjects to complete a jump in the anterior/posterior direction.[90] Subjects were positioned 40% of their body height away from the edge of a force plate. A 30 cm hurdle was placed at the midpoint of this distance. Subjects were instructed to jump in the anterior direction using a two-footed jump take-off, over the 30 cm hurdle, and land on the force plate on only the test leg, stabilize as quickly as possible, place their hands on their hips, and balance for 5 seconds while looking straight ahead. Five successful trials were collected and averaged for analyses on both the dominant and non-dominant lower extremity. Subjects were given three practice trials with a one-minute rest period between practice trials and test trials to prevent fatigue. Visual representation is provided in Figure 17.

Trials were discarded and repeated if subjects fail to jump over or come in contact with the hurdle, hop on the test leg after landing, the non-weight-bearing leg touches down off of the force place, or if subjects remove their hands from hips for longer than three seconds. Trials were not be discarded if a subject touches down with the non-weight-bearing leg so long as the touchdown occurred on the force plate, they resume the one-legged stance as quickly as possible, and none of the aforementioned trial exclusion criteria occur.

3.8 DATA REDUCTION

3.8.1 Lower Extremity Musculoskeletal Injury Rate

Injury rate was utilized as a measure of lower extremity musculoskeletal injury incidence. Lower extremity musculoskeletal injury rate was defined as the number of lower extremity musculoskeletal injuries per 1,000 athlete exposures. Injury rates was calculated for overall number of injuries as well as particular categories including, game vs. practice situations, sport type (soccer, football, volleyball, etc.), sex, and point in athletic season (pre-season, competitive season, post-season). These injury rates were calculated by dividing the number of musculoskeletal injuries that occur during each of the particular categories by the total number of athlete-exposures associated with that category and multiplying by 1,000.

3.8.2 Isometric Strength

For all measures of isometric strength, average peak force across three successful trials was captured in kilograms and normalized to body weight for comparison across subjects (%BW = (average (kg)/subject body weight (kg))*100). Isometric strength measurements normalized to body weight was utilized to calculate strength ratios between each subject's dominant and non-dominant lower extremity. Isometric strength measurements normalized to body weight was also be utilized to calculate strength ratios between opposing muscle groups on each subject's dominant and non-dominant lower extremity including: ankle eversion/inversion, knee flexion/extension, hip adduction/abduction, and hip external/internal rotation.

3.8.3 Static Postural Stability

Static postural stability is expressed as the standard deviation of ground reaction forces.[40] Following the completion of data collection, a custom Matlab (MathWorks, v7.0.4, Natick, MA) script was used to processes and filter the data. All ground reaction force data was passed through a low-pass Butterworth filter with a cut off frequency of 20 Hz. The ground reaction forces from each successful trial are normalized to body weight (%BW). The standard deviation of the ground reaction forces in the anterior/posterior, medial/lateral, and vertical directions, as well as center of pressure in the anterior/posterior and medial/lateral directions are calculated across three successful trials for all conditions. An average of the ground reaction forces in each direction for each condition was calculated in order to explain the subject's overall static proprioception under each condition.

3.8.4 Dynamic Postural Stability

Dynamic postural stability is expressed through the use of the Dynamic Postural Stability Index.[99] The Dynamic Postural Stability Index calculation creates a stability index for each anatomical direction as well as a composite of all three direction utilizing the first three seconds of ground reaction force data following initial contact with the force plate.[99] For the purposes of this study, initial contact is defined as the point in which the vertical ground reaction force exceeds five percent of the subject's body weight.[90] Following the completion of data collection, a custom Matlab (MathWorks, v7.0.4, Natick, MA) script processes and filters the data. All ground reaction force data is passed through a low-pass Butterworth filter with a cut off frequency of 20 Hz. An individual Dynamic Postural Stability Index score is calculated for each of the five successful trials. An average of the Dynamic Postural Stability Index scores from the five successful trials is calculated in order to explain a subject's overall dynamic postural stability.[99] The DPSI equation is illustrated in Figure 18.

$$\text{DPSI} = ((\sqrt{[\Sigma(0-x)^2 + \Sigma(0-y)^2 + (\text{Body Weight}-z)^2/\text{Number of Data Points}]})/\text{Body Weight}))$$

Figure 18. Dynamic Postural Stability Index Equation

3.9 DATA ANALYSIS

All data was analyzed using IBM SPSS Statistics 22 (IBM Corp., Armonk, NY) and STATA 13 (STATA Corp LP, College Station, Texas). Descriptive statistics were calculated for all variables (mean and standard deviation, or median and interquartile range, or proportions, as applicable).

Data was tested for normality utilizing a Shapiro Wilk test. Statistical significance was set *a priori* at alpha = 0.05, two-sided.

Specific Aim 1: Descriptive statistics were used to describe musculoskeletal characteristics of the lower extremity including range of motion, flexibility, strength, static postural stability, and dynamic postural stability in NCAA Division I male and female athletes participating in lower extremity dominant sports at the University of Pittsburgh. Data was also stratified by sport type (soccer, football, volleyball, etc.), and sex. Mean, standard deviation, and 95% confidence intervals, or median and interquartile range, dependent upon the normality assessment, were calculated for all variables. Fisher's exact tests were utilized to compare proportion of subjects with history of injury between groups based on sport type and sex. All descriptive statistics can serve as normative data for these musculoskeletal characteristics in NCAA Division I male and female athletes participating in lower extremity dominant sports at the University of Pittsburgh.

Specific Aim 2: Injury incidence rate, injury incidence rate ratios, and corresponding 95% confidence intervals were calculated in order to describe the incidence of lower extremity musculoskeletal injury in NCAA Division I University of Pittsburgh male and female athletes participating in lower extremity dominant sports. The proportion of lower extremity musculoskeletal injuries in each category was described. All data was analyzed in groups including, all subjects, game vs. practice situations, sport type (soccer, football, volleyball, etc.), sex, and point in athletic season (pre-season, competitive season, post-season). Injury incidence was also calculated according to limb dominance, injury sublocation, injury type, cause of injury, mechanism of injury, and injury onset.

Specific Aim 3: Simple Poisson regression analyses were performed using STATA 13 (STATA Corp LP, College Station, Texas). Separate simple Poisson regression analysis was conducted to assess the association between the predictor variables including, range of motion, flexibility, strength, static postural stability, and dynamic postural stability, and lower extremity musculoskeletal injury rates in NCAA Division I male and female athletes participating in lower extremity dominant sports at the University of Pittsburgh. The risk factor analysis was performed for the following groups, all subjects, sport type (soccer, football, volleyball, etc.), and sex.

4.0 RESULTS

The first purpose of this study was to describe the musculoskeletal characteristics of the lower extremity, including range of motion, flexibility, strength, static postural stability, and dynamic postural stability in NCAA Division I athletes participating in lower extremity dominant sports at the University of Pittsburgh. The second purpose of this study was to estimate the incidence of lower extremity musculoskeletal injury in NCAA Division I athletes participating in lower extremity dominant sports at the University of Pittsburgh. An evaluation of the association between musculoskeletal characteristics of the lower extremity, including range of motion, flexibility, strength, static postural stability, and dynamic postural stability, and the rate of lower extremity musculoskeletal injury in NCAA Division I athletes participating in lower extremity dominant sports at the University of Pittsburgh was also included in this study.

4.1 SUBJECTS

4.1.1 Demographic Data

Figure 19 represents the study design, subject recruitment, subject enrollment, and study procedures. All men's and women's athletes participating in lower extremity dominant sports at the University of Pittsburgh who expressed interest in participating in this study and met the eligibility criteria for subject enrollment were invited to participate in the present study. A total of 131 NCAA Division I athletes participating in lower extremity dominant sports at the University of Pittsburgh volunteered for this study. The breakdown of participation by sport is as follows: 48 soccer athletes (Men: 24, Women: 24), 43 football athletes, 16 volleyball athletes, 24 basketball athletes (Men: 11, Women: 13).

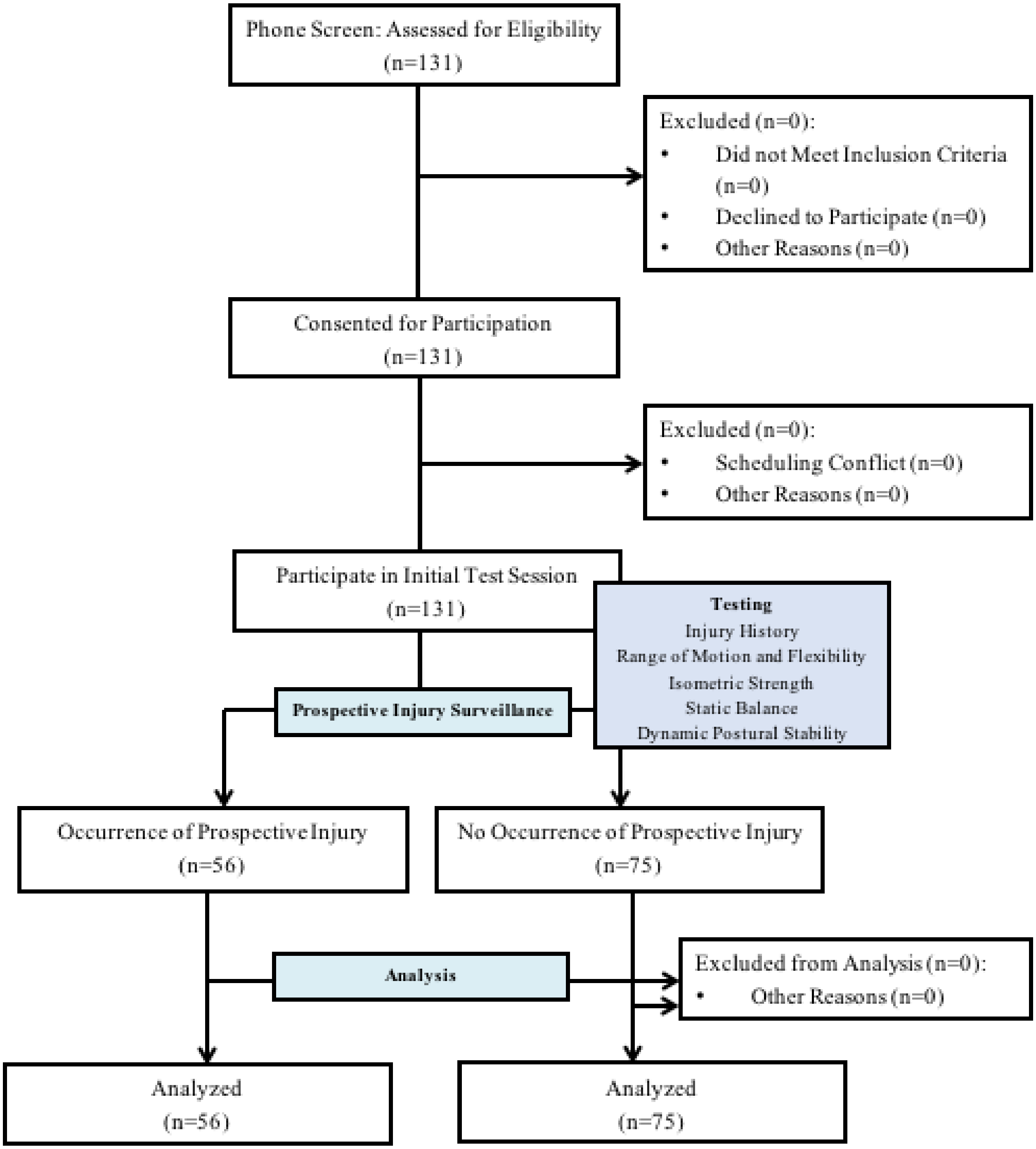

Figure 19. Subject Flow Diagram

Subject characteristics are presented in Table 3 and Table 4. Table 3 represents overall subject characteristics, and stratified by sex. Table 4 represents subject characteristics by sport type, and stratified by sex, if applicable. Overall, for the men's and women's lower extremity dominant sport athletes the mean ± standard deviation for age, height, and weight were 19.5 ± 1.3 years, 180.3 ± 10.5 cm, and 80.1 ± 18.5 kg. Overall, for the men's lower extremity dominant sport athletes the mean ± standard deviation for age, height, and weight were 19.7 ± 1.4 years, 185.2 ± 8.5 cm, and 88.6 ± 18.1 kg. Overall, for the women's lower extremity dominant sport athletes the mean ± standard deviation for age, height, and weight were 19.3 ± 1.2 years, 173.1 ± 8.9 cm, and 67.5 ± 10.0 kg.

Table 3. Subject Characteristics Overall and Stratified by Sex

	Overall			Men			Women		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Age (yrs)	131	19.5 (1.3)	19.0 (18.0, 20.0)	78	19.7 (1.4)	19.0 (18.8, 21.0)	53	19.3 (1.2)	19.2 (18.0, 20.0)
Height (cm)	131	180.3 (10.5)	180.3 (173.5, 185.9)	78	185.2 (8.5)	184.2 (179.7, 190.6)	53	173.1 (8.9)	172.7 (166.2, 180.3)
Weight (kg)	131	80.1 (18.5)	76.9 (66.5, 89.3)	78	88.6 (18.1)	85.3 (76.7, 94.9)	53	67.5 (10.0)	65.4 (62.0, 74.1)

Table 4. Subject Characteristics Stratified by Sex and Sport Type

	Overall			Men			Women		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Soccer									
Age (yrs)	48	19.4 (1.2)	19.0 (18.0, 20.0)	24	19.4 (1.3)	19.0 (18.3, 20.0)	24	19.4 (1.1)	20.0 (18.0, 20.0)
Height (cm)	48	173.6 (9.8)	172.7 (16.4, 182.2)	24	180.7 (7.6)	181.9 (175.3, 185.4)	24	166.4 (5.8)	166.4 (161.5, 170.3)
Weight (kg)	48	69.7 (10.5)	69.1 (61.7, 76.0)	24	75.9 (10.3)	72.5 (70.0, 82.5)	24	63.6 (6.4)	63.7 (59.5, 68.0)
Football									
Age (yrs)	--	--	--	43	19.5 (1.4)	19.0 (18.0, 20.0)	--	--	--
Height (cm)	--	--	--	43	184.8 (6.2)	184.3 (180.1, 190.5)	--	--	--
Weight (kg)	--	--	--	43	93.4 (18.0)	88.4 (83.1, 95.2)	--	--	--
Volleyball									
Age (yrs)	--	--	--	--	--	--	16	19.3 (1.3)	19.0 (18.3, 20.0)
Height (cm)	--	--	--	--	--	--	16	179.8 (6.8)	182.6 (174.1, 185.4)
Weight (kg)	--	--	--	--	--	--	16	68.5 (11.3)	70.7 (65.2, 82.9)
Basketball									
Age (yrs)	24	20.0 (1.5)	20.0 (19.0, 21.0)	11	20.9 (1.3)	21.0 (20.0, 22.0)	13	19.2 (1.2)	19.0 (18.0, 20.5)
Height (cm)	24	186.1 (12.5)	180.3 (176.2, 198.8)	11	196.7 (7.8)	200.9 (190.5, 199.9)	13	177.0 (7.5)	176.4 (172.0, 180.3)
Weight (kg)	24	84.6 (19.1)	76.5 (69.0, 100.3)	11	97.6 (18.5)	100.4 (84.9, 103.2)	13	73.5 (11.2)	69.4 (65.3, 78.8)

Body composition is presented in Table 5 and Table 6. Table 5 represents overall body composition, and stratified by sex. Table 6 represents body composition by sport type, and stratified by sex, if applicable. Overall, for the men's and women's lower extremity dominant sport athletes the percent fat mass and percent fat free mass (mean ± standard deviation) were 15.9 ± 7.6 percent and 83.4 ± 10.4 percent. Overall, for the men's lower extremity dominant sport athletes the percent fat mass and percent fat free mass (mean ± standard deviation) were 11.5 ± 5.8 percent and 87.3 ± 11.5 percent. Overall, for the women's lower extremity dominant sport athletes the percent fat mass and percent fat free mass (mean ± standard deviation) were 22.1 ± 5.1 percent and 77.9 ± 5.1 percent.

Table 5. Body Composition Overall and Stratified by Sex

	Overall			**Men**			**Women**		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Fat Mass (kg)	129	12.8 (7.7)	11.7 (7.2, 15.5)	76	10.9 (8.5)	8.2 (5.9, 13.1)	53	15.5 (5.3)	14.5 (12.0, 17.4)
Fat Free Mass (kg)	129	67.3 (15.8)	145.2 (54.3, 79.4)	76	77.1 (12.7)	77.4 (69.5, 83.5)	53	53.3 (6.4)	53.1 (47.8, 57.9)
Total Body Mass (kg)	129	80.1 (18.5)	76.9 (66.5, 89.3)	76	88.6 (18.1)	85.3 (76.7, 94.9)	53	67.5 (10.0)	65.4 (62.0, 74.1)
Percent Fat Mass (%)	129	15.9 (7.6)	15.1 (8.8, 21.3)	76	11.5 (5.8)	10.2 (7.2, 14.8)	53	22.1 (5.1)	21.0 (18.9, 26.0)
Percent Fat Free Mass (%)	129	83.4 (10.4)	84.3 (78.4, 91.1)	76	87.3 (11.5)	89.8 (85.0, 92.8)	53	77.9 (5.1)	79.0 (74.1, 81.1)

Table 6. Body Composition Stratified by Sex and Sport Type

	Overall			Men			Women		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Soccer									
Fat Mass (kg)	48	10.6 (4.5)	9.8 (6.7, 14.7)	24	7.7 (3.8)	6.7 (5.1, 9.3)	24	13.5 (2.9)	13.8 (11.2, 15.3)
Fat Free Mass (kg)	48	59.2 (11.3)	57.8 (48.7, 66.7)	24	68. (8.0)	66.7 (63.0, 73.5)	24	50.1 (5.0)	50.1 (46.6, 54.1)
Total Body Mass (kg)	48	69.7 (10.5)	69.1 (61.7, 76.0)	24	75.9 (10.3)	72.5 (70.0, 82.5)	24	63.6 (6.4)	63.7 (59.5, 68.0)
Percent Fat Mass (%)	48	15.5 (6.8)	17.2 (8.5, 20.9)	24	9.9 (4.0)	8.5 (7.1, 11.8)	24	21.1 (3.7)	20.2 (18.5, 23.9)
Percent Fat Free Mass (%)	48	84.0 (6.8)	82.8 (79.1, 91.5)	24	90.1 (4.0)	91.5 (88.2, 93.0)	24	78.9 (3.7)	79.8 (76.2, 81.5)
Football									
Fat Mass (kg)	--	--	--	43	11.7 (9.8)	9.1 (6.3, 12.7)	--	--	--
Fat Free Mass (kg)	--	--	--	43	80.8 (12.5)	80.8 (75.7, 85.1)	--	--	--
Total Body Mass (kg)	--	--	--	43	93.4 (18.0)	88.4 (83.1, 95.2)	--	--	--
Percent Fat Mass (%)	--	--	--	43	11.6 (6.5)	10.3 (7.2, 14.8)	--	--	--
Percent Fat Free Mass (%)	--	--	--	43	86.3 (14.6)	89.6 (84.9, 92.8)	--	--	--
Volleyball									
Fat Mass (kg)	--	--	--	--	--	--	16	16.8 (6.1)	14.3 (12.8, 24.1)
Fat Free Mass (kg)	--	--	--	--	--	--	16	56.0 (5.1)	57.0 (51.1, 58.8)
Total Body Mass (kg)	--	--	--	--	--	--	16	68.5 (11.3)	70.7 (65.2, 82.9)
Percent Fat Mass (%)	--	--	--	--	--	--	16	22.5 (5.2)	20.6 (19.1, 28.4)
Percent Fat Free Mass (%	--	--	--	--	--	--	16	77.5 (5.2)	79.4 (71.6, 80.9)
Basketball									
Fat Mass (kg)	22	16.8 (7.3)	16.0 (13.4, 19.5)	9	15.9 (8.5)	15.8 (9.1, 18.6)	13	17.0 (6.6)	16.2 (14.1, 22.4)
Fat Free Mass (kg)	22	67.0 (16.6)	62.0 (53.8, 81.4)	9	82.9 (12.6)	81.8 (74.0, 89.4)	13	56.0 (7.6)	55.1 (49.2, 61.0)
Total Body Mass (kg)	22	84.6 (19.1)	76.5 (69.0, 100.3)	9	97.6 (18.5)	100.4 (84.9, 103.2)	13	73.5 (11.2)	69.4 (65.3, 78.8)
Percent Fat Mass (%)	22	20.0 (7.4)	19.1 (15.5, 25.3)	9	15.2 (5.4)	15.7 (10.4, 18.6)	13	23.3 (6.9)	22.9 (19.4, 28.3)
Percent Fat Free Mass (%)	22	80.0 (7.4)	80.9 (74.8, 84.5)	9	84.7 (5.4)	84.3 (81.4, 89.6)	13	76.7 (6.9)	77.1 (71.7, 80.6)

4.2 MUSCULOSKELETAL CHARACTERISTICS OF THE LOWER EXTREMITY

The first specific aim of this study was to describe musculoskeletal characteristics of the lower extremity including range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability in NCAA Division I University of Pittsburgh male and female athletes participating in lower extremity dominant sports. Descriptive statistics were used to describe musculoskeletal characteristics of the lower extremity including range of motion, flexibility, strength, static postural stability, and dynamic postural stability in NCAA Division I male and female athletes participating in lower extremity dominant sports at the University of Pittsburgh. Data were stratified by sport type (soccer, football, volleyball, basketball) and sex. Mean and standard deviation, and median and interquartile range were calculated for all variables. Fisher's exact tests were utilized to compare proportion of subjects with a history of lower extremity musculoskeletal injury between groups based on sport type and sex. All descriptive statistic calculations serve as normative data for these musculoskeletal characteristics in NCAA Division I male and female athletes participating in lower extremity dominant sports at the University of Pittsburgh.

4.2.1 Lower Extremity Range of Motion and Flexibility

Lower extremity range of motion and flexibility is presented in Table 7, Table 8, Table 9, and Table 10. Table 7 represents overall lower extremity range of motion and flexibility, and stratified by sex, if applicable. Table 8 represents lower extremity range of motion and flexibility by sport type. Table 9 and Table 10 represent soccer and basketball lower extremity range of motion and flexibility, stratified by sex, respectively. In men's and women's soccer athletes, significant differences were noted in both weight-bearing ankle dorsiflexion and active ankle dorsiflexion; women's soccer athletes demonstrated greater weight-bearing ankle dorsiflexion (Non-Dominant: Men's – 5.7 ± 1.8, Women's – 6.8 ± 2.1) and active ankle dorsiflexion (Dominant: Men's – 6.8 ± 3.4, Women's – 8.9 ± 3.6). No significant differences were noted in any flexibility variables when comparing men's and women's basketball athletes.

Table 7. Lower Extremity Range of Motion and Flexibility Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Overall						
Weight-Bearing Ankle Dorsiflexion (cm)	130	6.8 (2.6)	7.0 (4.8, 8.2)	131	7.3 (7.6)	6.5 (4.8, 8.3)
Active Ankle Dorsiflexion (º)	131	6.8 (2.6)	7.3 (4.3, 10.0)	131	7.3 (3.4)	7.7 (4.3, 9.7)
Active Knee Extension (º)	131	14.3 (9.0)	13.3 (7.0, 20.7)	131	13.4 (8.6)	12.0 (6.7, 18.7)
Straight Leg Raise (º)	131	82.8 (6.0)	82.3 (79.3, 87.0)	131	82.5 (6.7)	82.7 (79.3, 86.0)
Men						
Weight-Bearing Ankle Dorsiflexion (cm)	77	6.4 (2.9)	6.0 (4.3, 7.8)	78	6.3 (2.9)	5.9 (4.5, 7.6)
Active Ankle Dorsiflexion (º)	78	6.8 (3.5)	7.3 (3.3, 9.7)	78	7.1 (3.3)	7.7 (4.0, 9.5)
Active Knee Extension (º)	78	13.9 (8.8)	12.9 (6.8, 19.8)	78	13.2 (8.7)	11.7 (6.3, 19.8)
Straight Leg Raise (º)	78	83.1 (5.9)	83.2 (79.2, 87.3)	78	82.4 (6.1)	82.9 (79.5, 86.7)
Women						
Weight-Bearing Ankle Dorsiflexion (cm)	53	7.4 (2.1)	7.6 (5.9, 8.6)	53	8.8 (11.3)	7.4 (5.9, 8.6)
Active Ankle Dorsiflexion (º)	53	7.4 (4.0)	6.7 (5.7, 10.2)	53	7.5 (3.7)	8.0 (4.8, 9.7)
Active Knee Extension (º)	53	14.9 (9.5)	13.7 (6.7, 21.9)	53	13.8 (8.6)	12.3 (7.0, 18.0)
Straight Leg Raise (º)	53	82.4 (6.2)	82.0 (80.0, 86.3)	53	82.6 (5.0)	82.0 (79.0, 85.9)

Table 8. Lower Extremity Range of Motion and Flexibility Stratified by Sport Type

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Soccer						
Weight-Bearing Ankle Dorsiflexion (cm)	48	6.2 (1.8)	6.0 (4.8, 7.3)	48	6.2 (2.0)	5.9 (4.7, 7.2)
Active Ankle Dorsiflexion (º)	48	7.9 (3.6)	7.3 (5.7, 10.3)	48	8.0 (2.9)	8.3 (5.7, 10.2)
Active Knee Extension (º)	48	14.3 (8.7)	13.7 (6.3, 20.6)	48	13.3 (9.7)	11.3 (6.1, 19.5)
Straight Leg Raise (º)	48	82.6 (6.0)	82.3 (79.9, 86.3)	48	83.6 (5.7)	83.3 (80.3, 87.0)
Football						
Weight-Bearing Ankle Dorsiflexion (cm)	42	6.3 (2.7)	6.1 (4.3, 8.0)	43	6.1 (2.6)	6.2 (4.6, 7.4)
Active Ankle Dorsiflexion (º)	43	7.0 (3.7)	8.0 (3.3, 9.7)	43	7.0 (3.6)	7.5 (3.7, 10.0)
Active Knee Extension (º)	43	13.0 (8.6)	11.7 (6.0, 18.3)	43	11.4 (6.6)	9.0 (6.3, 15.7)
Straight Leg Raise (º)	43	82.9 (5.6)	82.6 (79.3, 87.7)	43	81.7 (6.1)	82.9 (78.7, 85.0)
Volleyball						
Weight-Bearing Ankle Dorsiflexion (cm)	16	7.8 (2.0)	8.2 (6.5, 9.2)	16	7.4 (2.0)	7.4 (6.0, 8.6)
Active Ankle Dorsiflexion (º)	16	5.9 (4.3)	6.7 (2.6, 8.8)	16	6.6 (4.4)	6.7 (3.8, 9.5)
Active Knee Extension (º)	16	16.7 (11.1)	13.0 (7.5, 26.1)	16	15.4 (6.9)	13.3 (10.0, 21.3)
Straight Leg Raise (º)	16	80.8 (6.9)	81.0 (78.0, 85.5)	16	81.3 (4.8)	80.3 (78.4, 85.0)
Basketball						
Weight-Bearing Ankle Dorsiflexion (cm)	24	8.2 (3.6)	8.0 (5.9, 10.1)	24	11.8 (16.7)	8.3 (6.5, 11.0)
Active Ankle Dorsiflexion (º)	24	6.1 (3.4)	4.7 (3.5, 7.6)	24	6.8 (3.5)	7.0 (3.5, 7.6)
Active Knee Extension (º)	24	15.1 (9.1)	16.7 (7.0, 23.0)	24	15.7 (9.9)	17.3 (6.7, 22.6)
Straight Leg Raise (º)	24	84.4 (6.0)	84.3 (80.9, 87.9)	24	82.4 (5.2)	81.3 (79.8, 85.2)

Table 9. Lower Extremity Range of Motion and Flexibility for Soccer Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Men's Soccer						
Weight-Bearing Ankle Dorsiflexion (cm)	24	5.7 (1.7)	5.7 (4.6, 7.1)	24	5.7 (1.8)	5.5 (4.4, 6.9)
Active Ankle Dorsiflexion (º)	24	6.8 (3.4)	5.7 (3.4, 9.9)	24	7.7 (2.8)	8.3 (5.7, 10.2)
Active Knee Extension (º)	24	14.4 (9.4)	13.3 (5.8, 20.4)	24	14.3 (10.1)	12.7 (6.4, 21.9)
Straight Leg Raise (º)	24	82.1 (5.4)	83.3 (77.7, 86.2)	24	83.7 (6.1)	84.0 (80.3, 86.9)
Women's Soccer						
Weight-Bearing Ankle Dorsiflexion (cm)	24	6.6 (1.9)	7.0 (4.9, 7.7)	24	6.8 (2.1)	7.0 (5.1, 7.5)
Active Ankle Dorsiflexion (º)	24	8.9 (3.6)	9.4 (6.0, 11.0)	24	8.2 (2.9)	8.7 (5.7, 10.2)
Active Knee Extension (º)	24	14.1 (8.2)	14.4 (6.7, 20.6)	24	12.4 (9.5)	9.8 (6.0, 17.6)
Straight Leg Raise (º)	24	83.0 (6.6)	82.0 (80.4, 87.1)	24	83.5 (5.5)	82.9 (79.5, 88.0)

Table 10. Lower Extremity Range of Motion and Flexibility for Basketball Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Men's Basketball						
Weight-Bearing Ankle Dorsiflexion (cm)	11	8.2 (2.3)	7.8 (3.7, 12.2)	11	14.3 (22.3)	8.9 (3.1, 12.3)
Active Ankle Dorsiflexion (º)	11	6.4 (3.7)	4.7 (3.0, 7.7)	11	7.1 (4.0)	6.3 (3.7, 9.0)
Active Knee Extension (º)	11	14.1 (10.1)	17.7 (7.0, 24.0)	11	14.3 (9.1)	22.3 (3.7, 23.3)
Straight Leg Raise (º)	11	83.0 (4.6)	83.3 (81.7, 88.3)	11	82.4 (4.0)	80.3 (79.0, 83.3)
Women's Basketball						
Weight-Bearing Ankle Dorsiflexion (cm)	13	8.3 (4.9)	8.1 (6.9, 9.2)	13	8.7 (4.7)	8.2 (6.9, 10.8)
Active Ankle Dorsiflexion (º)	13	5.7 (3.3)	4.5 (4.2, 8.5)	13	6.5 (2.9)	5.3 (3.7, 9.5)
Active Knee Extension (º)	13	16.2 (8.1)	13.0 (5.3, 22.7)	13	17.4 (11.0)	13.8 (7.2, 19.0)
Straight Leg Raise (º)	13	86.1 (7.2)	84.3 (79.0, 86.7)	13	82.4 (6.5)	82.9 (80.4, 85.5)

Lower extremity range of motion and flexibility ratios are presented in Table 11 and Table 12. Table 11 represents overall lower extremity range of motion and flexibility, and stratified by sex. Table 12 represents lower extremity range of motion and flexibility by sport type, and stratified by sex, if applicable. Sport types that encompass men's athletes (soccer, football, and basketball) demonstrate significant differences in dominant/non-dominant straight leg raise ratios. Football athletes have the highest ratio of dominant/non-dominant straight leg raise ratio (mean ± standard deviation) at 1.02 ± 0.08, followed by men's basketball at 1.00 ± 0.07, and finally, soccer at 0.98 ± 0.05.

Table 11. Lower Extremity Range of Motion and Flexibility Ratios Overall

	Overall			Men			Women		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Dominant/Non-Dominant Weight-Bearing Ankle Dorsiflexion Ratio	130	1.03 (0.39)	1.01 (0.92, 1.26)	77	1.05 (0.48)	1.01 (0.90, 1.10)	53	1.00 (0.19)	1.01 (0.92, 1.11)
Dominant/Non-Dominant Active Ankle Dorsiflexion Ratio	129	1.02 (0.74)	0.97 (0.69, 1.26)	78	1.03 (0.58)	0.95 (0.68, 1.23)	51	1.01 (0.93)	1.03 (0.72, 1.32)
Dominant/Non-Dominant Active Knee Extension Ratio	131	1.38 (1.12)	0.97 (0.72, 1.52)	78	1.45 (1.25)	0.99 (0.72, 1.68)	53	1.26 (0.88)	0.97 (0.73, 1.42)
Dominant/Non-Dominant Straight Leg Raise Ratio	131	1.01 (0.07)	1.00 (0.96, 1.05)	78	1.01 (0.07)	1.00 (0.96, 1.06)	53	1.00 (0.06)	1.00 (0.95, 1.03)

Table 12. Lower Extremity Range of Motion and Flexibility Ratios Stratified by Sex and Sport Type

	Overall			Men			Women		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Soccer									
Dominant/Non-Dominant Weight-Bearing Ankle Dorsiflexion Ratio	48	1.00 (0.16)	1.01 (0.90, 1.07)	24	1.02 (0.20)	1.04 (09.4, 1.09)	24	0.99 (0.12)	1.00 (0.88, 1.04)
Dominant/Non-Dominant Active Ankle Dorsiflexion Ratio	48	1.06 (0.54)	0.96 (0.77, 1.26)	24	0.98 (0.67)	0.87 (0.48, 1.21)	24	1.14 (0.38)	1.09 (0.88, 1.04)
Dominant/Non-Dominant Active Knee Extension Ratio	48	1.49 (1.21)	1.08 (0.69, 1.77)	24	1.47 (1.36)	0.83 (0.65, 1.76)	24	1.50 (1.08)	1.19 (0.81, 1.97)
Dominant/Non-Dominant Straight Leg Raise Ratio	48	0.99 (0.06)	0.99 (0.95, 1.03)	24	0.98 (0.05)	0.99 (0.95, 1.03)	24	1.00 (0.64)	0.99 (0.95, 1.03)
Football									
Dominant/Non-Dominant Weight-Bearing Ankle Dorsiflexion Ratio	--	--	--	42	1.10 (0.61)	1.01 (0.93, 1.10)	--	--	--
Dominant/Non-Dominant Active Ankle Dorsiflexion Ratio	--	--	--	43	1.12 (0.59)	1.04 (0.71, 1.33)	--	--	--
Dominant/Non-Dominant Active Knee Extension Ratio	--	--	--	43	1.31 (0.78)	1.02 (0.85, 1.64)	--	--	--
Dominant/Non-Dominant Straight Leg Raise Ratio	--	--	--	43	1.02 (0.08)	1.00 (0.97, 1.07)	--	--	--
Volleyball									
Dominant/Non-Dominant Weight-Bearing Ankle Dorsiflexion Ratio	--	--	--	--	--	--	16	1.00 (0.19)	1.06 (0.94, 1.15)
Dominant/Non-Dominant Active Ankle Dorsiflexion Ratio	--	--	--	--	--	--	15	0.75 (1.40)	0.91 (0.58, 1.42)
Dominant/Non-Dominant Active Knee Extension Ratio	--	--	--	--	--	--	16	1.17 (0.80)	0.96 (0.61, 1.49)
Dominant/Non-Dominant Straight Leg Raise Ratio	--	--	--	--	--	--	16	0.99 (0.06)	1.00 (0.93, 1.03)
Basketball									
Dominant/Non-Dominant Weight-Bearing Ankle Dorsiflexion Ratio	24	0.94 (0.26)	0.99 (0.85, 1.10)	11	0.92 (0.25)	0.99 (0.81, 1.10)	13	0.95 (0.28)	0.98 (0.90, 1.11)
Dominant/Non-Dominant Active Ankle Dorsiflexion Ratio	23	0.95 (0.74)	0.80 (0.58, 1.16)	11	0.83 (0.26)	0.82 (0.67, 1.05)	12	1.05 (1.00)	0.73 (0.48, 1.30)
Dominant/Non-Dominant Active Knee Extension Ratio	24	1.41 (1.56)	0.92 (0.66, 1.16)	11	1.97 (2.20)	0.72 (0.57, 4.82)	13	0.93 (0.26)	0.96 (0.71, 1.08)
Dominant/Non-Dominant Straight Leg Raise Ratio	24	1.03 (0.06)	1.01 (0.99, 1.08)	11	1.00 (0.07)	1.08 (1.00, 1.09)	13	1.01 (0.05)	1.01 (0.98, 1.04)

4.2.2 Lower Extremity Isometric Strength

Lower extremity isometric strength is presented in Table 13, Table 14, Table 15, and Table 16. Table 13 represents overall lower extremity isometric strength, and stratified by sex. Table 14 represents lower extremity isometric strength by sport type. Table 15 and Table 16 represent soccer and basketball lower extremity isometric strength, stratified by sex, respectively.

Significant differences in normalized lower extremity strength were noted for all variables when comparing men's sport types (soccer, football, and basketball). Women's sport types (soccer, volleyball, and basketball) demonstrated significant differences in all normalized lower extremity strength variables, excluding hip external rotation. Men's and women's soccer athletes demonstrate no significant differences in normalized lower extremity strength. Men's and women's basketball athletes demonstrate significant differences in normalized strength at the ankle and hip, excluding hip external rotation. Women's basketball athletes demonstrated greater normalized strength than men's basketball athletes.

Table 13. Lower Extremity Isometric Strength Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Overall						
Ankle Dorsiflexion (%BW)	130	26.3 (9.0)	23.7 (19.3, 33.7)	130	25.6 (9.0)	23.3 (19.3, 32.3)
Ankle Plantarflexion (%BW)	128	25.1 (8.7)	23.9 (18.7, 29.1)	127	24.9 (8.6)	23.3 (18.6, 28.8)
Ankle Inversion (%BW)	130	21.2 (8.2)	19.4 (15.4, 27.2)	130	20.8 (7.9)	19.1 (14.5, 27.4)
Ankle Eversion (%BW)	130	20.4 (7.5)	18.1 (15.2, 26.4)	130	20.1 (7.5)	18.5 (14.8, 24.9)
Hip Abduction (%BW)	130	19.7 (5.6)	18.2 (16.1, 22.8)	131	19.2 (4.9)	18.2 (16.1, 21.9)
Hip Adduction (%BW)	130	20.4 (5.2)	19.9 (16.7, 23.5)	130	20.2 (5.6)	19.7 (16.9, 23.3)
Hip Internal Rotation (%BW)	131	17.1 (4.4)	17.2 (14.2, 20.5)	131	16.4 (4.5)	16.5 (13.0, 19.7)
Hip External Rotation (%BW)	131	18.7 (4.8)	18.9 (14.4, 22.3)	131	19.2 (4.9)	19.1 (15.4, 22.2)
Knee Flexion (%BW)	131	33.5 (11.2)	30.5 (25.7, 40.4)	130	32.4 (11.5)	29.7 (24.8, 39.0)
Knee Extension (%BW)	130	48.4 (18.1)	45.2 (36.3, 58.5)	131	48.2 (18.2)	46.1 (36.0, 58.8)
Men						
Ankle Dorsiflexion (%BW)	77	26.0(9.0)	23.7 (19.8, 32.1)	77	25. (9.5)	23.2 (17.7, 31.4)
Ankle Plantarflexion (%BW)	75	23.6 (8.8)	21.8 (17.7, 26.5)	75	23.7 (8.6)	21.7 (17.7, 27.0)
Ankle Inversion (%BW)	77	21.2 (8.5)	19.2 (14.7, 27.2)	77	20.7 (8.3)	18.2 (14.2, 27.4)
Ankle Eversion (%BW)	77	20.3 (7.8)	17.7 (14.0, 26.6)	77	20.1 (7.8)	17.8 (14.9, 25.6)
Hip Abduction (%BW)	77	19.4 (6.1)	17.7 (15.5, 22.8)	78	18.9 (5.3)	17.5 (15.7, 22.0)
Hip Adduction (%BW)	77	20.3 (5.7)	19.8 (16.2, 23.1)	77	20.1 (6.1)	19.3 (15.5, 23.3)
Hip Internal Rotation (%BW)	78	16.8 (4.7)	16.3 (13.4, 19.7)	78	15.9 (4.6)	15.7 (12.5, 19.3)
Hip External Rotation (%BW)	78	18.9 (5.0)	19.2 (14.2, 22.6)	78	19.8 (5.5)	19.5 (15.1, 23.4)
Knee Flexion (%BW)	78	35.0 (12.2)	33.6 (26.4, 43.2)	77	33.9 (12.5)	31.4 (25.7, 40.8)
Knee Extension (%BW)	77	50.3 (20.3)	47.4 (35.5, 63.2)	78	50.2 (20.2)	48.3 (35.5, 62.6)
Women						
Ankle Dorsiflexion (%BW)	53	26.8 (9.2)	23.8 (20.1, 35.3)	53	25.8 (8.2)	23.7 (20.1, 32.7)
Ankle Plantarflexion (%BW)	53	27.3 (8.2)	26.2 (22.6, 30.5)	52	26.5 (8.5)	25.7 (21.7, 30.0)
Ankle Inversion (%BW)	53	21.2 (7.7)	19.6 (15.8, 26.8)	53	21.0 (7.5)	20.6 (14.9, 28.3)
Ankle Eversion (%BW)	53	20.4 (7.1)	19.2 (16.2, 25.1)	53	20.1 (7.0)	19.7 (14.7, 24.2)
Hip Abduction (%BW)	53	20.1 (4.8)	19.4 (16.9, 23.1)	53	19.5 (4.4)	19.6 (16.7, 21.7)
Hip Adduction (%BW)	53	20.4 (4.3)	19.9 (17.5, 24.1)	53	20.5 (4.7)	20.3 (17.2, 23.5)
Hip Internal Rotation (%BW)	53	17.7 (4.0)	17.8 (14.7, 20.6)	53	17.1 (4.1)	17.8 (13.4, 20.4)
Hip External Rotation (%BW)	53	18.3 (4.5)	18.8 (15.3, 21.7)	53	18.4 (3.7)	18.9 (16.0, 21.0)
Knee Flexion (%BW)	53	31.2 (9.3)	29.0 (24.6, 36.4)	53	30.2 (9.5)	27.8 (23.8, 38.2)
Knee Extension (%BW)	53	45.6 (14.0)	41.8 (36.4, 55.5)	53	45.2 (14.5)	45.2 (36.3, 50.4)

Table 14. Lower Extremity Isometric Strength Overall and Stratified by Sport Type

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Soccer						
Ankle Dorsiflexion (%BW)	48	29.1 (8.6)	27.1 (21.8, 36.1)	48	28.7 (8.6)	27.8 (21.1, 34.8)
Ankle Plantarflexion (%BW)	48	28.9 (8.0)	26.6 (24.0, 33.0)	47	27.9 (7.7)	26.3 (23.1, 31.8)
Ankle Inversion (%BW)	48	24.0 (7.6)	21.6 (17.4, 30.0)	48	24.2 (7.6)	23.2 (17.9, 29.1)
Ankle Eversion (%BW)	48	23.7 (7.4)	21.6 (18.0, 30.5)	48	23.5 (7.2)	21.4 (17.7, 29.8)
Hip Abduction (%BW)	48	22.3 (5.4)	20.6 (17.8, 25.8)	48	21.5 (4.5)	21.0 (17.4, 24.6)
Hip Adduction (%BW)	48	22.8 (5.4)	22.6 (19.0, 25.2)	48	22.8 (5.4)	22.5 (19.8, 26.3)
Hip Internal Rotation (%BW)	48	19.2 (4.1)	19.2 (16.9, 21.1)	48	18.5 (4.0)	18.5 (15.9, 20.2)
Hip External Rotation (%BW)	48	20.1 (4.5)	20.0 (16.68, 22.5)	48	20.4 (5.0)	19.7 (17.1, 23.3)
Knee Flexion (%BW)	48	36.4 (11.4)	31.1 (26.5, 46.1)	48	34.6 (10.4)	30.7 (27.2, 42.4)
Knee Extension (%BW)	48	53.9 (15.9)	51.5 (43.7, 65.1)	48	52.8 (17.2)	50.5 (39.7, 61.7)
Football						
Ankle Dorsiflexion (%BW)	42	25.7 (8.9)	23.3 (17.5, 30.2)	42	24.8 (9.4)	22.6 (16.7, 29.8)
Ankle Plantarflexion (%BW)	40	21.9 (7.4)	19.9 (16.6, 24.0)	40	22.5 (7.6)	20.3 (17.1, 26.3)
Ankle Inversion (%BW)	42	20.6 (7.5)	19.2 (14.8, 23.0)	42	19.9 (6.9)	18.1 (14.8, 23.0)
Ankle Eversion (%BW)	42	19.6 (6.7)	17.5 (13.8, 23.8)	42	19.5 (6.2)	18.2 (15.8, 21.4)
Hip Abduction (%BW)	42	18.5 (5.5)	17.0 (15.2, 20.4)	43	18.2 (4.5)	16.6 (15.8, 19.7)
Hip Adduction (%BW)	42	19.3 (4.2)	19.2 (16.3, 21.5)	42	19.4 (5.2)	18.6 (15.2, 22.2)
Hip Internal Rotation (%BW)	43	16.6 (3.8)	15.8 (13.7, 19.2)	43	15.5 (4.0)	15.4 (12.1, 18.8)
Hip External Rotation (%BW)	43	18.8 (4.8)	19.0 (14.1, 22.6)	43	19.8 (4.6)	19.7 (16.5, 23.1)
Knee Flexion (%BW)	43	35.4 (11.8)	33.8 (26.9, 40.7)	42	35.6 (12.6)	33.0 (27.3, 40.6)
Knee Extension (%BW)	42	51.5 (21.0)	46.0 (37.3, 63.9)	43	52.0 (19.5)	45.9 (37.4, 64.2)
Volleyball						
Ankle Dorsiflexion (%BW)	16	18.8 (4.7)	19.4 (15.5, 22.9)	16	18.5 (4.2)	20.0 (16.0, 20.7)
Ankle Plantarflexion (%BW)	16	21.7 (5.5)	22.6 (18.7, 25.9)	16	21.2 (5.1)	21.4 (18.2, 25.2)
Ankle Inversion (%BW)	16	15.6 (3.9)	15.9 (12.0, 18.5)	16	14.9 (4.3)	14.6 (12.5, 18.9)
Ankle Eversion (%BW)	16	14.7 (4.6)	15.8 (12.9, 17.5)	16	14.4 (4.2)	14.7 (11.2, 16.5)
Hip Abduction (%BW)	16	17.0 (3.3)	17.0 (14.8, 19.4)	16	17.1 (3.2)	17.3 (14.7, 20.0)
Hip Adduction (%BW)	16	19.1 (3.8)	19.9 (15.8, 21.3)	16	18.3 (3.8)	18.5 (15.2, 22.1)
Hip Internal Rotation (%BW)	16	16.1 (3.9)	16.4 (12.3, 19.5)	16	14.8 (3.7)	13.3 (12.5, 17.8)
Hip External Rotation (%BW)	16	17.4 (4.9)	17.9 (13.8, 22.5)	16	17.6 (4.3)	18.4 (14.2, 21.0)
Knee Flexion (%BW)	16	25.4 (6.1)	25.2 (20.3, 29.4)	16	23.6 (5.6)	23.1 (19.6, 29.4)
Knee Extension (%BW)	16	37.9 (9.4)	37.0 (31.5, 43.2)	16	39.8 (9.6)	39.9 (33.6, 46.3)
Basketball						
Ankle Dorsiflexion (%BW)	24	27.0 (9.8)	24.8 (20.7, 36.7)	24	25.2 (8.6)	24.0 (18.6, 32.2)
Ankle Plantarflexion (%BW)	24	25.2 (11.2)	24.6 (17.9, 29.0)	24	25.3 (11.6)	23.4 (17.0, 28.8)
Ankle Inversion (%BW)	24	20.5 (10.3)	19.6 (11.0, 30.7)	24	19.6 (9.3)	19.2 (11.1, 29.2)
Ankle Eversion (%BW)	24	18.9 (8.0)	17.6 (11.4, 25.6)	24	18.1 (8.6)	17.8 (11.0, 22.9)
Hip Abduction (%BW)	24	18.3 (5.7)	18.2 (12.7, 22.5)	24	17.7 (5.7)	17.1 (12.9, 21.7)
Hip Adduction (%BW)	24	18.1 (5.3)	18.6 (13.3, 22.1)	24	17.5 (5.5)	17.3 (12.2, 21.8)
Hip Internal Rotation (%BW)	24	14.8 (4.9)	15.8 (10.7, 17.7)	24	14.7 (5.1)	14.4 (11.1, 19.7)
Hip External Rotation (%BW)	24	16.4 (4.6)	16.0 (13.2, 20.5)	24	16.8 (4.6)	16.2 (13.2, 20.1)
Knee Flexion (%BW)	24	29.5 (9.2)	28.7 (22.9, 36.3)	24	28.3 (10.8)	27.3 (20.2, 38.3)
Knee Extension (%BW)	24	38.8 (15.0)	37.0 (28.0, 53.0)	24	37.8 (16.6)	38.1 (25.5, 46.1)

Table 15. Lower Extremity Isometric Strength for Soccer Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Men's Soccer						
Ankle Dorsiflexion (%BW)	24	28.9 (9.4)	28.0 (21.2, 37.8)	24	29.2 (10.1)	29.2 (20.4, 35.9)
Ankle Plantarflexion (%BW)	24	28.9 (10.1)	25.7 (23.0, 34.0)	24	28.4 (9.4)	25.5 (22.7, 36.1)
Ankle Inversion (%BW)	24	25.8 (8.8)	27.3 (17.8, 32.0)	24	25.5 (8.9)	27.0 (17.7, 30.6)
Ankle Eversion (%BW)	24	24.9 (8.5)	26.6 (17.2, 31.0)	24	24.6 (8.5)	27.6 (16.0, 30.9)
Hip Abduction (%BW)	24	23.2 (6.0)	22.4 (17.8, 26.6)	24	22.3 (5.3)	21.9 (17.5, 26.6)
Hip Adduction (%BW)	24	24.2 (6.2)	23.0 (20.1, 26.2)	24	23.7 (12.9)	23.3 (19.0, 28.9)
Hip Internal Rotation (%BW)	24	19.1 (4.8)	19.1 (15.9, 21.3)	24	18.3 (4.4)	18.1 (15.5, 20.2)
Hip External Rotation (%BW)	24	20.8 (4.8)	20.8 (17.1, 23.5)	24	21.4 (6.3)	20.8 (16.4, 24.2)
Knee Flexion (%BW)	24	38.3 (12.9)	36.3 (26.5, 48.4)	24	35.7 (11.4)	34.1 (26.8, 45.4)
Knee Extension (%BW)	24	55.2 (18.0)	51.5 (44.4, 68.6)	24	54.0 (18.6)	53.3 (39.7, 63.1)
Women's Soccer						
Ankle Dorsiflexion (%BW)	24	29.2 (7.9)	25.8 (21.8, 35.7)	24	28.2 (7.1)	27.3 (21.1, 33.7)
Ankle Plantarflexion (%BW)	24	28.9 (5.3)	27.2 (24.5, 32.7)	23	27.4 (5.6)	26.3 (23.3, 31.8)
Ankle Inversion (%BW)	24	22.1 (5.8)	20.8 (17.2, 27.5)	24	22.8 (6.1)	21.7 (18.8, 28.4)
Ankle Eversion (%BW)	24	22.5 (6.1)	20.7 (18.0, 29.4)	24	22.4 (5.5)	20.7 (18.9, 26.8)
Hip Abduction (%BW)	24	21.5 (4.8)	19.9 (17.8, 23.6)	24	20.6 (3.5)	20.3 (17.4, 22.8)
Hip Adduction (%BW)	24	21.4 (4.1)	21.5 (18.2, 24.5)	24	22.1 (4.5)	22.5 (19.9, 24.9)
Hip Internal Rotation (%BW)	24	19.2 (3.4)	19.2 (17.1, 20.8)	24	18.7 (3.5)	18.5 (16.3, 20.7)
Hip External Rotation (%BW)	24	19.4 (4.3)	19.2 (15.9, 22.2)	24	19.4 (3.2)	19.5 (15.9, 22.2)
Knee Flexion (%BW)	24	34.4 (9.5)	30.4 (26.5, 39.7)	24	33.5 (9.3)	29.3 (27.2, 39.8)
Knee Extension (%BW)	24	52.7 (13.7)	49.9 (41.5, 62.0)	24	51.5 (16.0)	48.4 (39.5, 61.0)

Table 16. Lower Extremity Isometric Strength for Basketball Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Men's Basketball						
Ankle Dorsiflexion (%BW)	11	20.8 (5.5)	23.11 (16.6, 24.5)	11	19.3 (4.1)	21.04 (15.6, 22.4)
Ankle Plantarflexion (%BW)	11	18.0 (4.5)	17.9 (13.8, 21.9)	11	17.9 (4.5)	18.1 (13.6, 22.4)
Ankle Inversion (%BW)	11	13.7 (5.1)	12.6 (10.2, 18.7)	11	13.0 (5.0)	12.4 (10.0, 17.6)
Ankle Eversion (%BW)	11	13.3 (3.5)	11.9 (10.01, 17.6)	11	12.5 (4.4)	12.3 (9.0, 17.5)
Hip Abduction (%BW)	11	14.9 (4.3)	14.0 (11.3, 17.8)	11	14.5 (3.6)	13.7 (11.5, 18.0)
Hip Adduction (%BW)	11	15.5 (4.5)	14.4 (11.9, 20.1)	11	14.5 (4.1)	14.0 (10.6, 17.5)
Hip Internal Rotation (%BW)	11	12.4 (4.5)	11.23 (9.6,15.2)	11	12.1 (4.6)	11.1 (9.0, 14.1)
Hip External Rotation (%BW)	11	15.4 (4.7)	13.9 (12.0, 16.6)	11	16.0 (5.5)	13.9(12.6, 19.3)
Knee Flexion (%BW)	11	26.1 (8.1)	23.3(18.3, 34.6)	11	23.8 (10.0)	23.6 (15.5, 34.9)
Knee Extension (%BW)	11	35.1 (16.1)	30.3 (21.4, 50.6)	11	34.9 (20.6)	26.1 (20.8, 58.7)
Women's Basketball						
Ankle Dorsiflexion (%BW)	13	32.3 (9.7)	36.3 (23.7, 39.9)	13	30.3 (8.3)	32.1 (24.7, 36.9)
Ankle Plantarflexion (%BW)	13	31.3 (11.5)	28.3 (24.3, 41.6)	13	31.5 (12.2)	28.8 (23.0, 42.7)
Ankle Inversion (%BW)	13	26.2 (10.1)	28.6 (18.9, 35.2)	13	25.1 (8.6)	29.2 (17.2, 32.8)
Ankle Eversion (%BW)	13	23.6 (7.66)	24.3 (17.7, 29.4)	13	22.9 (8.5)	21.9 (18.2, 27.2)
Hip Abduction (%BW)	13	21.3 (5.1)	21.7 (18.1, 26.0)	13	20.3 (5.9)	20.4 (16.0, 24.6)
Hip Adduction (%BW)	13	20.3 (5.2)	19.2 (17.4, 24.2)	13	20.2 (5.2)	19.9 (16.1, 24.5)
Hip Internal Rotation (%BW)	13	16.9 (4.4)	17.4 (15.5, 19.4)	13	16.9 (4.6)	18.7 (13.2, 21.5)
Hip External Rotation (%BW)	13	17.3 (4.5)	19.3 (15.0, 20.8)	13	17.6 (3.7)	18.5 (15.1, 20.5)
Knee Flexion (%BW)	13	32.3 (9.5)	32.0 (25.9, 41.8)	13	32.1 (10.3)	33.8 (25.3, 38.6)
Knee Extension (%BW)	13	42.0 (13.7)	40.1 (34.9, 54.4)	13	40.3 (12.6)	40.7 (33.4, 45.8)

Lower extremity isometric strength ratios are presented in Table 17, Table 18, Table 19, Table 20, Table 21 and Table 22. Table 17 represents overall lower extremity dominant/non-dominant isometric strength ratios, and stratified by sex. Table 18 represents overall lower extremity agonist/antagonist isometric strength ratios, and stratified by sex. Table 19 represents lower extremity dominant/non-dominant isometric strength ratios by sport type, and stratified by sex, if applicable. Table 20 represents lower extremity agonist/antagonist isometric strength ratios by sport. Table 21 and Table 22 represent soccer and basketball lower extremity agonist/antagonist isometric strength ratios, stratified by sex, respectively. Overall, no significant differences were demonstrated in dominant/non-dominant lower extremity strength ratios when comparing men’s and women’s lower extremity dominant athletes. No significant differences in agonist/antagonist lower extremity strength ratios were noted for men’s and women’s soccer athletes. Men’s and women’s basketball athletes demonstrate statistically significant differences in hip external rotation/internal rotation strength ratios. Men’s basketball athletes demonstrate greater hip external rotation/internal rotation strength ratios (mean ± standard deviation) when compared to women’s basketball athletes (Dominant: Men’s Basketball – 1.29 ± 0.26, Women’s Basketball – 1.05 ± 0.22; Non-Dominant: Men’s Basketball – 1.40 ± 0.37, Women’s Basketball – 1.08 ± 0.24).

Table 17. Lower Extremity Isometric Strength Ratios – Dominant/Non-Dominant Overall and Stratified by Sex

	Overall			Men			Women		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Dominant/Non-Dominant Ankle Dorsiflexion Ratio	129	1.04 (0.12)	1.03 (0.97, 1.08)	76	1.04 (0.13)	1.03 (0.96, 1.08)	53	1.04 (0.11)	1.03 (0.98, 1.10)
Dominant/Non-Dominant Ankle Plantarflexion Ratio	126	1.01 (0.10)	1.01 (0.95, 1.07)	74	1.00 (0.09)	1.00 (0.95, 1.06)	52	1.03 (0.11)	1.02 (0.95, 1.11)
Dominant/Non-Dominant Ankle Inversion Ratio	129	1.03 (0.17)	1.01 (0.92, 1.14)	76	1.04 (0.16)	1.01 (0.93, 1.15)	53	1.03 (0.19)	1.00 (0.91, 1.13)
Dominant/Non-Dominant Ankle Eversion Ratio	129	1.02 (0.16)	1.02 (0.90, 1.14)	76	1.02 (0.17)	1.02 (0.88, 1.11)	53	1.02 (0.16)	1.02 (0.93, 1.13)
Dominant/Non-Dominant Hip Abduction Ratio	130	1.03 (0.13)	1.00 (0.94, 1.09)	77	1.02 (0.11)	1.01 (0.94, 1.08)	53	1.03 (0.14)	0.98 (0.94, 0.98)
Dominant/Non-Dominant Hip Adduction Ratio	129	1.02 (0.12)	1.02 (0.94, 1.12)	76	1.03 (0.13)	1.03 (0.94, 1.14)	53	1.01 (0.11)	1.00 (0.93, 1.09)
Dominant/Non-Dominant Hip Internal Rotation Ratio	131	1.06 (0.16)	1.01 (0.97, 1.18)	78	1.08 (0.16)	1.06 (0.99, 1.18)	53	1.05 (0.15)	1.06 (0.96, 1.18)
Dominant/Non-Dominant Hip External Rotation Ratio	131	0.98 (0.14)	0.98 (0.89, 1.07)	78	0.97 (0.13)	0.98 (0.88, 1.03)	53	1.00 (0.15)	0.98 (0.89, 1.11)
Dominant/Non-Dominant Knee Flexion Ratio	130	1.06 (0.16)	1.05 (0.96, 1.12)	77	1.06 (0.18)	1.05 (0.96, 1.15)	53	1.05 (0.11)	1.05 (0.97, 1.10)
Dominant/Non-Dominant Knee Extension Ratio	130	1.02 (0.17)	1.02 (0.91, 1.13)	77	1.03 (0.18)	1.00 (0.92, 1.14)	53	1.20 (0.16)	1.02 (0.90, 1.13)

Table 18. Lower Extremity Isometric Strength Ratios – Agonist/Antagonist Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Overall						
Ankle Dorsiflexion/Plantarflexion Ratio	128	1.06 (0.23)	1.01 (0.90, 1.23)	127	1.04 (0.23)	0.99 (0.87, 1.18)
Ankle Eversion/Inversion Ratio	130	0.98 (0.18)	0.98 (0.87, 1.07)	130	0.99 (0.17)	0.96 (0.89, 1.07)
Hip Adduction/Abduction Ratio	130	1.06 (0.17)	1.10 (0.96, 1.18)	130	1.06 (0.14)	1.05 (0.97, 1.15)
Hip External Rotation/Internal Rotation Ratio	131	1.11 (0.23)	1.11 (0.95, 1.22)	131	1.21 (0.25)	1.20 (1.02, 1.36)
Knee Flexion/Extension Ratio	130	0.73 (0.20)	0.70 (0.60, 0.83)	130	0.71 (0.22)	0.66 (0.56, 0.84)
Men						
Ankle Dorsiflexion/Plantarflexion Ratio	75	1.12 (0.21)	1.11 (0.95, 1.30)	75	1.08 (0.22)	1.05 (0.94, 1.23)
Ankle Eversion/Inversion Ratio	77	0.98 (0.18)	0.95 (0.87, 1.07)	77	0.99 (0.15)	0.97 (0.89, 1.08)
Hip Adduction/Abduction Ratio	77	1.07 (0.18)	1.11 (0.96, 1.21)	77	1.06 (0.14)	1.04 (0.96, 1.15)
Hip External Rotation/Internal Rotation Ratio	77	1.16 (0.23)	1.15 (1.02, 1.23)	77	1.28 (0.26)	1.26 (1.11, 1.44)
Knee Flexion/Extension Ratio	78	0.75 (0.22)	0.74 (0.60, 0.89)	78	0.72 (0.24)	0.68 (0.53, 0.92)
Women						
Ankle Dorsiflexion/Plantarflexion Ratio	53	0.99 (0.23)	0.92 (0.83, 1.14)	52	0.98 (0.21)	0.90 (0.83, 1.10)
Ankle Eversion/Inversion Ratio	53	0.98 (0.18)	0.99 (0.88, 1.07)	53	0.98 (0.19)	0.94 (0.86, 1.06)
Hip Adduction/Abduction Ratio	53	1.04 (0.16)	1.09 (0.95, 1.15)	53	1.06 (0.15)	1.06 (0.98, 1.15)
Hip External Rotation/Internal Rotation Ratio	53	1.05 (0.21)	1.01 (0.90, 1.16)	53	1.10 (0.20)	1.08 (0.96, 1.23)
Knee Flexion/Extension Ratio	53	0.71 (0.16)	0.66 (0.61, 0.80)	53	0.69 (0.18)	0.66 (0.57, 0.82)

Table 19. Lower Extremity Isometric Strength Ratios – Dominant/Non-Dominant Stratified by Sex and Sport Type

	Overall			Men			Women		
	n	Mean (SD)	Median	n	Mean (SD)	Median	n	Mean (SD)	Median
Soccer									
Dominant/Non-Dominant Ankle Dorsiflexion Ratio	48	1.02 (0.14)	1.03 (0.96, 1.06)	24	1.01 (0.17)	0.97 (0.92, 1.04)	24	1.03 (0.09)	1.05 (1.00, 1.09)
Dominant/Non-Dominant Ankle Plantarflexion Ratio	47	1.04 (0.11)	1.03 (0.95, 1.09)	24	1.01 (0.71)	1.03 (0.97, 1.07)	23	1.06 (0.14)	1.05 (0.95, 1.14)
Dominant/Non-Dominant Ankle Inversion Ratio	48	1.00 (0.16)	0.99 (0.92, 1.04)	24	1.02 (0.14)	0.99 (0.94, 1.04)	24	0.99 (0.18)	0.98 (0.86, 1.05)
Dominant/Non-Dominant Ankle Eversion Ratio	48	1.02 (0.13)	1.02 (0.93, 1.10)	24	1.02 (0.14)	1.05 (0.91, 1.09)	24	1.01 (0.13)	1.02 (0.93, 1.12)
Dominant/Non-Dominant Hip Abduction Ratio	48	1.04 (0.13)	1.00 (0.93, 1.10)	24	1.04 (0.10)	1.04 (0.97, 1.08)	24	1.04 (0.15)	0.97 (0.92, 1.12)
Dominant/Non-Dominant Hip Adduction Ratio	48	1.01 (0.14)	1.00 (0.90, 1.10)	24	1.03 (0.15)	1.01 (0.89, 1.13)	24	0.98 (0.12)	0.97 (0.91, 1.06)
Dominant/Non-Dominant Hip Internal Rotation Ratio	48	1.04 (0.15)	1.05 (0.97, 1.13)	24	1.05 (0.14)	1.06 (0.99, 1.13)	24	1.04 (0.16)	1.03 (0.94, 1.17)
Dominant/Non-Dominant Hip External Rotation Ratio	48	1.00 (0.14)	1.00 (0.92, 1.08)	24	1.00 (0.14)	1.00 (0.93, 1.04)	24	1.00 (0.14)	1.00 (0.89, 1.12)
Dominant/Non-Dominant Knee Flexion Ratio	48	1.05 (0.13)	1.03 (0.98, 1.14)	24	1.07 (0.14)	1.05 (0.98, 1.19)	24	1.03 (0.12)	1.02 (0.97, 1.08)
Dominant/Non-Dominant Knee Extension Ratio	48	1.04 (0.17)	1.06 (0.92, 1.18)	24	1.04 (0.17)	1.04 (0.92, 1.16)	24	1.04 (0.16)	1.08 (0.92, 1.20)
Football									
Dominant/Non-Dominant Ankle Dorsiflexion Ratio	--	--	--	41	1.05 (0.10)	1.05 (1.00, 1.09)	--	--	--
Dominant/Non-Dominant Ankle Plantarflexion Ratio	--	--	--	39	0.99 (0.10)	0.98(0.95, 1.05)	--	--	--
Dominant/Non-Dominant Ankle Inversion Ratio	--	--	--	41	1.04 (0.16)	1.03 (0.92, 1.16)	--	--	--
Dominant/Non-Dominant Ankle Eversion Ratio	--	--	--	41	0.99 (0.18)	1.00 (0.86, 1.09)	--	--	--
Dominant/Non-Dominant Hip Abduction Ratio	--	--	--	42	1.02 (0.12)	0.99 (0.93, 1.09)	--	--	--
Dominant/Non-Dominant Hip Adduction Ratio	--	--	--	41	1.02 (0.12)	1.02 (0.94, 1.12)	--	--	--
Dominant/Non-Dominant Hip Internal Rotation Ratio	--	--	--	43	1.09 (0.15)	1.06 (0.99, 1.23)	--	--	--
Dominant/Non-Dominant Hip External Rotation Ratio	--	--	--	43	0.95 (0.13)	0.96 (0.87, 1.01)	--	--	--
Dominant/Non-Dominant Knee Flexion Ratio	--	--	--	42	1.03 (0.19)	1.02 (0.95, 1.11)	--	--	--
Dominant/Non-Dominant Knee Extension Ratio	--	--	--	42	1.01 (0.14)	0.96 (0.91, 1.07)	--	--	--
Volleyball									
Dominant/Non-Dominant Ankle Dorsiflexion Ratio	--	--	--	--	--	--	16	1.02 (0.10)	1.02 (0.94, 1.12)
Dominant/Non-Dominant Ankle Plantarflexion Ratio	--	--	--	--	--	--	16	1.02 (0.65)	1.01 (0.99, 1.04)
Dominant/Non-Dominant Ankle Inversion Ratio	--	--	--	--	--	--	16	1.08 (0.20)	1.00 (0.91, 1.26)
Dominant/Non-Dominant Ankle Eversion Ratio	--	--	--	--	--	--	16	1.02 (0.19)	1.06 (0.86, 1.19)
Dominant/Non-Dominant Hip Abduction Ratio	--	--	--	--	--	--	16	0.99 (0.08)	0.98 (0.95, 1.07)
Dominant/Non-Dominant Hip Adduction Ratio	--	--	--	--	--	--	16	1.05 (0.09)	1.05 (0.96, 1.12)
Dominant/Non-Dominant Hip Internal Rotation Ratio	--	--	--	--	--	--	16	1.09 (0.13)	1.09 (1.05, 1.18)
Dominant/Non-Dominant Hip External Rotation Ratio	--	--	--	--	--	--	16	0.99 (0.15)	0.96 (0.90, 1.09)
Dominant/Non-Dominant Knee Flexion Ratio	--	--	--	--	--	--	16	1.08 (0.10)	1.09 (1.05, 1.12)
Dominant/Non-Dominant Knee Extension Ratio	--	--	--	--	--	--	16	0.96 (0.12)	0.92 (0.88, 1.04)
Basketball									
Dominant/Non-Dominant Ankle Dorsiflexion Ratio	24	1.07 (0.14)	1.03 (0.97, 1.16)	11	1.07 (0.13)	1.06 (0.96, 1.20)	13	1.06 (0.16)	1.00 (0.96, 1.13)
Dominant/Non-Dominant Ankle Plantarflexion Ratio	24	1.01 (0.09)	1.02 (0.93, 1.07)	11	1.01 (0.10)	1.02 (0.92, 1.07)	13	1.00 (0.09)	1.00 (0.93, 1.07)
Dominant/Non-Dominant Ankle Inversion Ratio	24	1.05 (0.19)	1.05 (0.93, 1.19)	11	1.07 (0.20)	1.01 (0.89, 1.25)	13	1.03 (0.18)	1.07 (0.93, 1.15)
Dominant/Non-Dominant Ankle Eversion Ratio	24	1.07 (1.69)	1.11 (0.94, 1.16)	11	1.10 (0.17)	1.14 (0.99, 1.26)	13	1.05 (0.17)	1.01 (0.91, 1.11)
Dominant/Non-Dominant Hip Abduction Ratio	24	1.05 (0.15)	1.02 (0.95, 1.13)	11	1.02 (0.12)	1.02 (0.98, 1.06)	13	1.07 (0.18)	1.03 (0.93, 1.18)
Dominant/Non-Dominant Hip Adduction Ratio	24	1.04 (0.12)	1.03 (0.94, 1.16)	11	1.08 (0.12)	1.11 (0.98, 1.19)	13	1.01 (0.11)	1.00 (0.93, 1.10)
Dominant/Non-Dominant Hip Internal Rotation Ratio	24	1.04 (0.21)	1.04 (0.92, 1.15)	11	1.07 (0.25)	1.08 (0.94, 1.14)	13	1.01 (0.17)	1.03 (0.83, 1.18)
Dominant/Non-Dominant Hip External Rotation Ratio	24	0.98 (0.16)	0.99 (0.87, 1.08)	11	0.98 (0.13)	1.01 (0.86, 1.09)	13	0.99 (0.19)	0.98 (0.92, 1.08)
Dominant/Non-Dominant Knee Flexion Ratio	24	1.09 (0.17)	1.06 (0.94, 1.17)	11	1.16 (0.21)	1.24 (0.96, 1.31)	13	1.02 (0.10)	1.04 (0.92, 1.12)
Dominant/Non-Dominant Knee Extension Ratio	24	1.06 (0.18)	1.03 (0.97, 1.20)	11	1.07 (0.17)	1.01 (0.97, 1.23)	13	1.05 (0.19)	1.04 (0.93, 1.12)

Table 20. Lower Extremity Isometric Strength Ratios – Agonist/Antagonist Stratified by Sport Type

	Dominant			Non-Dominant		
	n	Mean (SD)	Median	n	Mean (SD)	Median
Soccer						
Ankle Dorsiflexion/Plantarflexion Ratio	48	1.02 (0.21)	0.99 (0.86, 1.10)	47	1.04 (0.25)	0.97 (0.88, 1.20)
Ankle Eversion/Inversion Ratio	48	1.00 (0.16)	1.02 (0.88, 1.05)	48	0.98 (0.15)	0.95 (0.89, 1.06)
Hip Adduction/Abduction Ratio	48	1.04 (0.19)	1.07 (0.97, 1.22)	48	1.07 (0.14)	1.08 (0.96, 1.15)
Hip External Rotation/Internal Rotation Ratio	48	1.06 (0.19)	1.06 (1.01, 1.18)	48	1.11 (0.21)	1.09 (0.97, 1.34)
Knee Flexion/Extension Ratio	48	0.70 (0.19)	0.68 (0.60, 0.83)	48	0.69 (0.19)	0.66 (0.55, 0.82)
Football						
Ankle Dorsiflexion/Plantarflexion Ratio	40	1.16 (0.20)	1.15 (1.00, 1.31)	40	1.11 (0.22)	1.08 (0.95, 1.28)
Ankle Eversion/Inversion Ratio	42	0.97 (0.18)	0.93 (0.85, 1.08)	42	1.00 (0.17)	1.00 (0.90, 1.10)
Hip Adduction/Abduction Ratio	42	1.08 (0.19)	1.13 (0.95, 1.22)	42	1.08 (0.16)	1.03 (0.96, 1.18)
Hip External Rotation/Internal Rotation Ratio	43	1.15 (0.25)	1.15 (0.98, 1.23)	43	1.31 (0.22)	1.32 (1.18, 1.46)
Knee Flexion/Extension Ratio	42	0.74 (0.21)	0.73 (0.59, 0.86)	42	0.72 (0.23)	0.69 (0.54, 0.92)
Volleyball						
Ankle Dorsiflexion/Plantarflexion Ratio	16	0.88 (0.13)	0.87 (0.79, 0.94)	16	0.88 (0.11)	0.85 (0.81, 0.95)
Ankle Eversion/Inversion Ratio	16	0.94 (0.21)	0.98 (0.80, 1.06)	16	1.00 (0.24)	0.96 (0.91, 1.04)
Hip Adduction/Abduction Ratio	16	1.12 (0.08)	1.13 (1.08, 1.17)	16	1.07 (0.13)	1.06 (0.97, 1.13)
Hip External Rotation/Internal Rotation Ratio	16	1.09 (0.24)	1.10 (0.92, 1.23)	16	1.20 (0.19)	1.31 (1.05, 1.38)
Knee Flexion/Extension Ratio	16	0.69 (0.13)	0.67 (1.28, 1.64)	16	0.61 (0.12)	0.59 (0.51, 0.71)
Basketball						
Ankle Dorsiflexion/Plantarflexion Ratio	24	1.12 (0.25)	1.05 (0.92, 1.31)	24	1.06 (0.23)	1.05 (0.90, 1.20)
Ankle Eversion/Inversion Ratio	24	0.99 (0.22)	0.92 (0.84, 1.07)	24	0.95 (0.15)	0.93 (0.81, 1.04)
Hip Adduction/Abduction Ratio	24	1.01 (0.15)	1.03 (0.92, 1.13)	24	1.00 (0.13)	1.02 (0.89, 1.08)
Hip External Rotation/Internal Rotation Ratio	24	1.15 (0.25)	1.14 (0.95, 1.34)	24	1.23 (0.34)	1.17 (0.99, 1.37)
Knee Flexion/Extension Ratio	24	0.83 (0.24)	0.79 (0.64, 0.93)	24	0.81 (0.26)	0.74 (0.60, 1.03)

Table 21. Lower Extremity Isometric Strength Ratios – Agonist/Antagonist for Soccer Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Men's Soccer						
Ankle Dorsiflexion/Plantarflexion Ratio	24	1.01 (0.20)	0.99 (0.76, 1.01)	24	1.04 (0.24)	1.05 (0.98, 1.23)
Ankle Eversion/Inversion Ratio	24	0.98 (0.18)	0.96 (0.91, 1.08)	24	0.97 (0.13)	0.95 (0.82, 1.08)
Hip Adduction/Abduction Ratio	24	1.06 (0.20)	1.07 (0.94, 1.16)	24	1.07 (0.10)	1.07 (0.88, 1.08)
Hip External Rotation/Internal Rotation Ratio	24	1.11 (0.17)	1.13 (1.14, 1.35)	24	1.18 (0.24)	1.20 (1.14, 1.48)
Knee Flexion/Extension Ratio	24	0.72 (0.21)	0.74 (0.60, 0.99)	24	0.70 (0.20)	0.67 (0.49, 1.14)
Women's Soccer						
Ankle Dorsiflexion/Plantarflexion Ratio	24	1.01 (0.22)	0.99 (0.83, 1.18)	23	1.03 (0.27)	0.91 (0.88, 1.18)
Ankle Eversion/Inversion Ratio	24	1.03 (0.13)	1.03 (0.98, 1.10)	24	1.00 (0.18)	0.97 (0.85, 1.14)
Hip Adduction/Abduction Ratio	24	1.02 (0.18)	1.07 (0.89, 1.16)	24	1.07 (0.16)	1.08 (1.00, 1.17)
Hip External Rotation/Internal Rotation Ratio	24	1.02 (0.20)	0.99 (0.87, 1.15)	24	1.05 (0.17)	1.04 (0.95, 1.17)
Knee Flexion/Extension Ratio	24	0.67 (0.16)	0.63 (0.56, 0.74)	24	0.68 (0.18)	0.65 (0.56, 0.81)

Table 22. Lower Extremity Isometric Strength Ratios – Agonist/Antagonist for Basketball Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Men's Basketball						
Ankle Dorsiflexion/Plantarflexion Ratio	11	1.16 (0.18)	1.26 (0.99, 1.31)	11	1.10 (0.16)	1.07 (0.98, 1.23)
Ankle Eversion/Inversion Ratio	11	1.02 (0.20)	1.05 (0.91, 1.08)	11	0.97 (0.13)	1.02 (0.82, 1.08)
Hip Adduction/Abduction Ratio	11	1.05 (0.10)	1.04 (0.94, 1.16)	11	0.99 (0.13)	1.00 (0.88, 1.08)
Hip External Rotation/Internal Rotation Ratio	11	1.29 (0.26)	1.32 (1.14, 1.35)	11	1.40 (0.37)	1.34 (1.14, 1.48)
Knee Flexion/Extension Ratio	11	0.82 (0.25)	0.79 (0.60, 0.99)	11	0.80 (0.36)	0.59 (0.49, 1.14)
Women's Basketball						
Ankle Dorsiflexion/Plantarflexion Ratio	13	1.08 (0.31)	0.94 (0.84, 1.29)	13	1.03 (0.28)	0.98 (0.80, 1.12)
Ankle Eversion/Inversion Ratio	13	0.96 (0.24)	0.88 (0.82, 1.05)	13	0.93 (0.16)	0.92 (0.81, 1.00)
Hip Adduction/Abduction Ratio	13	0.97 (0.17)	0.98 (0.83, 1.10)	13	1.01 (0.14)	1.05 (0.92, 1.10)
Hip External Rotation/Internal Rotation Ratio	13	1.05 (0.22)	0.98 (0.90, 1.25)	13	1.08 (0.24)	1.02 (0.90, 1.18)
Knee Flexion/Extension Ratio	13	0.80 (0.17)	0.78 (0.65, 0.89)	13	0.81 (0.17)	0.81 (0.67, 0.89)

4.2.3 Static Postural Stability: Eyes-Open

Eyes-open static postural stability is presented in Table 23, Table 24, Table 25, and Table 26. Table 23 represents overall eyes-open static postural stability, and stratified by sex. Table 24 represents eyes-open static postural stability by sport type. Table 25 and Table 26 represent soccer and basketball eyes-open static postural stability, stratified by sex, respectively. Overall, men's and women's lower extremity dominant athletes demonstrate statistically significant differences in eyes open static postural stability; generally, men's athletes demonstrate worse eyes open static balance balance than women's athletes. Significant differences in eyes open static postural stability are demonstrated between men's and women's soccer athletes, while no significant differences in eyes open static postural stability are noted in men's and women's basketball athletes. In soccer athletes, females tend to demonstrate better static balance with their eyes open compared to males.

Table 23. Eyes-Open Static Postural Stability Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Overall						
Composite Score	128	8.29 (8.53)	6.71 (4.89, 8.66)	130	8.02 (5.61)	6.44 (4.93, 9.28)
Vertical Ground Reaction Force	128	6.57 (8.41)	4.89 (3.72, 6.79)	130	6.23 (5.07)	4.90 (3.67, 7.10)
Anterior/Posterior Ground Reaction Force	128	3.04 (1.32)	2.69 (2.10, 3.68)	130	3.15 (1.60)	2.79 (2.17, 3.88)
Medial/Lateral Ground Reaction Force	128	3.61 (1.89)	3.13 (2.28, 4.01)	130	3.76 (2.17)	3.08 (2.49, 4.35)
Anterior/Posterior Center of Pressure	128	343.73 (2493.429)	11.55 (8.45, 19.37)	130	199.61 (1580.21)	11.65 (8.80, 18.05)
Medial/Lateral Center of Pressure	128	1193.88 (10160.62)	7.76 (5.79, 14.30)	130	889.64 (9512.46)	7.42 (5.81, 14.34)
Men						
Composite Score	75	9.46 (10.31)	7.60 (6.37, 9.58)	77	3.63 (1.70)	7.55 (6.12, 10.47)
Vertical Ground Reaction Force	75	7.46 (10.30)	5.41 (4.46, 7.26)	77	7.13 (5.72)	5.73 (4.54, 8.05)
Anterior/Posterior Ground Reaction Force	75	3.43 (1.25)	3.27 (2.53, 4.02)	77	3.63 (1.70)	3.19 (2.59, 4.07)
Medial/Lateral Ground Reaction Force	75	4.13 (1.92)	3.52 (2.93, 4.82)	77	4.33 (2.39)	3.49 (2.83, 4.99)
Anterior/Posterior Center of Pressure	75	551.53 (3201.18)	14.04 (9.27, 24.72)	77	321.17 (2025.49)	13.75 (9.98, 26.98)
Medial/Lateral Center of Pressure	75	1961.12 (13059.70)	9.14 (6.34, 24.08)	77	1462.33 (12214.93)	9.08 (6.73, 22.31)
Women						
Composite Score	53	6.64 (4.66)	5.10 (4.09, 7.20)	53	6.31 (3.95)	4.96 (4.28, 6.61)
Vertical Ground Reaction Force	53	5.32 (4.34)	4.02 (3.07, 5.87)	53	4.93 (3.61)	3.68 (3.21, 5.05)
Anterior/Posterior Ground Reaction Force	53	2.50 (1.25)	2.11 (1.74, 2.85)	53	2.47 (1.17)	2.18 (1.78, 2.73)
Medial/Lateral Ground Reaction Force	53	2.88 (1.60)	2.31 (1.95, 3.20)	53	2.92 (1.44)	2.64 (1.90, 3.43)
Anterior/Posterior Center of Pressure	53	28.04 (80.50)	9.50 (7.54, 12.87)	53	12.59 (12.82)	10.40 (7.91, 12.48)
Medial/Lateral Center of Pressure	53	28.28 (96.52)	6.37 (5.13, 8.37)	53	8.59 (8.60)	6.45 (5.42, 8.14)

Table 24. Eyes-Open Static Postural Stability Stratified by Sport Type

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Soccer						
Composite Score	47	7.48 (12.83)	5.10 (4.28, 6.73)	48	5.82 (2.82)	4.96 (4.25, 6.45)
Vertical Ground Reaction Force	47	6.13 (12.90)	3.76 (3.23, 4.89)	48	4.33 (2.11)	3.70 (3.22, 4.88)
Anterior/Posterior Ground Reaction Force	47	2.61 (1.28)	2.27 (1.77, 2.86)	48	2.65 (1.64)	2.20 (1.70, 2.83)
Medial/Lateral Ground Reaction Force	47	2.67 (1.04)	2.37 (2.07, 3.07)	48	2.74 (1.22)	2.51 (1.89, 3.08)
Anterior/Posterior Center of Pressure	47	498.31 (3330.44)	8.92 (7.09, 13.92)	48	150.03 (945.26)	9.80 (7.93, 12.51)
Medial/Lateral Center of Pressure	47	866.14 (5908.72)	6.17 (4.98, 8.57)	48	125.61 (809.99)	5.81 (4.78, 7.48)
Football						
Composite Score	41	8.98 (3.93)	8.01 (6.71, 9.71)	42	9.13 (4.09)	7.81 (6.43, 10.56)
Vertical Ground Reaction Force	41	6.99 (3.44)	6.26 (4.76, 7.93)	42	7.05 (3.25)	6.24 (4.86, 8.27)
Anterior/Posterior Ground Reaction Force	41	3.42 (1.11)	3.24 (2.54, 4.00)	42	3.55 (1.36)	3.26 (2.65, 3.97)
Medial/Lateral Ground Reaction Force	41	4.28 (2.05)	3.60 (3.13, 4.66)	42	4.46 (2.33)	3.58 (2.92, 5.60)
Anterior/Posterior Center of Pressure	41	437.01 (2558.98)	13.99 (10.25, 29.03)	42	408.66 (2530.41)	15.21 (11.70, 41.50)
Medial/Lateral Center of Pressure	41	2554.89 (16454.65)	12.33 (6.84, 25.38)	42	2449.44 (16276.12)	11.14 (7.17, 32.09)
Volleyball						
Composite Score	16	6.62 (3.03)	5.84 (4.06, 8.14)	16	6.20 (2.06	6.01 (4.80, 7.09)
Vertical Ground Reaction Force	16	3.94 (2.86)	4.08 (3.04, 6.21)	16	4.43 (1.59)	4.37 (3.09, 4.85)
Anterior/Posterior Ground Reaction Force	16	2.68 (0.83)	2.52 (2.05, 3.46)	16	2.69 (0.95)	2.42 (2.18, 3.17)
Medial/Lateral Ground Reaction Force	16	3.35 (1.40)	2.82 (2.08, 4.11)	16	3.29 (1.27)	3.12 (2.62, 3.70)
Anterior/Posterior Center of Pressure	16	14.91 (22.90)	9.06 (7.24, 10.50)	16	9.85 (3.70)	8.27 (7.10, 11.78)
Medial/Lateral Center of Pressure	16	11.86 (19.66)	6.78 (5.23, 8.21)	16	7.19 (2.13)	6.93 (6.02, 7.69)
Basketball						
Composite Score	24	9.80 (5.77)	7.97 (6.46, 11.09)	24	11.72 (9.94)	8.46 (6.45, 12.74)
Vertical Ground Reaction Force	24	7.82 (5.23)	6.08 (5.24, 8.73)	24	9.80 (9.51)	6.67 (5.14, 10.59)
Anterior/Posterior Ground Reaction Force	24	3.49 (1.70)	3.47 (2.32, 3.89)	24	3.79 (1.92)	3.23 (2.40, 4.28)
Medial/Lateral Ground Reaction Force	24	4.53 (2.33)	3.80 (2.78, 6.02)	24	4.86 (2.84)	3.89 (2.92, 5.98)
Anterior/Posterior Center of Pressure	24	71.44 (129.17)	15.59 (10.12, 24.72)	24	26.07 (38.72)	14.35 (10.75, 20.94)
Medial/Lateral Center of Pressure	24	96.47 (197.95)	10.37 (6.76, 34.06)	24	46.25 (147.54)	10.34 (6.94, 19.08)

Table 25. Eyes-Open Static Postural Stability for Soccer Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Men's Soccer						
Composite Score	23	10.09 (18.02)	6.45 (4.88, 7.49)	24	7.16 (3.41)	6.14 (5.12, 8.04)
Vertical Ground Reaction Force	23	8.41 (18.22)	4.46 (3.72, 5.33)	24	5.20 (2.61)	4.32 (3.71, 5.90)
Anterior/Posterior Ground Reaction Force	23	3.23 (1.46)	2.85 (2.35, 4.02)	24	3.44 (2.00)	2.79 (2.37, 4.15)
Medial/Lateral Ground Reaction Force	23	3.22 (1.18)	2.89 (2.36, 3.62)	24	3.36 (1.42	2.88 (2.50, 3.93)
Anterior/Posterior Center of Pressure	23	985.22 (4708.61)	9.25 (7.08, 15.04)	24	287.09 (1336.55)	9.98 (8.04, 13.75)
Medial/Lateral Center of Pressure	23	1724.24 (8355.07)	6.27 (5.33, 9.82)	24	243.42 (1145.26)	6.70 (5.06, 9.13)
Women's Soccer						
Composite Score	24	4.98 (2.30)	4.34 (3.90, 5.28)	24	4.49 (0.99)	4.37 (3.86, 4.67)
Vertical Ground Reaction Force	24	3.94 (2.26)	3.33 (3.06, 4.21)	24	3.47 (0.85)	3.47 (3.04, 3.58)
Anterior/Posterior Ground Reaction Force	24	2.03 (0.72)	1.84 (1.54, 2.23)	24	1.86 (0.40)	1.82 (1.56, 1.97)
Medial/Lateral Ground Reaction Force	24	2.15 (0.49)	2.13 (1.76, 2.44)	24	2.13 (0.51)	2.11 (1.78, 2.54)
Anterior/Posterior Center of Pressure	24	11.40 (8.87)	8.92 (7.09, 12.09)	24	12.97 (17.66)	9.76 (7.93, 11.04)
Medial/Lateral Center of Pressure	24	8.04 (9.76)	5.52 (4.61, 7.60)	24	7.81 (10.53)	5.69 (4.64, 6.50)

Table 26. Eyes-Open Static Postural Stability for Basketball Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median	n	Mean (SD)	Median
Men's Basketball						
Composite Score	11	9.90 (2.91)	10.02 (7.51, 12.01)	11	13.97 (12.97)	12.70 (7.62, 13.53)
Vertical Ground Reaction Force	11	7.21 (2.17)	7.26 (5.38, 9.67)	11	11.64 (12.59)	10.25 (5.74, 10.73)
Anterior/Posterior Ground Reaction Force	11	4.34 (2.10)	3.82 (3.33, 4.07)	11	9.00 (3.82)	4.05 (3.23, 4.31)
Medial/Lateral Ground Reaction Force	11	5.95 (3.37)	5.81 (3.61, 6.14)	11	16.45 (6.72)	4.93 (3.89, 6.45)
Anterior/Posterior Center of Pressure	11	63.40 (92.31)	21.73 (14.04, 78.59)	11	37.61 (54.21)	20.11 (10.75, 21.71)
Medial/Lateral Center of Pressure	11	102.83 (213.26)	24.08 (8.87, 59.73)	11	83.58 (211.79)	16.12 (7.83, 31.52)
Women's Basketball						
Composite Score	13	9.72 (7.53)	6.77 (5.82, 9.64)	13	9.81 (6.36)	7.39 (5.88, 10.98)
Vertical Ground Reaction Force	13	8.32 (6.92)	5.75 (4.74, 7.81)	13	8.25 (5.95)	6.09 (4.61, 9.05)
Anterior/Posterior Ground Reaction Force	13	3.14 (1.99)	2.33 (1.85, 3.53)	13	3.33 (1.68)	2.52 (2.15, 4.30)
Medial/Lateral Ground Reaction Force	13	3.75 (2.49)	2.80 (2.14, 4.78)	13	3.94 (1.99)	3.24 (2.57, 4.99)
Anterior/Posterior Center of Pressure	13	78.82 (159.68)	12.47 (9.21, 16.29)	13	15.48 (8.42)	13.14 (10.77, 16.74)
Medial/Lateral Center of Pressure	13	90.64 (192.20)	7.97 (5.86, 14.44)	13	12.03 (9.37)	9.05 (6.36, 14.16)

4.2.4 Static Postural Stability: Eyes-Closed

Eyes-closed static postural stability is presented in Table 27, Table 28, Table 29, and Table 30. Table 27 represents overall eyes-closed static postural stability, and stratified by sex. Table 28 represents eyes-closed static postural stability by sport type. Table 29 and 30 represent soccer and basketball eyes-closed static postural stability, stratified by sex, respectively. Overall, men's and women's lower extremity dominant athletes demonstrate significantly different eyes closed static postural stability; women's athletes demonstrate significantly better static balance compared to men's athletes. Significant differences in all eyes closed static postural stability variables were demonstrated in men's and women's soccer athletes. Following similar trends to overall sex comparisons of eyes closed static postural stability; women's soccer athletes demonstrated significantly better eyes closed static postural stability. Only anterior/posterior ground reaction forces and medial/lateral ground reaction forces demonstrated significant differences in eyes closed static postural stability in men's and women's basketball athletes.

Table 27. Eyes-Closed Static Postural Stability Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Overall						
Composite Score	129	19.45 (12.03)	17.00 (12.69, 22.91)	129	19.71 (10.97)	16.07 (12.11, 24.38)
Vertical Ground Reaction Force	129	14.53 (11.10)	12.24 (8.91, 16.71)	129	14.60 (9.46)	11.81 (8.64, 17.17)
Anterior/Posterior Ground Reaction Force	129	6.55 (2.56)	6.08 (4.85, 8.05)	129	6.50 (2.71)	5.94 (4.42, 8.26)
Medial/Lateral Ground Reaction Force	129	10.70 (5.03)	9.67 (7.36, 13.36)	129	11.04 (5.90)	8.59 (6.85, 14.32)
Anterior/Posterior Center of Pressure	129	172.22 (1320.49)	17.16 (13.73, 22.44)	129	84.06 (590.03)	16.82 (13.85, 22.88)
Medial/Lateral Center of Pressure	129	209.95 (1447.31)	19.38 (12.57, 26.21)	129	165.11 (1356.65)	16.61 (11.77, 30.77)
Men						
Composite Score	76	22.79 (13.78)	20.67 (15.44, 26.29)	77	22.99 (11.78)	19.37 (14.91, 27.95)
Vertical Ground Reaction Force	76	17.1 (13.18)	14.47 (10.77, 18.77)	77	17.04 (10.50)	14.26(10.66, 20.26)
Anterior/Posterior Ground Reaction Force	76	7.47 (2.44)	7.07 (5.81, 8.62)	77	7.36 (2.70)	6.49 (5.29, 8.76)
Medial/Lateral Ground Reaction Force	76	12.36 (5.09)	11.4 (8.65, 15.05)	77	12.89 (6.27)	11.17 (8.25, 15.97)
Anterior/Posterior Center of Pressure	76	206.55 (1598.08)	18.64 (14.73, 25.65)	77	111.75 (743.01)	18.32 (14.65, 25.48)
Medial/Lateral Center of Pressure	76	189.51 (1350.04)	20.90 (14.13, 32.16)	77	242.61 (1729.68)	22.04 (11.55, 34.32)
Women						
Composite Score	53	14.67 (6.54)	12.84 (10.42, 17.25)	52	14.84 (7.39)	12.8 (10.40, 16.85)
Vertical Ground Reaction Force	53	10.72 (5.24)	8.99 (7.78, 12.84)	52	10.97 (6.17)	9.38 (7.40, 12.53)
Anterior/Posterior Ground Reaction Force	53	5.22 (2.12)	4.88 (3.68, 6.01)	52	5.22 (2.19)	4.49 (3.63, 6.20)
Medial/Lateral Ground Reaction Force	53	8.30 (3.86)	7.79 (5.11, 10.74)	52	8.29 (3.96)	7.17 (5.97, 9.03)
Anterior/Posterior Center of Pressure	53	120.08 (730.88)	15.13 (12.79, 18.77)	52	40.61 (172.50)	14.78 (12.67, 18.84)
Medial/Lateral Center of Pressure	53	241.00 (1596.97)	15.20 (11.11, 22.68)	52	43.55 (183.27)	14.34 (11.86, 21.69)

Table 28. Eyes-Closed Static Postural Stability Overall and Stratified by Sport Type

	Dominant			Non-Dominant		
	n	Mean (SD)	Median	n	Mean (SD)	Median
Soccer						
Composite Score	48	16.09 (8.29)	13.47 (10.71, 18.32)	47	15.53 (10.39)	12.55 (9.94, 17.11)
Vertical Ground Reaction Force	48	11.97 (7.09)	9.57 (7.75, 14.09)	47	11.74 (9.89)	9.38 (7.01, 12.42)
Anterior/Posterior Ground Reaction Force	48	5.90 (2.62)	5.31 (3.86, 7.39)	47	5.31 (2.32)	4.75 (3.63, 6.72)
Medial/Lateral Ground Reaction Force	48	8.68 (4.14)	7.77 (5.32, 11.35)	47	8.15 (3.70)	7.39 (5.29, 9.86)
Anterior/Posterior Center of Pressure	48	316.91 (2050.83)	15.56 (12.54, 21.67)	47	160.72 (969.77)	14.78 (12.10, 19.80)
Medial/Lateral Center of Pressure	48	271.98 (1732.84)	17.04 (11.11, 20.95)	47	349.26 (2255.24)	12.69 (10.64, 16.91)
Football						
Composite Score	41	22.02 (11.00)	20.63 (15.84, 23.42)	42	23.87 (11.65)	20.73 (15.82, 30.51)
Vertical Ground Reaction Force	41	16.55 (10.42)	14.74 (11.05, 17.95)	42	17.67 (9.98)	15.13 (11.68, 20.44)
Anterior/Posterior Ground Reaction Force	41	7.15 (1.86)	6.96 (5.82, 8.31)	42	7.59 (2.86)	6.46 (5.43, 9.02)
Medial/Lateral Ground Reaction Force	41	12.19 (4.55)	11.12 (9.63, 14.14)	42	13.55 (6.71)	11.34 (8.44, 9.02)
Anterior/Posterior Center of Pressure	41	26.30 (23.45)	18.59 (15.15, 24.41)	42	33.18 (44.14)	18.90 (14.98, 28.17)
Medial/Lateral Center of Pressure	41	36.87 (44.47)	20.90 (13.92, 32.90)	42	63.38 (161.94)	22.10 (11.54, 36.65)
Volleyball						
Composite Score	16	16.51 (5.53)	14.70 (12.66, 21.86)	16	17.30 (8.03)	13.81 (11.75, 20.72)
Vertical Ground Reaction Force	16	11.51 (4.28)	10.12 (8.97, 15.62)	16	12.55 (6.93)	10.15 (8.38, 14.42)
Anterior/Posterior Ground Reaction Force	16	6.10 (1.88)	5.82 (4.57, 7.78)	16	6.02 (2.32)	5.34 (3.92, 8.51)
Medial/Lateral Ground Reaction Force	16	9.97 (3.54)	8.83 (7.10, 13.69)	16	9.88 (4.41)	8.20 (6.91, 12.08)
Anterior/Posterior Center of Pressure	16	16.97 (3.97)	16.59 (13.78, 19.66)	16	17.55 (5.64)	15.84 (13.92, 21.71)
Medial/Lateral Center of Pressure	16	17.92 (7.01)	14.68 (12.76, 24.33)	16	20.18 (9.32)	17.77 (12.99, 24.92)
Basketball						
Composite Score	24	23.75 (19.35)	17.76 (14.87, 29.26)	24	22.21 (9.58)	18.92 (14.19, 30.58)
Vertical Ground Reaction Force	24	18.20 (18.46)	13.16 (10.47, 20.41)	24	16.19 (7.38)	14.32 (10.08, 21.14)
Anterior/Posterior Ground Reaction Force	24	7.10 (3.47)	5.70 (4.84, 9.11)	24	7.24 (2.50)	6.26 (5.38, 9.55)
Medial/Lateral Ground Reaction Force	24	12.66 (6.68)	11.54 (8.62, 16.97)	24	13.06 (6.28)	11.26 (8.13, 14.73)
Anterior/Posterior Center of Pressure	24	257.45 (1097.17)	17.42 (14.26, 27.24)	24	73.19 (256.22)	17.33 (14.63, 22.04)
Medial/Lateral Center of Pressure	24	545.21 (2397.16)	23.02 (14.74, 38.39)	24	88.67 (271.24)	23.30 (12.61, 34.69)

Table 29. Eyes-Closed Static Postural Stability for Soccer Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median	n	Mean (SD)	Median
Men's Soccer						
Composite Score	24	20.04 (8.59)	17.94 (13.13, 26.49)	24	20.26 (12.67)	16.00 (12.84, 23.40)
Vertical Ground Reaction Force	24	14.92 (7.72)	13.59 (8.84, 18.74)	24	15.56 (12.61)	11.28 (8.55, 16.82)
Anterior/Posterior Ground Reaction Force	24	7.31 (2.38)	6.89 (5.63, 8.14)	24	6.61 (2.44)	6.24 (4.78, 7.68)
Medial/Lateral Ground Reaction Force	24	10.79 (4.28)	10.03 (7.42, 13.69)	24	10.29 (3.91)	9.35 (7.46, 13.34)
Anterior/Posterior Center of Pressure	24	612.69 (2900.26)	16.65 (13.03, 25.67)	24	299.86 (1356.32)	15.60 (13.12, 22.33)
Medial/Lateral Center of Pressure	24	524.39 (2450.01)	19.75 (12.85, 24.77)	24	669.43 (3154.92)	12.60 (10.71, 23.26)
Women's Soccer						
Composite Score	24	12.14 (5.85)	10.80 (8.29, 14.90)	23	10.58 (2.82)	10.71 (8.89, 12.26)
Vertical Ground Reaction Force	24	9.03 (5.02)	8.03 (5.93, 10.90)	23	7.75 (2.36)	7.60 (6.14, 9.38)
Anterior/Posterior Ground Reaction Force	24	4.49 (2.06)	3.91 (3.34, 5.03)	23	3.97 (1.12)	3.79 (3.33, 4.53)
Medial/Lateral Ground Reaction Force	24	6.56 (2.70)	5.80 (4.48, 7.94)	23	5.92 (1.55)	6.05 (4.49, 7.12)
Anterior/Posterior Center of Pressure	24	21.13 (24.22)	15.07 (11.52, 18.77)	23	15.54 (7.52)	13.85 (11.72, 17.33)
Medial/Lateral Center of Pressure	24	19.56 (22.59)	12.76 (9.44, 18.15)	23	15.17 (8.86)	12.95 (10.64, 16.03)

Table 30. Eyes-Closed Static Postural Stability for Basketball Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean	Median	n	Mean	Median
Men's Basketball						
Composite Score	11	31.65 (25.78)	27.70 (20.22, 33.14)	11	25.59 (10.06)	22.07 (18.92, 37.14)
Vertical Ground Reaction Force	11	24.52 (25.67)	19.79 (14.38, 23.56)	11	17.91 (7.46)	16.01 (11.92, 26.52)
Anterior/Posterior Ground Reaction Force	11	9.00 (3.83)	8.63 (5.68, 10.05)	11	8.16 (2.39)	7.78 (6.22, 10.80)
Medial/Lateral Ground Reaction Force	11	16.45 (6.72)	17.55 (11.59, 21.12)	11	16.06 (7.11)	14.26 (11.26, 23.41)
Anterior/Posterior Center of Pressure	11	41.46 (49.10)	24.27 (16.97, 32.90)	11	22.76 (14.25)	17.81 (16.05, 25.86)
Medial/Lateral Center of Pressure	11	69.44 (120.18)	28.46 (14.74, 59.13)	11	44.56 (40.44)	29.45 (21.31, 70.65)
Women's Basketball						
Composite Score	13	17.06 (7.63)	16.08 (11.95, 21.66)	13	19.34 (8.50)	15.7 (13.18, 23.12)
Vertical Ground Reaction Force	13	12.86 (6.03)	12.21 (8.73, 15.48)	13	14.73 (7.27)	12.13 (9.65, 16.25)
Anterior/Posterior Ground Reaction Force	13	9.46 (4.87)	5.11 (4.21, 7.08)	13	6.46 (2.40)	6.02 (4.56, 7.46)
Medial/Lateral Ground Reaction Force	13	9.46 (4.87)	8.91 (6.75, 11.77)	13	10.53 (4.29)	8.40 (7.58, 13.04)
Anterior/Posterior Center of Pressure	13	455.45 (1521.82)	14.86 (13.50, 19.93)	13	119.41 (355.31)	16.50 (14.46, 20.40)
Medial/Lateral Center of Pressure	13	981.34 (3323.51)	21.58 (15.08, 31.87)	13	129.10 (376.74)	20.84 (13.03, 29.60)

4.2.5 Dynamic Postural Stability

Dynamic postural stability is presented in Table 31, Table 32, Table 33, and Table 34. Table 31 represents overall dynamic postural stability, and stratified by sex. Table 32 represents dynamic postural stability by sport type. Table 33 and Table 34 represent soccer and basketball dynamic postural stability, stratified by sex, respectively. Only anterior/posterior ground reaction forces were significantly different between men’s and women’s lower extremity dominant athletes for dynamic postural stability. Men’s athletes demonstrate slightly better dynamic postural stability than women’s athletes. This holds true for men’s and women’s soccer athletes as well; the only significant difference noted is in anterior/posterior ground reaction force, with men’s athletes demonstrating slightly better dynamic postural stability than women’s athletes (mean ± standard deviation) (Men’s Soccer: 0.135 ± 0.013, Women’s Soccer: 0.142 ± 0.010). Men’s and women’s basketball athletes do not demonstrate a significant difference in anterior/posterior ground reaction forces, but do demonstrate statistically significant differences in dynamic postural stability index composite scores, vertical ground reaction forces, and medial/lateral ground reaction forces.

Table 31. Dynamic Postural Stability Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Overall						
Composite Score	128	0.352 (0.036)	0.352 (0.327, 0.373)	128	0.358 (0.036)	0.357 (0.332, 0.384)
Vertical Ground Reaction Force	128	0.323 (0.038)	0.324 (0.297, 0.347)	128	0.328 (0.382)	0.330 (0.300, 0.356)
Anterior/Posterior Ground Reaction Force	128	0.104 (0.011)	0.136 (0.129, 0.143)	128	0.139 (0.010)	0.139 (0.131, 0.147)
Medial/Lateral Ground Reaction Force	128	0.027 (0.005)	0.357 (0.023, 0.030)	128	0.027 (0.005)	0.026 (0.023, 0.031)
Men						
Composite Score	75	0.354 (0.039)	0.350 (0.331, 0.379)	75	0.356 (0.038)	0.354 (0.328, 0.389)
Vertical Ground Reaction Force	75	0.326 (0.041)	0.322 (0.301, 0.355)	75	0.327 (0.040)	0.326 (0.299, 0.360)
Anterior/Posterior Ground Reaction Force	75	0.133 (0.011)	0.134 (0.126, 0.143)	75	0.136 (0.010)	0.136 (0.128, 0.145)
Medial/Lateral Ground Reaction Force	75	0.028 (0.006)	0.028 (0.024, 0.031)	75	0.270 (0.006)	0.026 (0.023, 0.031)
Women						
Composite Score	53	0.349 (0.031)	0.353 (0.326, 0.371)	53	0.360 (0.033)	0.359 (0.335, 0.383)
Vertical Ground Reaction Force	53	0.318 (0.033)	0.324 (0.293, 0.341)	53	0.329 (0.035)	0.334 (0.303, 0.356)
Anterior/Posterior Ground Reaction Force	53	0.141 (0.009)	0.140 (0.135, 0.145)	53	0.142 (0.010)	0.142 (0.136, 0.149)
Medial/Lateral Ground Reaction Force	53	0.026 (0.005)	0.027 (0.023, 0.029)	53	0.027 (0.005)	0.026 (0.024, 0.030)

Table 32. Dynamic Postural Stability Stratified by Sport Type

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Soccer						
Composite Score	48	0.350 (0.035)	0.353 (0.324, 0.377)	48	0.360 (0.037)	0.362 (0.333, 0.384)
Vertical Ground Reaction Force	48	0.321 (0.038)	0.324 (0.291, 0.350)	48	0.330 (0.039)	0.332 (0.304, 0.358)
Anterior/Posterior Ground Reaction Force	48	0.136 (0.010)	0.136 (0.128, 0.143)	48	0.139 (0.011)	0.139 (0.130, 0.147)
Medial/Lateral Ground Reaction Force	48	0.027 (0.005)	0.027 (0.023, 0.029)	48	0.026 (0.005)	0.026 (0.022, 0.030)
Football						
Composite Score	40	0.349 (0.036)	0.378 (0.328, 0.370)	40	0.352 (0.039)	0.354 (0.326, 0.379)
Vertical Ground Reaction Force	40	0.321 (0.038)	0.318 (0.299, 0.341)	40	0.322 (0.041)	0.325 (0.296, 0.356)
Anterior/Posterior Ground Reaction Force	40	0.133 (0.011)	0.132 (0.125, 0.142)	40	0.137 (0.010)	0.135 (0.128, 0.145)
Medial/Lateral Ground Reaction Force	40	0.027 (0.005)	0.026 (0.024, 0.029)	40	0.026 (0.006)	0.026 (0.022, 0.030)
Volleyball						
Composite Score	16	0.341 (0.030)	0.344 (0.322, 0.363)	16	0.354 (0.032)	0.354 (0.335, 0.370)
Vertical Ground Reaction Force	16	0.307 (0.032)	0.307 (0.286, 0.335)	16	0.322 (0.342)	0.319 (0.300, 0.341)
Anterior/Posterior Ground Reaction Force	16	0.144 (0.011)	0.147 (0.135, 0.152)	16	0.144 (0.010)	0.145 (0.138, 0.149)
Medial/Lateral Ground Reaction Force	16	0.027 (0.005)	0.027 (0.024, 0.030)	16	0.029 (0.005)	0.028 (0.024, 0.033)
Basketball						
Composite Score	24	0.369 (0.037)	0.369 (0.341, 0.391)	24	0.366 (0.033)	0.364 (0.339, 0.395)
Vertical Ground Reaction Force	24	0.341 (0.038)	0.337 (0.309, 0.365)	24	0.337 (0.034)	0.335 (0.306, 0.364)
Anterior/Posterior Ground Reaction Force	24	0.137 (0.008)	0.138 (0.133, 0.143)	24	0.140 (0.009)	0.142 (0.133, 0.147)
Medial/Lateral Ground Reaction Force	24	0.028 (0.006)	0.029 (0.023, 0.033)	24	0.028 (0.005)	0.029 (0.025, 0.031)

Table 33. Dynamic Postural Stability for Soccer Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Men's Soccer						
Composite Score	24	0.351 (0.036)	0.35 (0.339, 0.381)	24	0.352 (0.037)	0.347 (0.328, 0.384)
Vertical Ground Reaction Force	24	0.323 (0.039)	0.321 (0.307, 0.351)	24	0.323 (0.039)	0.317 (0.299, 0.353)
Anterior/Posterior Ground Reaction Force	24	0.134 (0.011)	0.135 (0.126, 0.144)	24	0.135 (0.013)	0.136 (0.127, 0.144)
Medial/Lateral Ground Reaction Force	24	0.028 (0.006)	0.027 (0.023, 0.030)	24	0.026 (0.006)	0.025 (0.022, 0.030)
Women's Soccer						
Composite Score	24	0.349 (0.356)	0.354 (0.315, 0.377)	24	0.368 (0.036)	0.371 (0.352, 0.384)
Vertical Ground Reaction Force	24	0.319 (0.037)	0.325 (0.281, 0.350)	24	0.338 (0.036)	0.341 (0.316, 0.359)
Anterior/Posterior Ground Reaction Force	24	0.139 (0.008)	0.140 (0.133, 0.143)	24	0.142 (0.010)	0.141 (0.133, 0.152)
Medial/Lateral Ground Reaction Force	24	0.027 (0.004)	0.027 (0.023, 0.029)	24	0.026 (0.004)	0.025 (0.022, 0.029)

Table 34. Dynamic Postural Stability for Basketball Overall and Stratified by Sex

	Dominant			Non-Dominant		
	n	Mean (SD)	Median (IQR)	n	Mean (SD)	Median (IQR)
Men's Basketball						
Composite Score	11	0.380 (0.048)	0.391 (0.333, 0.397)	11	0.381 (0.034)	0.392 (0.347, 0.410)
Vertical Ground Reaction Force	11	0.353 (0.049)	0.363 (0.303, 0.371)	11	0.353 (0.034)	0.360 (0.323, 0.381)
Anterior/Posterior Ground Reaction Force	11	0.134 (0.010)	0.137 (0.123, 0.144)	11	0.138 (0.010)	0.136 (0.133, 0.147)
Medial/Lateral Ground Reaction Force	11	0.032 (0.005)	0.333 (0.027, 0.036)	11	0.031 (0.004)	0.032 (0.029, 0.034)
Women's Basketball						
Composite Score	13	0.360 (0.021)	0.354 (0.342, 0.371)	13	0.354 (0.027)	0.349 (0.333, 0.375)
Vertical Ground Reaction Force	13	0.330 (0.022)	0.324 (0.311, 0.342)	13	0.323 (0.028)	0.318 (0.298, 0.346)
Anterior/Posterior Ground Reaction Force	13	0.139 (0.006)	0.138 (0.135, 0.142)	13	0.141 (0.007)	0.143 (0.134, 0.147)
Medial/Lateral Ground Reaction Force	13	0.024 (0.005)	0.025 (0.020, 0.028)	13	0.026 (0.006)	0.026 (0.021, 0.030)

4.3 LOWER EXTREMITY MUSCULOSKELETAL INJURY HISTORY

A comparison of the proportion of athletes with a history of lower extremity musculoskeletal injury between groups based on sport type (soccer, football, volleyball, basketball) and sex was accomplished utilizing Fisher's exact tests. History of lower extremity musculoskeletal injury was reported for the one-year prior to each athlete's test session. History of lower extremity musculoskeletal injury was analyzed as overall lower extremity musculoskeletal injury, and stratified by anatomical location (ankle, knee, hip, lower extremity muscle, other lower extremity location). Other lower extremity location injury includes the foot and other anatomical locations not previously described.

A Fisher's exact test was performed to examine the relationship between sex and history of overall lower extremity musculoskeletal injury; the relationship between these variables was not significant, $p = 0.851$. A Fisher's exact test was performed to examine the relationship between sport type, stratified by sex, and history of overall lower extremity musculoskeletal injury; the relationship between these variables was not significant, p = 0.114 for male sport types and p = 0.871 for female sport types. A Fisher's exact test was performed to examine the relationship between soccer athletes and basketball athletes, stratified by sex, and history of overall lower extremity musculoskeletal injury; the relationship between these variables was not significant, p = 0.193 for soccer athletes and p = 0.675 for basketball athletes. A Fisher's exact test was performed to examine the relationship between sex and history of ankle injury; the relationship between these variables was not significant, p = 0.315. A Fisher's exact test was performed to examine the relationship between sport type, stratified by sex, and history of ankle injury; the relationship between these variables was not significant, p = 1.000 for male sport types and p = 0.401 for female sport types. A Fisher's exact test was performed to examine the relationship between soccer athletes and basketball athletes, stratified by sex, and history of ankle injury; the relationship between these variables was not significant, p = 1.000 for soccer athletes and p = 0.0.223 for basketball athletes. A Fisher's exact test was performed to examine the relationship between sex and history of knee injury; the relationship between these variables was not significant, p = 0.685. A Fisher's exact test was performed to examine the relationship between sport type, stratified by sex, and history of knee injury; the relationship between these variables was not significant, p = 1.000 for male sport types and p = 1.000 for female sport types. A Fisher's exact test was performed to examine the relationship between soccer athletes and basketball athletes, stratified by sex, and history of knee injury; the relationship between these variables was not significant, p = 1.000 for soccer athletes and p = 1.000 for basketball athletes. No history of hip injury was reported for any sport type and/or sex. A Fisher's exact test was performed to examine the relationship between sex and history of lower extremity muscle injury; the relationship between these variables was not significant, p = 0.739. A Fisher's exact test was performed to examine the relationship between sport type, stratified by sex, and history of lower extremity muscle injury; the relationship between these variables was not significant, p = 0.654 for male sport types and p = 0.598 for female sport types. A Fisher's exact test was performed to examine the relationship between soccer athletes and basketball athletes, stratified by sex, and history of lower extremity muscle injury; the relationship between these variables was not significant, p = 1.000 for soccer athletes and p = 1.000 for basketball athletes. A Fisher's exact test was performed to examine the relationship between sex and history of other lower extremity musculoskeletal injury; the relationship between these variables was not significant, p = 0.789. A Fisher's exact test was performed to examine the relationship between sport type, stratified by sex, and history of other lower extremity musculoskeletal injury; the relationship between these variables was not significant, p = 0.718 for male sport types and p = 0.888 for female sport types. A Fisher's exact test was performed to examine the relationship between soccer athletes and basketball athletes, stratified by sex, and history of other lower extremity musculoskeletal injury; the relationship between these variables was not significant, p = 1.000 for soccer athletes and p = 0.888 for basketball athletes. Fisher's exact tests are represented in Table 35, Table 36, Table 37, Table 38, Table 39.

Table 35. Fisher's Exact Tests - Sex

	Men's Lower Extremity Dominant Sport Athletes	Women's Lower Extremity Dominant Sport Athletes	P-Value
	% of Athletes with Injury History	% of Athletes with Injury History	
All Lower Extremity Musculoskeletal Injury	32.05	33.96	0.851
Ankle Musculoskeletal Injury	5.13	11.32	0.315
Knee Musculoskeletal Injury	3.85	5.66	0.685
Lower Extremity Muscle Injury	8.97	5.66	0.739
Other Lower Extremity Musculoskeletal Injury	12.82	15.09	0.798

Table 36. Fisher's Exact Tests – Men's Sport Types

	Men's Soccer	Men's Basketball	Football	P-Value
	% of Athletes with Injury History	% of Athletes with Injury History	% of Athletes with Injury History	
All Lower Extremity Musculoskeletal Injury	16.67	45.45	37.21	0.114
Ankle Musculoskeletal Injury	4.17	0.00	6.98	1.000
Knee Musculoskeletal Injury	4.17	0.00	4.65	1.000
Lower Extremity Muscle Injury	4.17	9.09	11.63	0.654
Other Lower Extremity Musculoskeletal Injury	8.33	9.09	16.28	0.718

Table 37. Fisher's Exact Tests – Women's Sport Types

	Women's Soccer	Women's Volleyball	Women's Basketball	P-Value
	% of Athletes with Injury History	% of Athletes with Injury History	% of Athletes with Injury History	
All Lower Extremity Musculoskeletal Injury	37.50	31.25	30.77	0.871
Ankle Musculoskeletal Injury	8.33	6.25	23.08	0.401
Knee Musculoskeletal Injury	4.17	6.25	7.69	1.000
Lower Extremity Muscle Injury	8.33	0.00	7.69	0.598
Other Lower Extremity Musculoskeletal Injury	12.50	18.75	15.38	0.888

Table 38. Fisher's Exact Tests – Soccer

	Men's Soccer	Women's Soccer	P-Value
	% of Athletes with Injury History	% of Athletes with Injury History	
All Lower Extremity Musculoskeletal Injury	16.67	37.50	0.193
Ankle Musculoskeletal Injury	4.17	8.33	1.000
Knee Musculoskeletal Injury	4.17	4.17	1.000
Lower Extremity Muscle Injury	4.17	8.33	1.000
Other Lower Extremity Musculoskeletal Injury	8.33	12.50	1.000

Table 39. Fisher's Exact Tests – Basketball

	Men's Basketball	Women's Basketball	P-Value
	% of Athletes with Injury History	% of Athletes with Injury History	
All Lower Extremity Musculoskeletal Injury	45.45	30.77	0.675
Ankle Musculoskeletal Injury	0.00	23.08	0.223
Knee Musculoskeletal Injury	0.00	7.69	1.000
Lower Extremity Muscle Injury	9.09	7.69	1.000
Other Lower Extremity Musculoskeletal Injury	9.09	15.38	1.000

4.4 LOWER EXTREMITY DOMINANT SPORT PARTICIPATION

The second specific aim of this study was to describe the incidence of lower extremity musculoskeletal injury in NCAA Division I University of Pittsburgh male and female athletes participating in lower extremity dominant sports. Injury incidence rate, injury incidence rate ratios, and corresponding 95% confidence intervals were utilized to describe the incidence of lower extremity musculoskeletal injury in NCAA Division I University of Pittsburgh male and female athletes participating in lower extremity dominant sports. Mean days lost due to injury was also calculated. The proportion of lower extremity musculoskeletal injuries in each category were described. All data was analyzed in groups including, all subjects, game vs. practice situations, sport type (soccer, football, volleyball, etc.), sex, and point in athletic season (pre-season, competitive season, post-season). Injury incidence was also calculated according to limb dominance, injury sublocation, injury type, cause of injury, mechanism of injury, and injury onset.

4.4.1 Overall

4.4.1.1 Overall Exposures

Practice and game exposures were tracked in 131 men's and women's lower extremity dominant athletes for one collegiate athletic season, following each athlete's test session. The 2016-2017 collegiate men's and women's athletic seasons were played between August 2016 and March 2017. The 131 men's and women's lower extremity dominant athletes participated in a pre-season, a competitive season, and a post-season. The 2016-2017 collegiate men's and women's athletic seasons encompassed a total of 614 possible exposures. 465 of the 614 exposures were practices and 149 of the 614 exposures were games. Pre-season encompassed a total of 156 exposures, all 156 of these exposures were practices. No game exposures were encountered during the pre-season. The competitive season was comprised of a total of 432 exposures. 290 of the 432 total competitive season exposures were practices and 143 of the 432 competitive season exposures were games. Post-season was comprised of 26 total exposures, 19 of these post-season exposures were practices and only seven were games.

The average number of total exposures for the 131 men's and women's lower extremity dominant athletes was 552.4 exposures out of the 614 possible total exposures (90.0%). Of the available 465 practice exposures, the 131 men's and women's lower extremity dominant athletes had an average participation of 429.8 practice exposures (92.4%). The average number of game exposures for the 131 men's and women's lower extremity dominant athletes was 122.6 out of the possible 149 game exposures (93.6%). The pre-season was comprised of 156 total exposures; all pre-season exposures were practices. Out of the 156 available pre-season exposures, the average participation of the 131 men's and women's lower extremity dominant athletes was 149.4 pre-season exposures (95.8%). There were a total of 432 available exposures during the competitive season. The average participation for the 131 men's and women's lower extremity dominant athletes was 380.2 of the 432 available competitive season exposures (88.0%). There was a total of 290 available practice exposures during the competitive season; the average men's and women's lower extremity dominant athlete participation was 263.5 of the practice exposures (90.9%). There were 143 available game exposures during the competitive season; on average the men's and women's lower extremity dominant athlete participation was 116.9 of the game exposures (81.7%). There were a total of 26 available exposures during the men's and women's lower extremity dominant athlete post-season; 19 of the 26 post-season exposures were practices and 7 were games. The average total post-season participation was 22.9 of 26 available post-season exposures (88.1%). There were 19 available practice exposures during the post-season and the average post-season practice participation was 17.1 post-season practices (90.0%). There were seven available game exposure and the average men's and women's lower extremity dominant athlete participation was 5.7 post-season game exposures (81.4%). Participation is represented in Table 40, Figure 20, and Figure 21.

Table 40. Overall Lower Extremity Dominant Sport Athlete Participation

	Total Possible Exposures Per Athletic Season	Average Participation Per Athletic Season	Percentage of Participation
Overall	614.00	552.40	90.00
Timing of Participation			
Pre-Season	156.00	149.40	95.80
Competitive Season	432.00	380.20	88.00
Post-Season	26.00	22.90	88.10
Type of Participation			
Pratice	465.00	429.80	92.40
Game	149.00	122.60	93.60
Competitive Season			
Pratice	290.00	263.50	90.90
Game	143.00	116.90	81.70
Post-Season			
Practice	19.00	17.10	90.00
Game	7.00	5.70	81.40

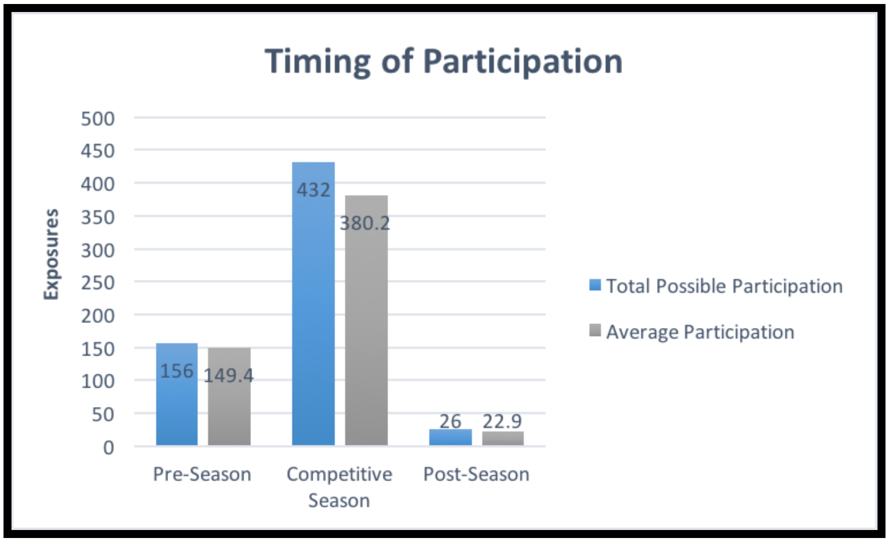

Figure 20. Timing of Participation – Overall Men's and Women's Lower Extremity Dominant Sport Athletes

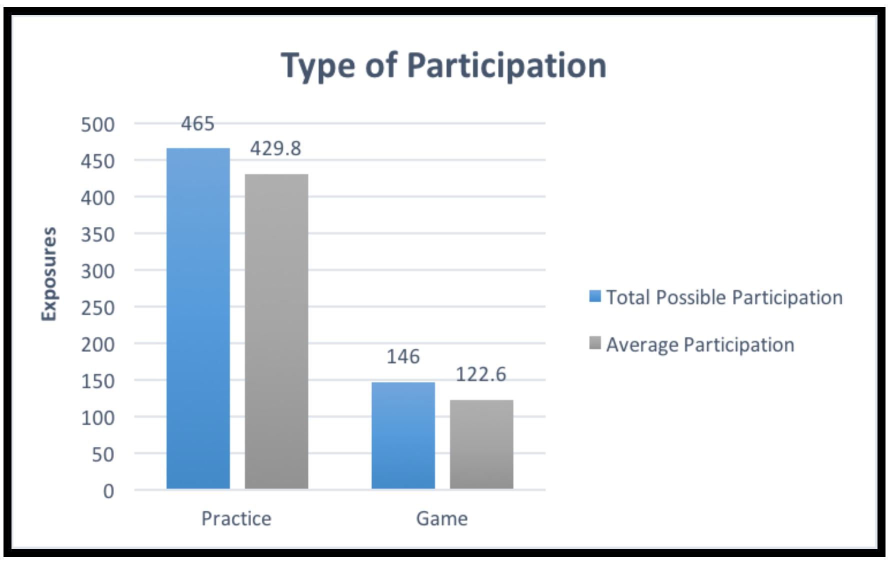

Figure 21. Type of Participation – Overall Men's and Women's Lower Extremity Dominant Sport Athletes

4.4.1.2 Men's Overall Exposures

Practice and game exposures were tracked in 78 men's lower extremity dominant athletes for one collegiate athletic season, following each athlete's test session. The 2016-2017 collegiate men's athletic season was played between August 2016 and March 2017. The 78 men's lower extremity dominant athletes participated in a pre-season, competitive season, and post-season. The 2016-2017 collegiate men's athletic season encompassed a total of 298 possible exposures per athlete. 232 of the 298 exposures were practices and 66 of the 298 exposures were games. Pre-season encompassed a total of 70 exposures, all 70 of these exposures were practices. No game exposures were encountered during the pre-season. The competitive season was comprised of a total of 209 exposures. 147 of the 209 total competitive season exposures were practices and 63 of the 209 competitive season exposures were games. Post-season was comprised of 19 total exposures, 15 of these post-season exposures were practices and only four were games.

The average number total exposures for 78 men's lower extremity dominant athletes was 268.8 exposures out of the available 298 exposures (90.2%). Of the available 232 practice exposures, the 78 men's lower extremity dominant athletes averaged participation of 213.4 practice exposures (92.0%). The average number of game exposures for the 78 men's lower extremity dominant athletes was 55.4 out of the available 66 game exposures (83.9%). There were a total of 70 available pre-season exposures; all of the 70 pre-season exposures were practices. Out of the 70 available pre-season exposures, the average of the 78 men's lower extremity dominant athlete exposures was 67.4 pre-season exposures (96.3%). There were a total of 209 available exposures during the men's athletic competitive season; 147 of the available competitive season exposures were practices and 63 were games. The average competitive season participation for the men's lower extremity dominant athletes was 184.7 of the 209 available competitive season exposures (88.4%). There was a total of 147 available practice exposures during the competitive season; the average men's lower extremity dominant sport participation was 132.7 competitive season practice exposures (90.3%). There were 63 available game exposures during the competitive season; on average the 78 men's lower extremity dominant athletes participated in 52.2 of the competitive season game exposures (82.9%). There were a total of 19 available exposures during the men's lower extremity dominant sport post-season; 15 of the 19 post-season exposures were practices and four were games. The average total post-season participation was 16.7 of 19 available post-season exposures (87.9%). There were 15 available practice exposures during the post-season and the average post-season practice participation was 13.4 post-season practices (89.3%). There were four available game exposures and the average men's lower extremity dominant sport participation was 3.2 post-season game exposures 80.0%). Participation is represented in Table 41, Figure 22, and Figure 23.

Table 41. Overall Men's Lower Extremity Dominant Sport Athlete Participation

	Total Possible Exposures Per Athletic Season	Average Participation Per Athletic Season	Percentage of Participation
Overall	298.00	268.80	90.20
Timing of Participation			
Pre-Season	70.00	67.40	96.30
Competitive Season	209.00	184.70	88.40
Post-Season	19.00	16.70	87.90
Type of Participation			
Pratice	232.00	213.40	92.00
Game	66.00	55.40	83.90
Competitive Season			
Pratice	147.00	132.70	90.30
Game	63.00	52.20	82.90
Post-Season			
Practice	15.00	13.40	89.30
Game	4.00	3.20	80.00

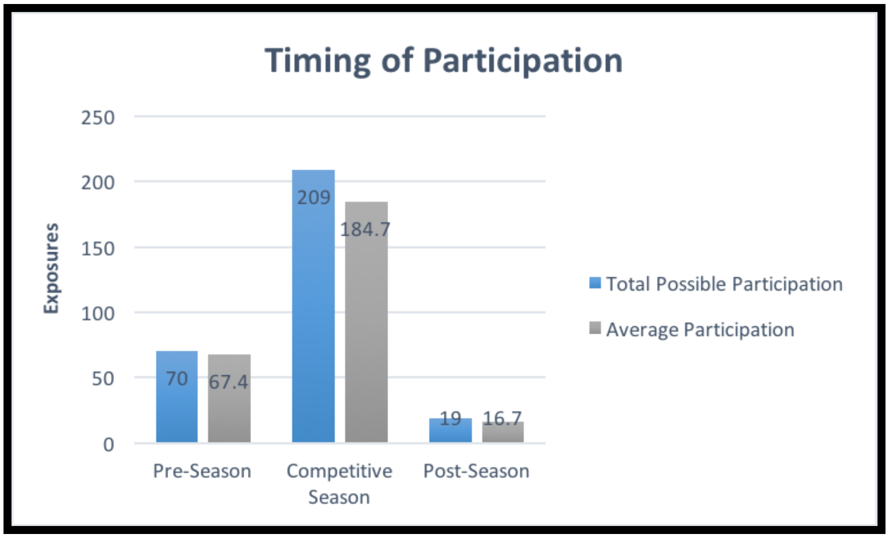

Figure 22. Timing of Participation – Overall Men's Lower Extremity Dominant Sport Athletes

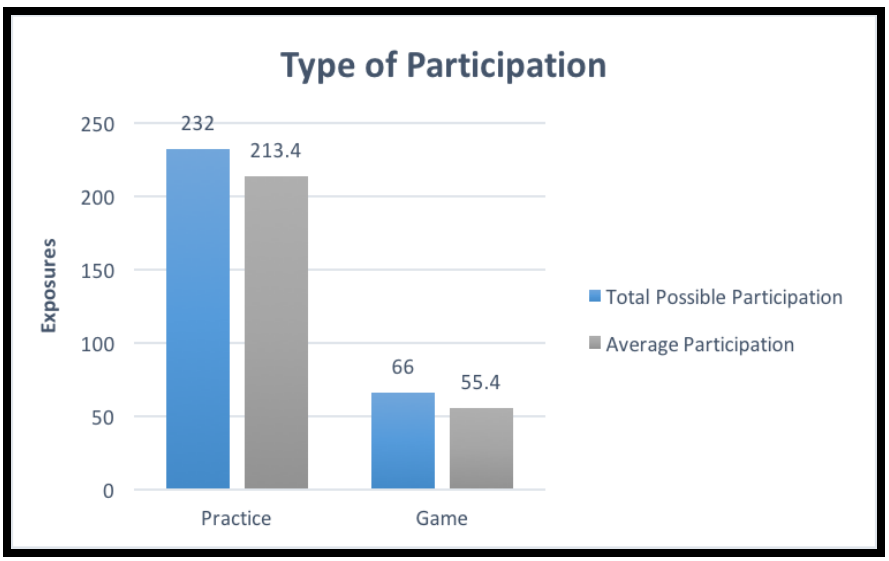

Figure 23. Type of Participation – Overall Men's Lower Extremity Dominant Sport Athletes

4.4.1.3 Women's Overall Exposures

Practice and game exposures were tracked in 53 women's lower extremity dominant athletes for one collegiate athletic season, following each athlete's test session. The 2016-2017 collegiate women's athletic season was played between August 2016 and March 2017. The 53 women's lower extremity dominant athletes participated in a pre-season, competitive season, and post-season. The 2016-2017 collegiate women's athletic season encompassed a total of 316 possible exposures per athlete. 233 of the 316 exposures were practices and 83 of the 316 exposures were games. Pre-season encompassed a total of 86 exposures, all 86 of these exposures were practices. No game exposures were encountered during the pre-season. The competitive season was comprised of a total of 223 exposures. 143 of the 223 total competitive season exposures were practices and 80 of the 223 competitive season exposures were games. Post-season was comprised of seven total exposures, four of these post-season exposures were practices and only three were games.

The average number total exposures for 53 women's lower extremity dominant athletes was 283.6 exposures out of the available 316 exposures (89.7%). Of the available 233 practice exposures, the 53 women's lower extremity dominant athletes averaged participation of 216.4 practice exposures (92.9%). The average number of game exposures for the 83 women's lower extremity dominant athletes was 67.2 out of the available 83 game exposures (81.0%). There were a total of 86 available pre-season exposures; all of the 86 pre-season exposures were practices. Out of the 86 available pre-season exposures, the average of the 53 women's lower extremity dominant athlete exposures was 82.0 pre-season exposures (95.3%). There were a total of 223 available exposures during the women's athletic competitive season; 143 of the available competitive season exposures were practices and 80 were games. The average competitive season participation for the women's lower extremity dominant athletes was 195.5 of the 223 available competitive season exposures (87.7%). There was a total of 143 available practice exposures during the competitive season; the average women's lower extremity dominant sport participation was 130.8 competitive season practice exposures (91.5%). There were 80 available game exposures during the competitive season; on average the 53 women's lower extremity dominant athletes participated in 64.7 of the competitive season game exposures (80.9%). There were a total of seven available exposures during the women's lower extremity dominant sport post-season; four of the seven post-season exposures were practices and 3 were games. The average total post-season participation was 6.2 of seven available post-season exposures (88.6%). There were four available practice exposures during the post-season and the average post-season practice participation was 3.7 post-season practices (92.5%). There were three available game exposures and the average women's lower extremity dominant sport participation was 2.52 post-season game exposures (84.0%). Participation is represented in Table 42, Figure 24, and Figure 25.

Table 42. Overall Women's Lower Extremity Dominant Sport Athlete Participation

	Total Possible Exposures Per Athletic Season	Average Participation Per Athletic Season	Percentage of Participation
Overall	316.00	283.60	89.70
Timing of Participation			
Pre-Season	86.00	82.00	95.30
Competitive Season	223.00	195.50	87.70
Post-Season	7.00	6.20	88.60
Type of Participation			
Pratice	233.00	216.40	92.90
Game	83.00	67.20	81.00
Competitive Season			
Pratice	143.00	130.80	91.50
Game	80.00	64.70	80.90
Post-Season			
Practice	4.00	3.70	92.50
Game	3.00	2.50	84.00

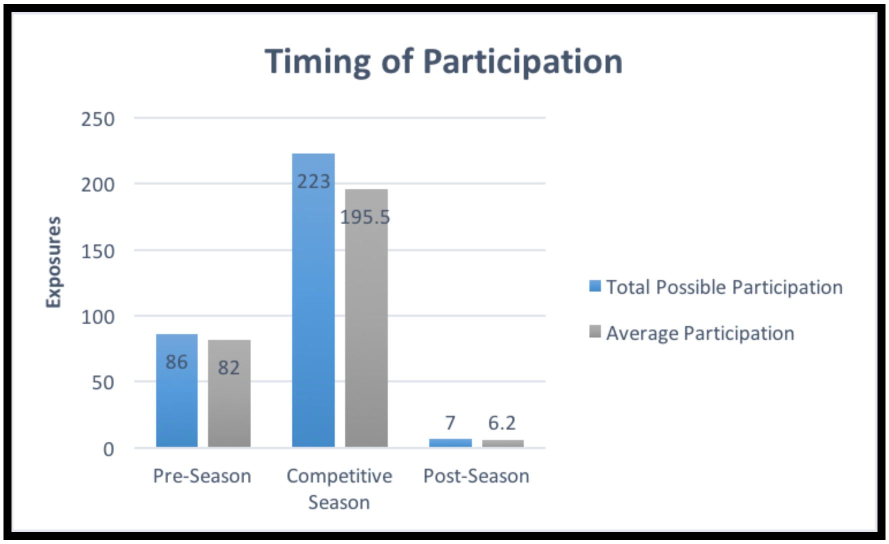

Figure 24. Timing of Participation – Overall Women's Lower Extremity Dominant Sport Athletes

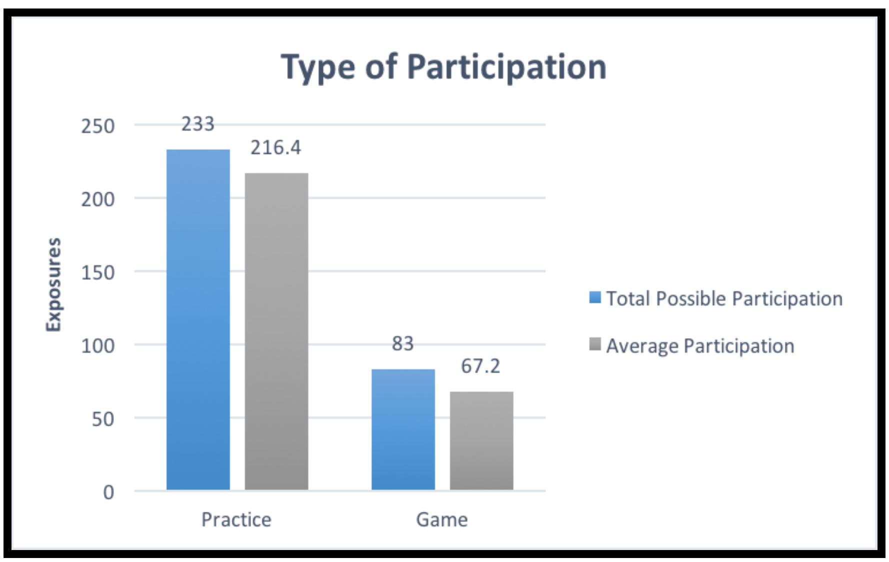

Figure 25. Type of Participation – Overall Women's Lower Extremity Dominant Sport Athletes

4.4.2 Soccer

4.4.2.1 Overall Soccer Exposures

Practice and game exposures were tracked in 48 men's and women's soccer athletes for one collegiate fall soccer season, following each athlete's test session. The 2016-2017 collegiate men's and women's soccer fall seasons were played between August 2016 and October 2016. The 48 men's and women's soccer athletes participated in a pre-season and a competitive season; only the men's soccer athletes participated in a post-season. The 2016-2017 collegiate men's and women's soccer fall seasons encompassed a total of 163 possible exposures per athlete. One hundred and twenty-five of the 163 exposures were practices and 38 of the 163 exposures were games. Pre-season encompassed a total of 33 exposures, all 33 of these exposures were practices. No game exposures were encountered during the pre-season. The competitive season was comprised of a total of 126 exposures. Eighty-nine of the 126 total competitive season exposures were practices and 38 of the 126 competitive season exposures were games. Post-season was comprised of four total exposures, three of these post-season exposures were practices and only one was a game.

The average number of total exposures for the 48 men's and women's soccer athletes was 143.7 exposures out of the 163 possible total exposures (88.2%). Of the available 125 practice exposures, the 48 men's and women's soccer athletes had an average participation of 113.1 practice exposures (90.5%). The average number of game exposures for the 48 men's and women's soccer athletes was 30.6 out of the possible 38 game exposures (80.5%). The pre-season was comprised of 33 total exposures; all pre-season exposures were practices. Out of the 33 available pre-season exposures, the average participation of the 48 men's and women's soccer athletes was 30.8 pre-season exposures (93.3%). There were a total of 126 available exposures during the competitive season. The average participation for the 48 men's and women's soccer athletes was 109.1 of the 126 available competitive season exposures (86.6%). There was a total of 89 available practice exposures during the competitive season; the average men's and women's soccer athlete participation was 79.5 of the practice exposures (89.3%). There were 38 available game exposures during the competitive season; on average the men's and women's soccer athlete participation was 29.7 of the game exposures (78.2%). There were a total of four available exposures during the men's and women's soccer post-season; three of the four post-season exposures were practices and one was a game. The average total post-season participation was 3.8 of 4 available post-season exposures (95.0%). There were three available practice exposures during the post-season and the average post-season practice participation was 2.9 post-season practices (96.7%). There was one available game exposure and the average men's and women's soccer participation was 0.9 post-season game exposures (90.0%). Participation is represented in Table 43, Figure 26, and Figure 27.

Table 43. Overall Men's and Women's Soccer Athlete Participation

	Total Possible Exposures Per Athletic Season	Average Participation Per Athletic Season	Percentage of Participation
Overall	163.00	143.70	88.20
Timing of Participation			
Pre-Season	33.00	30.80	93.30
Competitive Season	126.00	109.10	86.60
Post-Season	4.00	3.80	95.00
Type of Participation			
Pratice	125.00	113.10	90.50
Game	38.00	30.60	80.50
Competitive Season			
Pratice	89.00	79.50	89.30
Game	38.00	29.70	78.20
Post-Season			
Practice	3.00	2.90	96.70
Game	1.00	0.90	90.00

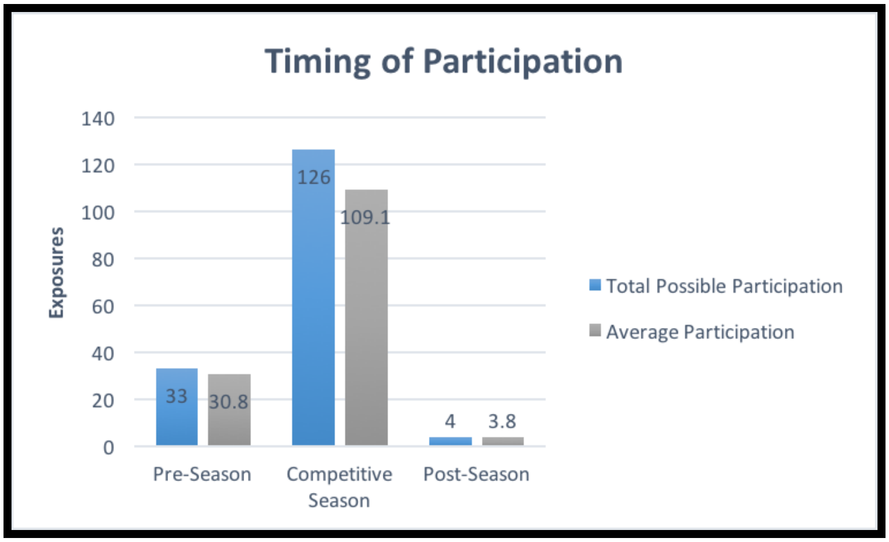

Figure 26. Timing of Participation – Overall Men's and Women's Soccer Athletes

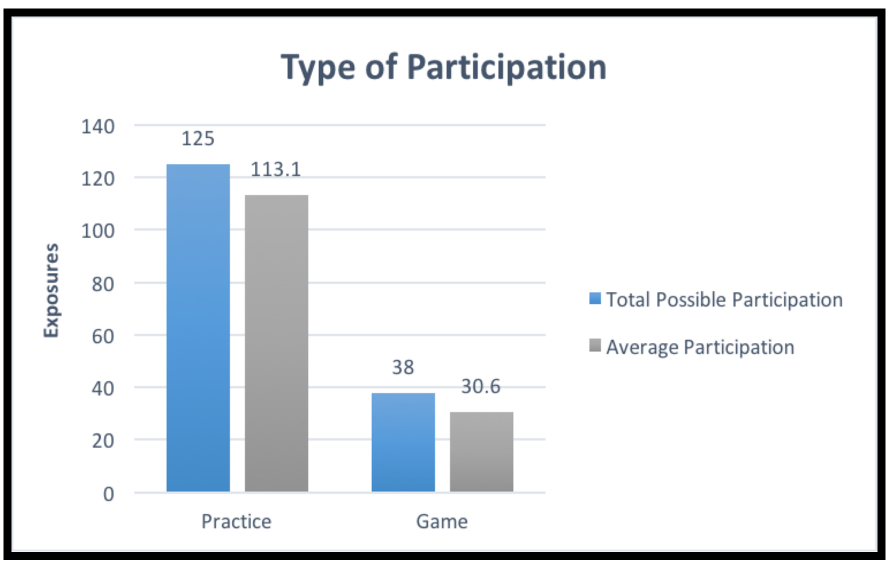

Figure 27. Type of Participation – Overall Men's and Women's Soccer Athletes

4.4.2.2 Men's Soccer Exposures

Practice and game exposures were tracked in 24 men's soccer athletes for one collegiate fall soccer season, following each athlete's test session. The 2016-2017 collegiate men's soccer fall season was played between August 2016 and October 2016. The 24 men's soccer athletes participated in a pre-season, competitive season, and post-season. The 2016-2017 collegiate men's soccer fall season encompassed a total of 80 possible exposures per athlete. Sixty of the 80 exposures were practices and 20 of the 80 exposures were games. Pre-season encompassed a total of nine exposures, all nine of these exposures were practices. No game exposures were encountered during the pre-season. The competitive season was comprised of a total of 67 exposures. Forty-eight of the 67 total competitive season exposures were practices and 20 of the 67 competitive season exposures were games. Post-season was comprised of four total exposures, three of these post-season exposures were practices and only one was a game.

The average number total exposures for 24 men's soccer athletes was 73.1 exposures out of the available 80 exposures (91.4%). Of the available 60 practice exposures, the 24 men's soccer athletes averaged participation of 55.3 practice exposures (92.2%). The average number of game exposures for the 24 men's soccer athletes was 17.8 out of the available 20 game exposures (89.0%). There were a total of nine available pre-season exposures; all of the nine pre-season exposures were practices. Out of the nine available pre-season exposures, the average of the 24 men's soccer athlete exposures was 8.0 pre-season exposures (88.9%). There were a total of 67 available exposures during the men's soccer competitive season; 48 of the available competitive season exposures were practices and 19 were games. The average competitive season participation for the men's soccer athletes was 61.3 of the 67 available competitive season exposures (91.5%). There was a total of 48 available practice exposures during the competitive season; the average men's soccer participation was 44.5 competitive season practice exposures (92.7%). There were 19 available game exposures during the competitive season; on average the 24 men's soccer athletes participated in 16.9 of the competitive season game exposures (88.9%). There were a total of four available exposures during the men's soccer post-season; three of the four post-season exposures were practices and one was a game. The average total post-season participation was 3.8 of four available post-season exposures (95.0%). There were three available practice exposures during the post-season and the average post-season practice participation was 2.9 post-season practices (96.7%). There was one available game exposure and the average men's soccer participation was 0.9 post-season game exposures (90.0%). Participation is represented in Table 44, Figure 28, and Figure 29.

Table 44. Men's Soccer Athlete Participation

	Total Possible Exposures Per Athletic Season	Average Participation Per Athletic Season	Percentage of Participation
Overall	80.00	73.10	91.40
Timing of Participation			
Pre-Season	9.00	8.00	88.90
Competitive Season	67.00	61.30	91.50
Post-Season	4.00	3.80	95.00
Type of Participation			
Pratice	60.00	55.30	92.20
Game	20.00	17.80	89.30
Competitive Season			
Pratice	48.00	44.50	92.70
Game	19.00	16.90	88.90
Post-Season			
Practice	3.00	2.90	96.70
Game	1.00	0.90	90.00

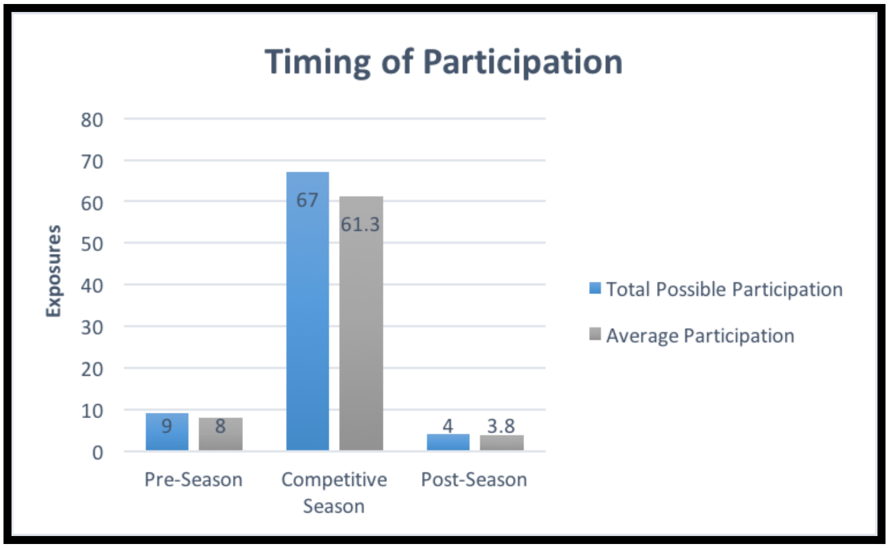

Figure 28. Timing of Participation – Men's Soccer Athletes

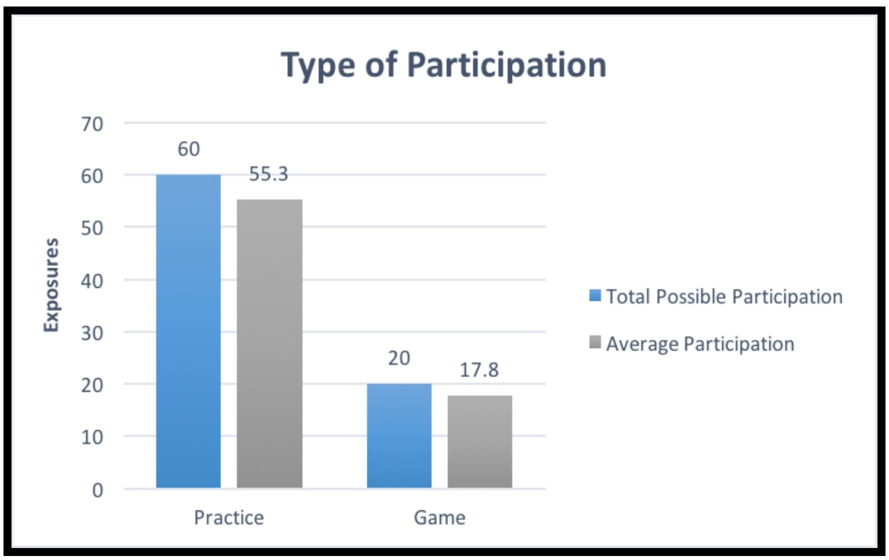

Figure 29. Type of Participation – Men's Soccer Athletes

4.4.2.3 Women's Soccer Exposures

Practice and game exposures were tracked in 24 women's soccer athletes for one collegiate fall soccer season, following each athlete's test session. The 2016-2017 collegiate women's soccer fall season was played between August 2016 and October 2016. The 24 women's soccer athletes participated in a pre-season and a competitive season; the competitive season did not result in an invitation to participate in the post-season. The 2016-2017 collegiate women's soccer fall season encompassed a total of 83 possible exposures per athlete. Sixty-five of the 83 exposures were practices and 18 of the 83 exposures were games. Pre-season encompassed a total of 24 exposures, all 24 of these exposures were practices. No game exposures were encountered during the pre-season. The competitive season was comprised of a total of 59 exposures. Forty-one of the 59 total competitive season exposures were practices and 18 of the 59 competitive season exposures were games.

The average number of total exposures for the 24 women's soccer athletes was 70.6 exposures out of the 83 possible total exposures (85.1%). Of the available 65 practice exposures, the 24 women's soccer athletes had an average participation of 57.8 practice exposures (88.9%). The average number of game exposures for the 24 women's soccer athletes was 12.8 out of the possible 18 game exposures (71.1%). The pre-season was comprised of 24 total exposures; all pre-season exposures were practices. Out of the 24 available pre-season exposures, the average participation of the 24 women's soccer athletes was 22.8 pre-season exposures (95.0%). There were a total of 59 available exposures during the competitive season. The average participation for the 24 women's soccer athletes was 47.8 of the 59 available competitive season exposures (81.0%). There was a total of 41 available practice exposures during the competitive season; the average women's soccer athlete participation was 35.0 of the practice exposures (85.4%). There were 18 available game exposures during the competitive season; on average the women's soccer athlete participation was 12.8 of the game exposures (71.1%). Participation is represented in Table 45, Figure 30, and Figure 31.

Table 45. Women's Soccer Athlete Participation

	Total Possible Exposures Per Athletic Season	Average Participation Per Athletic Season	Percentage of Participation
Overall	83.00	70.60	85.10
Timing of Participation			
Pre-Season	24.00	22.80	95.00
Competitive Season	59.00	47.80	81.00
Type of Participation			
Pratice	65.00	57.80	88.90
Game	18.00	12.80	71.10
Competitive Season			
Pratice	41.00	35.00	85.40
Game	18.00	12.80	71.10

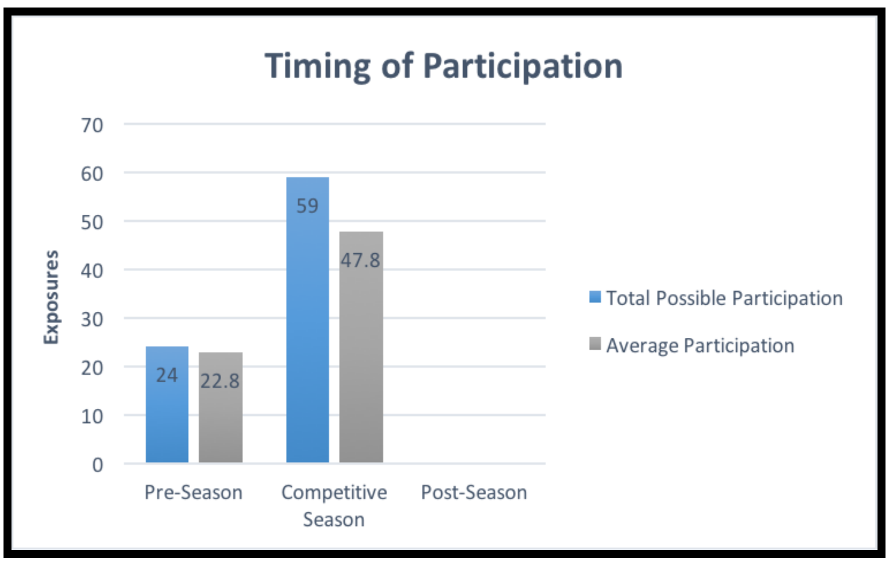

Figure 30. Timing of Participation – Women's Soccer Athletes

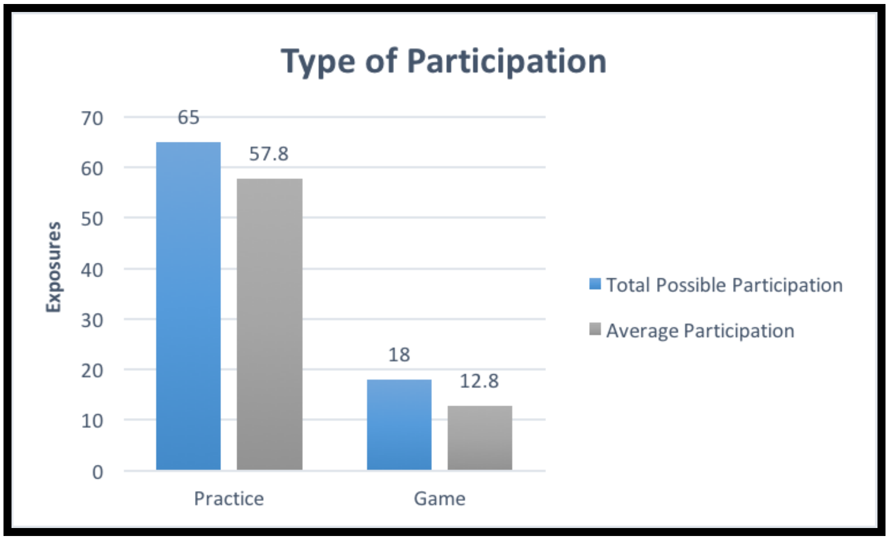

Figure 31. Type of Participation – Women's Soccer Athletes

4.4.3 Football

4.4.3.1 Overall Football Exposures

Practice and game exposures were tracked in 43 football athletes for one collegiate fall football season, following each athlete's test session. The 2016-2017 collegiate football fall season was played between August 2016 and December 2016. The 43 football athletes participated in a pre-season, a competitive season, and a post-season. The 2016-2017 collegiate football fall season encompassed a total of 90 possible exposures per athlete. Seventy-eight of the 90 exposures were practices and 12 of the 90 exposures were games. Pre-season encompassed a total of 24 exposures, all 24 of these exposures were practices. No game exposures were encountered during the pre-season. The competitive season was comprised of a total of 55 exposures. Forty-four of the 55 total competitive season exposures were practices and 11 of the 55 competitive season exposures were games. Post-season was comprised of 11 total exposures, 10 of these post-season exposures were practices and only one was a game.

The average number of total exposures for the 43 football athletes was 79.9 exposures out of the 90 possible total exposures (88.8%). Of the available 78 practice exposures, the 43 football athletes had an average participation of 69.3 practice exposures (88.8%). The average number of game exposures for the 43 football athletes was 10.6 out of the possible 12 game exposures (88.3%). The pre-season was comprised of 24 total exposures; all pre-season exposures were practices. Out of the 24 available pre-season exposures, the average participation of the 43 football athletes was 22.4 pre-season exposures (93.3%). There were a total of 55 available exposures during the competitive season. The average participation for the 43 football athletes was 47.9 of the 55 available competitive season exposures (87.1%). There was a total of 44 available practice exposures during the competitive season; the average football athlete participation was 38.2 of the practice exposures (86.8%). There were 11 available game exposures during the competitive season; on average the football athlete participation was 9.8 of the game exposures (89.1%). There were a total of 11 available exposures during the football post-season; 10 of the 11 post-season exposures were practices and 1 was a game. The average total post-season participation was 9.5 of 11 available post-season exposures (86.4%). There were 10 available practice exposures during the post-season and the average post-season practice participation was 8.7 post-season practices (87.0%). There was 1 available game exposure and the average football participation was 0.84 post-season game exposures (84.0%). Participation is represented in Table 46, Figure 32, and Figure 33.

Table 46. Football Athlete Participation

	Total Possible Exposures Per Athletic Season	Average Participation Per Athletic Season	Percentage of Participation
Overall	90.00	79.90	88.80
Timing of Participation			
Pre-Season	24.00	22.40	93.30
Competitive Season	55.00	47.90	93.30
Post-Season	11.00	9.50	86.40
Type of Participation			
Pratice	78.00	69.30	88.80
Game	12.00	10.60	88.30
Competitive Season			
Pratice	44.00	38.20	86.80
Game	11.00	9.80	89.10
Post-Season			
Practice	10.00	8.70	87.00
Game	1.00	0.84	84.00

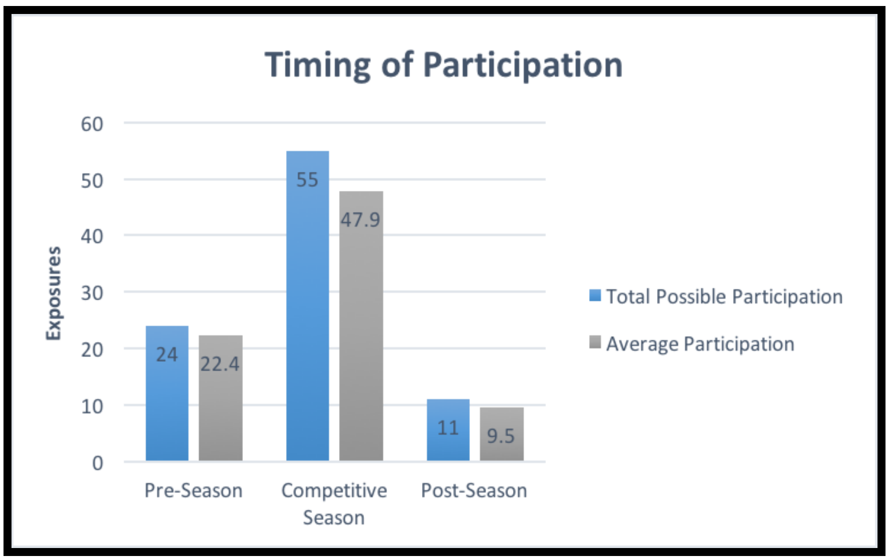

Figure 32. Timing of Participation – Football Athletes

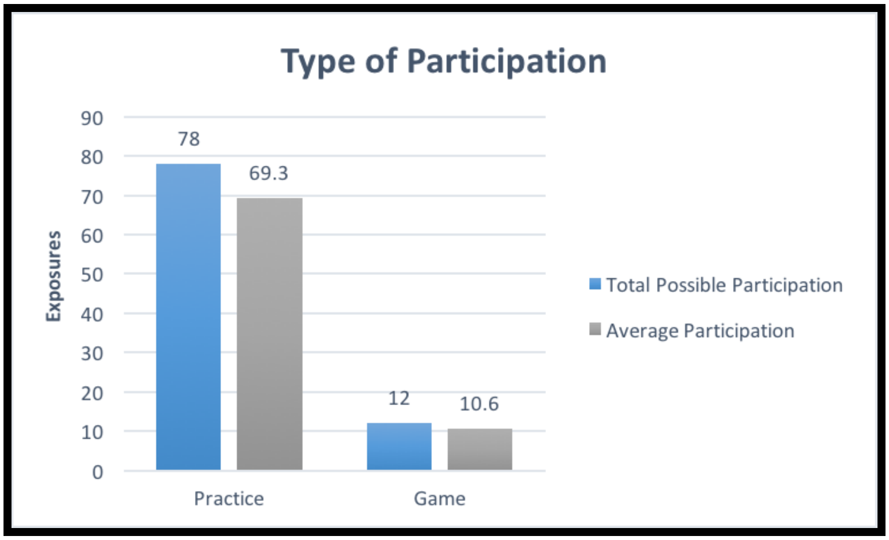

Figure 33. Type of Participation – Football Athletes

4.4.4 Volleyball

4.4.4.1 Overall Volleyball Exposures

Practice and game exposures were tracked in 16 women's volleyball athletes for one collegiate fall volleyball season, following each athlete's test session. The 2016-2017 collegiate women's volleyball fall season was played between August 2016 and December 2016. The 16 women's volleyball athletes participated in a pre-season, a competitive season, and a post-season. The 2016-2017 collegiate women's volleyball fall season encompassed a total of 113 possible exposures per athlete. Seventy-nine of the 113 exposures were practices and 34 of the 113 exposures were games. Pre-season encompassed a total of 25 exposures, all 25 of these exposures were practices. No game exposures were encountered during the pre-season. The competitive season was comprised of a total of 84 exposures. Fifty-two of the 84 total competitive season exposures were practices and 32 of the 84 competitive season exposures were games. Post-season was comprised of 4 total exposures, two of these post-season exposures were practices and two were games.

The average number of total exposures for the 16 women’s volleyball athletes was 109.2 exposures out of the 113 possible total exposures (96.6%). Of the available 79 practice exposures, the 16 women’s volleyball athletes had an average participation of 76.4 practice exposures (96.7%). The average number of game exposures for the 16 women’s volleyball athletes was 32.8 out of the possible 34 game exposures (96.5%). The pre-season was comprised of 25 total exposures; all pre-season exposures were practices. Out of the 25 available pre-season exposures, the average participation of the 16 women’s volleyball athletes was 25.0 pre-season exposures (100.0%). There were a total of 84 available exposures during the competitive season. The average participation for the 16 women’s volleyball athletes was 80.5 of the 84 available competitive season exposures (95.8%). There was a total of 52 available practice exposures during the competitive season; the average women’s volleyball athlete participation was 49.6 of the practice exposures (95.4%). There were 32 available game exposures during the competitive season; on average the women’s volleyball athlete participation was 30.9 of the game exposures (96.6%). There were a total of four available exposures during the women’s volleyball post-season; two of the four post-season exposures were practices and two were games. The average total post-season participation was 3.7 of four available post-season exposures (92.5%). There were two available practice exposures during the post-season and the average post-season practice participation was 1.8 post-season practices (90.0%). There were two available game exposures and the average women’s volleyball participation was 1.9 post-season game exposures (95.0%). Participation is represented in Table 47, Figure 34, and Figure 35.

Table 47. Women's Volleyball Athlete Participation

	Total Possible Exposures Per Athletic Season	Average Participation Per Athletic Season	Percentage of Participation
Overall	113.00	109.20	96.60
Timing of Participation			
Pre-Season	25.00	25.00	100.00
Competitive Season	84.00	80.50	95.80
Post-Season	4.00	3.70	92.50
Type of Participation			
Pratice	79.00	76.40	96.70
Game	34.00	32.80	96.50
Competitive Season			
Pratice	52.00	49.60	95.40
Game	32.00	30.90	96.60
Post-Season			
Practice	2.00	1.80	90.00
Game	2.00	1.90	95.00

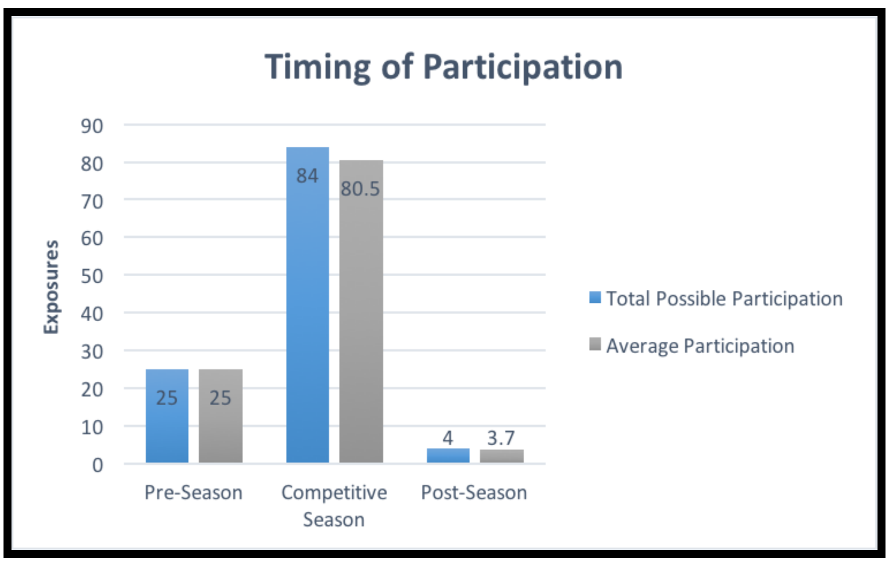

Figure 34. Timing of Participation – Women's Volleyball Athletes

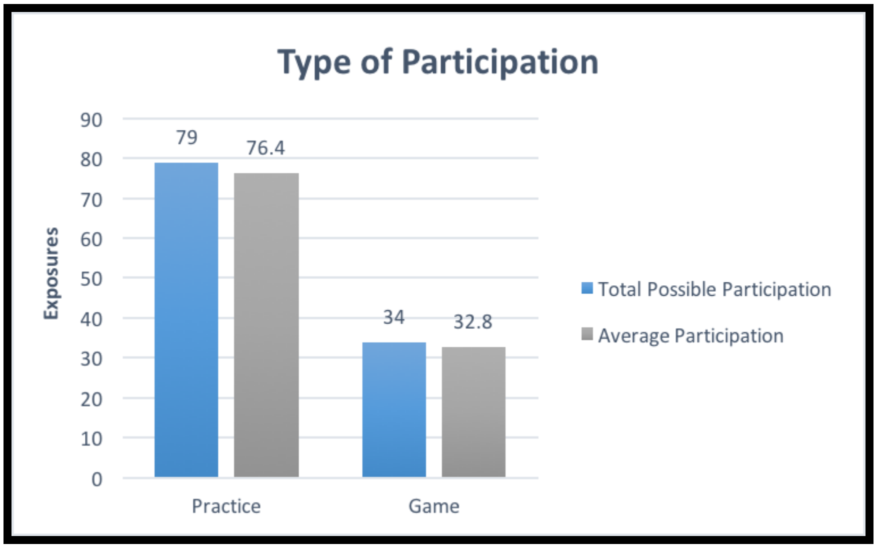

Figure 35. Type of Participation – Women's Volleyball Athletes

4.4.5 Basketball

4.4.5.1 Overall Basketball Exposures

Practice and game exposures were tracked in 24 men's and women's basketball athletes for one collegiate winter basketball season, following each athlete's test session. The 2016-2017 collegiate men's and women's basketball winter seasons were played between November 2016 and March 2017. The 24 men's and women's basketball athletes participated in a pre-season, a competitive season, and a post-season. The 2016-2017 collegiate men's and women's basketball winter seasons encompassed a total of 248 possible exposures per athlete. 183 of the 248 exposures were practices and 65 of the 248 exposures were games. Pre-season encompassed a total of 74 exposures, all 74 of these exposures were practices. No game exposures were encountered during the pre-season. The competitive season was comprised of a total of 167 exposures. 105 of the 167 total competitive season exposures were practices and 62 of the 167 competitive season exposures were games. Post-season was comprised of 7 total exposures, four of these post-season exposures were practices and only three were games.

The average number of total exposures for the 24 men's and women's basketball athletes was 219.6 exposures out of the 248 possible total exposures (88.5%). Of the available 183 practice exposures, the 24 men's and women's basketball athletes had an average participation of 171 practice exposures (93.4%). The average number of game exposures for the 24 men's and women's basketball athletes was 48.6 out of the possible 65 game exposures (74.8%). The pre-season was comprised of 74 total exposures; all pre-season exposures were practices. Out of the 74 available pre-season exposures, the average participation of the 24 men's and women's basketball athletes was 71.2 pre-season exposures (96.2%). There were a total of 167 available exposures during the competitive season. The average participation for the 24 men's and women's basketball athletes was 142.7 of the 167 available competitive season exposures (85.4%). There was a total of 105 available practice exposures during the competitive season; the average men's and women's basketball athlete participation was 96.2 of the practice exposures (91.6%). There were 62 available game exposures during the competitive season; on average the men's and women's basketball athlete participation was 46.5 of the game exposures (75.0%). There were a total of seven available exposures during the men's and women's basketball post-season; four of the seven post-season exposures were practices and three were games. The average total post-season participation was 5.9 of seven available post-season exposures (84.3%). There were four available practice exposures during the post-season and the average post-season practice participation was 3.7 post-season practices (92.5%). There were three available game exposure and the average men's and women's basketball participation was 2.1

post-season game exposures (70.0%). Participation is represented in Table 48, Figure 36, and Figure 37.

Table 48. Overall Men's and Women's Basketball Athlete Participation

	Total Possible Exposures Per Athletic Season	Average Participation Per Athletic Season	Percentage of Participation
Overall	248.00	219.60	88.50
Timing of Participation			
Pre-Season	74.00	71.20	96.20
Competitive Season	167.00	142.70	85.40
Post-Season	7.00	5.90	84.30
Type of Participation			
Pratice	79.00	76.40	96.70
Game	34.00	32.80	96.50
Competitive Season			
Pratice	105.00	96.20	91.60
Game	62.00	46.50	75.00
Post-Season			
Practice	4.00	3.70	92.50
Game	3.00	2.10	70.00

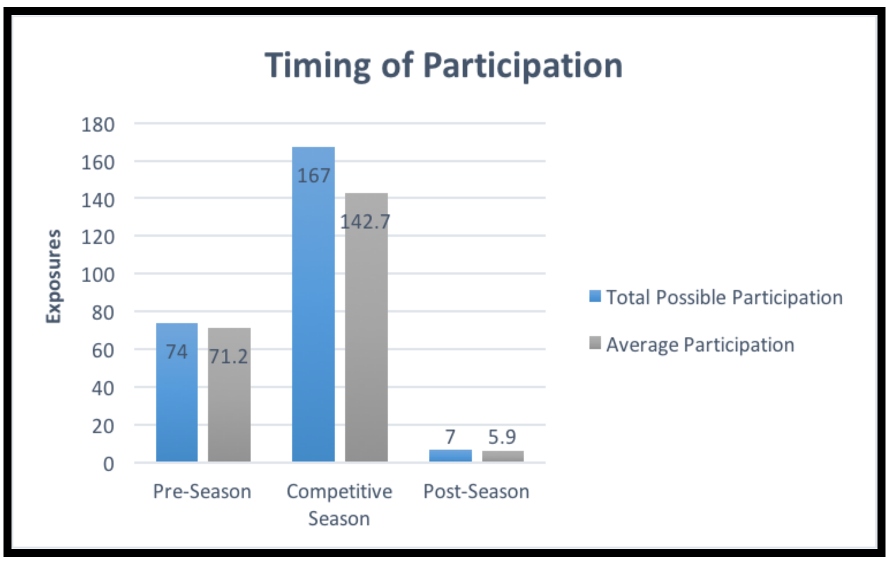

Figure 36. Timing of Participation – Overall Men's and Women's Basketball Athletes

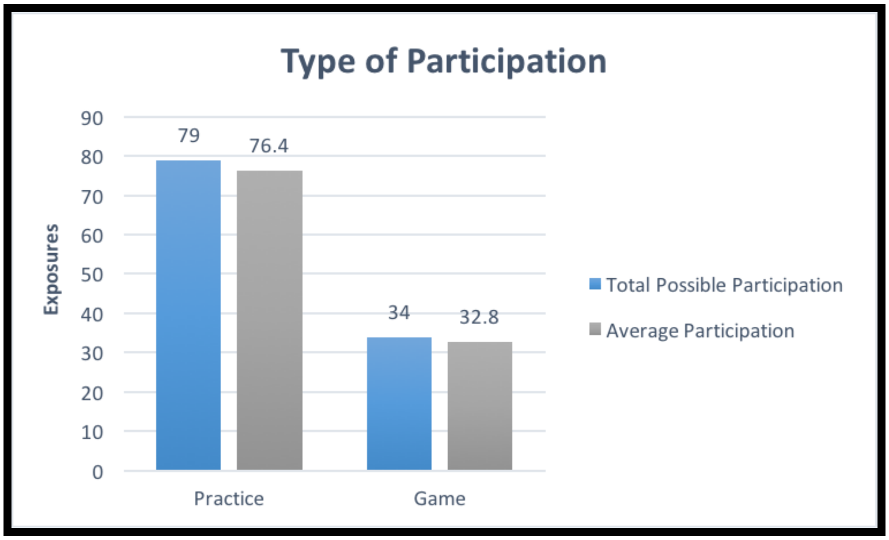

Figure 37. Type of Participation – Overall Men's and Women's Basketball Athletes

4.4.5.2 Men's Basketball Exposures

Practice and game exposures were tracked in 11 men's basketball athletes for one collegiate winter basketball season, following each athlete's test session. The 2016-2017 collegiate men's basketball winter season was played between November 2016 and March 2017. The 11 men's basketball athletes participated in a pre-season, competitive season, and post-season. The 2016-2017 collegiate men's basketball winter season encompassed a total of 128 possible exposures per athlete. 94 of the 128 exposures were practices and 34 of the 128 exposures were games. Pre-season encompassed a total of 37 exposures, all 37 of these exposures were practices. No game exposures were encountered during the pre-season. The competitive season was comprised of a total of 87 exposures. 55 of the 87 total competitive season exposures were practices and 32 of the 87 competitive season exposures were games. Post-season was comprised of four total exposures, two of these post-season exposures were practices and only two were games.

The average number total exposures for 11 men's basketball athletes was 115.8 exposures out of the available 128 exposures (90.5%). Of the available 94 practice exposures, the

11 men's basketball athletes averaged participation of 88.8 practice exposures (94.5%). The average number of game exposures for the 11 men's basketball athletes was 27.0 out of the available 34 game exposures (79.4%). There were a total of 37 available pre-season exposures; all of the 37 pre-season exposures were practices. Out of the 37 available pre-season exposures, the average of the 11 men's basketball athlete exposures was 37.0 pre-season exposures (100.0%). There were a total of 87 available exposures during the men's basketball competitive season; 55 of the available competitive season exposures were practices and 32 were games. The average competitive season participation for the men's basketball athletes was 75.5 of the 87 available competitive season exposures (86.8%). There was a total of 55 available practice exposures during the competitive season; the average men's basketball participation was 50.0 competitive season practice exposures (90.9%). There were 32 available game exposures during the competitive season; on average the 11 men's basketball athletes participated in 25.5 of the competitive season game exposures (79.7%). There were a total of four available exposures during the men's basketball post-season; two of the four post-season exposures were practices and two were games. The average total post-season participation was 3.4 of four available post-season exposures (85.0%). There were two available practice exposures during the post-season and the average post-season practice participation was 1.8 post-season practices (90.0%). There were two available game exposures and the average men's basketball participation was 1.5 post-season game exposures (75.0%). Participation is represented in Table 49, Figure 38, and Figure 39.

Table 49. Men's Basketball Athlete Participation

	Total Possible Exposures Per Athletic Season	Average Participation Per Athletic Season	Percentage of Participation
Overall	128.00	115.80	90.50
Timing of Participation			
Pre-Season	37.00	37.00	100.00
Competitive Season	87.00	75.50	86.80
Post-Season	4.00	3.40	85.00
Type of Participation			
Pratice	94.00	88.80	94.50
Game	34.00	27.00	79.40
Competitive Season			
Pratice	55.00	50.00	90.90
Game	32.00	25.50	79.70
Post-Season			
Practice	2.00	1.80	90.90
Game	2.00	1.50	75.00

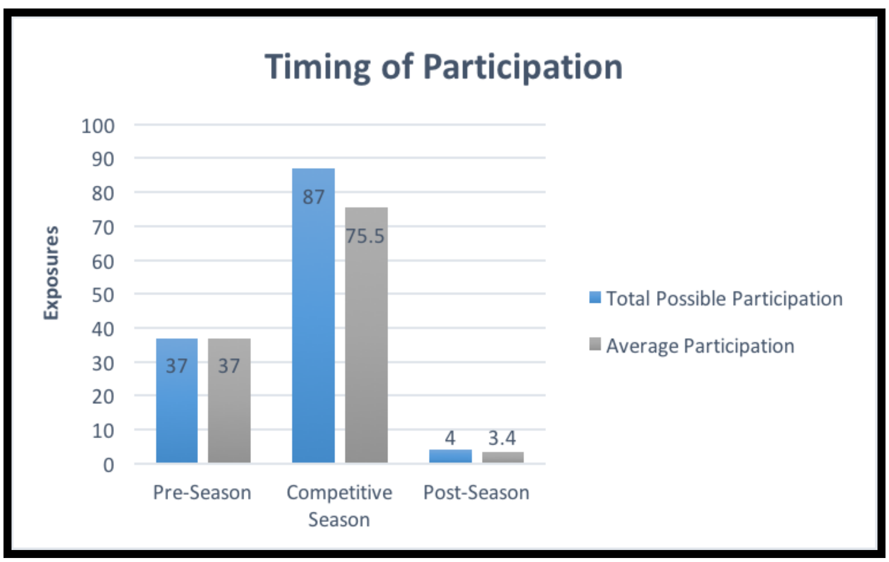

Figure 38. Timing of Participation – Men's Basketball Athletes

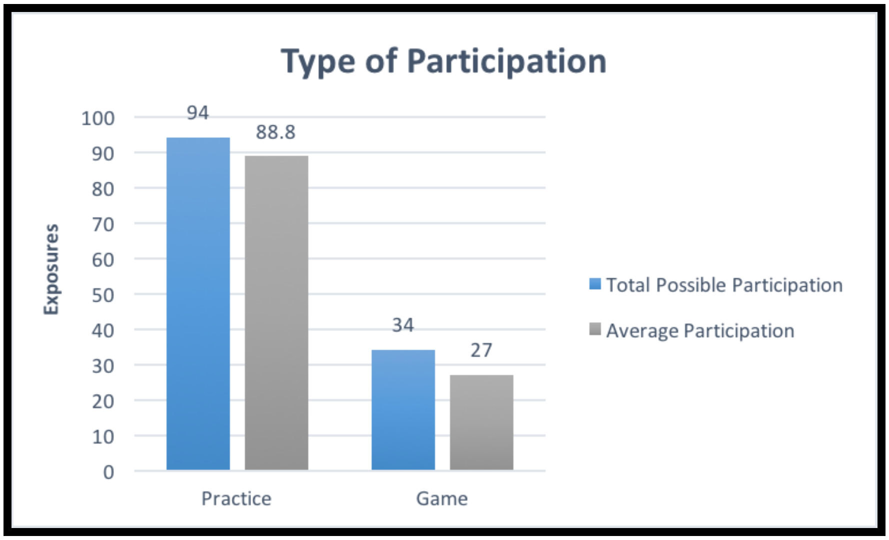

Figure 39. Type of Participation – Men's Basketball Athletes

4.4.5.3 Women's Basketball Exposures

Practice and game exposures were tracked in 13 women's basketball athletes for one collegiate winter basketball season, following each athlete's test session. The 2016-2017 collegiate women's basketball winter season was played between November 2016 and March 2017. The 13 women's basketball athletes participated in a pre-season, competitive season, and post-season. The 2016-2017 collegiate women's basketball winter season encompassed a total of 120 possible exposures per athlete. 89 of the 120 exposures were practices and 31 of the 120 exposures were games. Pre-season encompassed a total of 37 exposures, all 37 of these exposures were practices. No game exposures were encountered during the pre-season. The competitive season was comprised of a total of 80 exposures. 50 of the 80 total competitive season exposures were practices and 30 of the 80 competitive season exposures were games. Post-season was comprised of three total exposures, two of these post-season exposures were practices and only one were games.

The average number total exposures for 13 women's basketball athletes was 103.8 exposures out of the available 120 exposures (86.5%). Of the available 89 practice exposures, the 13 women's basketball athletes averaged participation of 82.2 practice exposures (92.4%). The average number of game exposures for the 13 women's basketball athletes was 21.6 out of the available 31 game exposures (72.0%). There were a total of 37 available pre-season exposures; all of the 37 pre-season exposures were practices. Out of the 37 available pre-season exposures, the average of the 13 women's basketball athlete exposures was 34.2 pre-season exposures (92.4%). There were a total of 80 available exposures during the women's basketball competitive season; 50 of the available competitive season exposures were practices and 30 were games. The average competitive season participation for the women's basketball athletes was 67.2 of the 80 available competitive season exposures (84.0%). There was a total of 50 available practice exposures during the competitive season; the average women's basketball participation was 46.2 competitive season practice exposures (92.4%). There were 30 available game exposures during the competitive season; on average the 13 women's basketball athletes participated in 21.0 of the competitive season game exposures (70.0%). There were a total of three available exposures during the women's basketball post-season; two of the three post-season exposures were practices and one were games. The average total post-season participation was 2.5 of three available post-season exposures (83.3%). There were two available practice exposures during the post-season and the average post-season practice participation was 1.9 post-season practices (95.0%). There were one available game exposures and the average women's basketball participation was 0.62 post-season game exposures (62.0%). Participation is represented in Table 50, Figure 40, and Figure 41.

Table 50. Women's Basketball Athlete Participation

	Total Possible Exposures Per Athletic Season	Average Participation Per Athletic Season	Percentage of Participation
Overall	120.00	103.80	86.50
Timing of Participation			
Pre-Season	37.00	34.20	92.40
Competitive Season	80.00	67.20	84.00
Post-Season	3.00	2.50	83.30
Type of Participation			
Pratice	89.00	82.20	92.40
Game	31.00	21.60	72.00
Competitive Season			
Pratice	50.00	46.20	92.40
Game	30.00	21.00	70.00
Post-Season			
Practice	2.00	1.90	95.00
Game	1.00	0.60	62.00

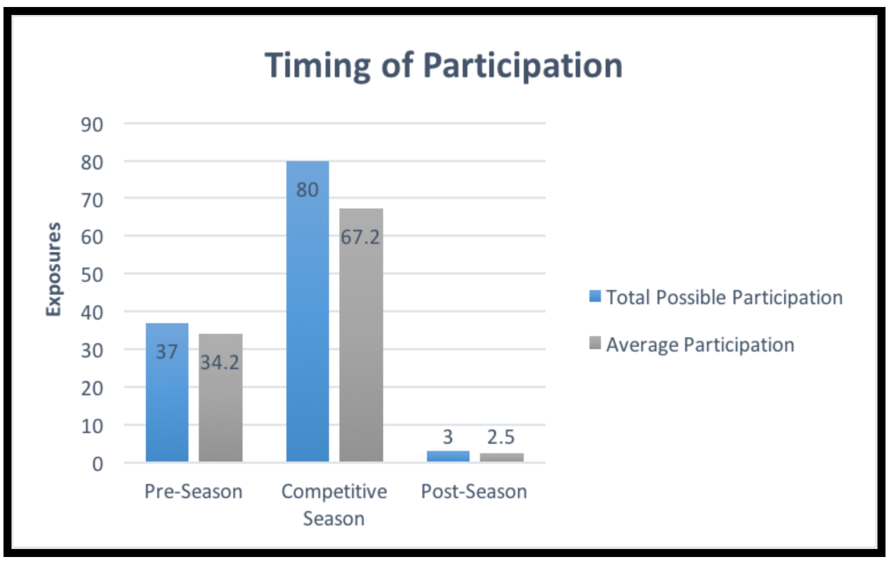

Figure 40. Timing of Participation – Women's Basketball Athletes

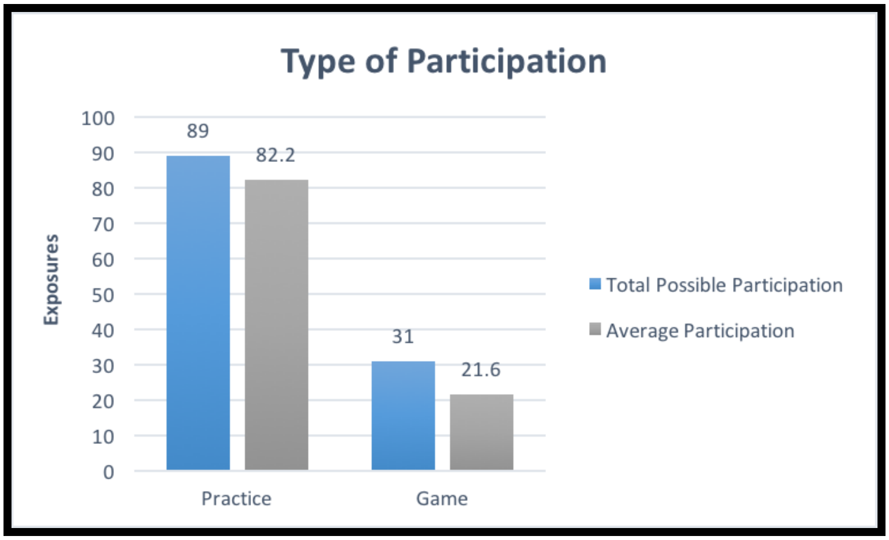

Figure 41. Type of Participation – Women's Basketball Athletes

4.5 LOWER EXTREMITY MUSCULOSKELETAL INJURY

4.5.1 Overall

4.5.1.1 Overall Lower Extremity Musculoskeletal Injuries

Lower extremity musculoskeletal injuries were prospectively tracked in 131 (Men's: 78, Women's: 53) lower extremity dominant athletes for one athletic season, following each athlete's test session. 56 out of 131 men's and women's lower extremity dominant athletes prospectively tracked over the course of one collegiate athletic season suffered a lower extremity musculoskeletal injury (42.7%). 12 of the men's and women's lower extremity dominant athletes prospectively tracked suffered more than one lower extremity musculoskeletal injury; 69 total lower extremity musculoskeletal injuries were suffered over the course of the collegiate athletic season. Of the 69 total lower extremity musculoskeletal injuries suffered during the collegiate athletic season, 24 occurred during the pre-season (34.8%), 41 occurred during the competitive season (59.4%), and 4 occurred during the post-season (0.06%). 59 of the 69 lower extremity musculoskeletal injuries suffered over the course of the collegiate athletic season occurred during a practice (85.5%), 7 occurred during a game (10.1%), and 3 were unknown (0.04%). There were 23 ankle injuries (33.3%), 13 knee injuries (18.8%), 5 hip injuries (0.07%), 17 muscle injuries (24.6%), and 11 injuries categorized as other (15.9%) out of the 69 total lower extremity musculoskeletal injuries suffered during the men's and women's collegiate athletic season. There were 58 acute injuries (84.1%) and 11 overuse injuries (15.9%), of the 69 total lower extremity musculoskeletal injuries suffered. Lower extremity musculoskeletal injury data is presented in Figure 42, Figure 43, Figure 44, and Figure 45.

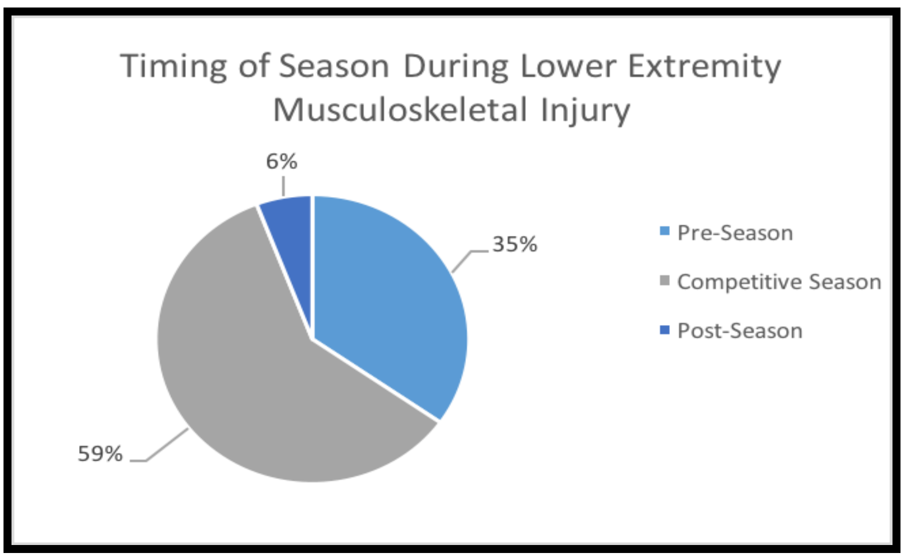

Figure 42. Timing of Season During Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Lower Extremity Dominant Sport Athletes

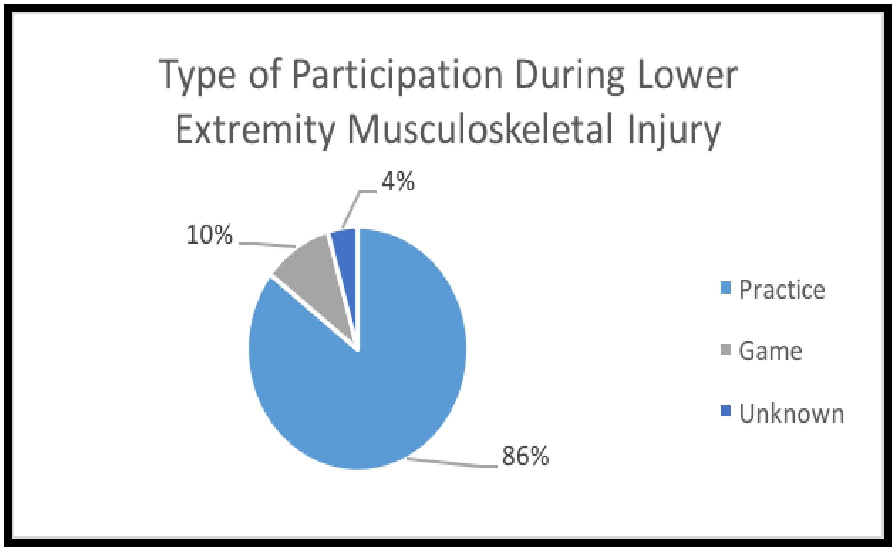

Figure 43. Type of Participation During Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Lower Extremity Dominant Sport Athletes

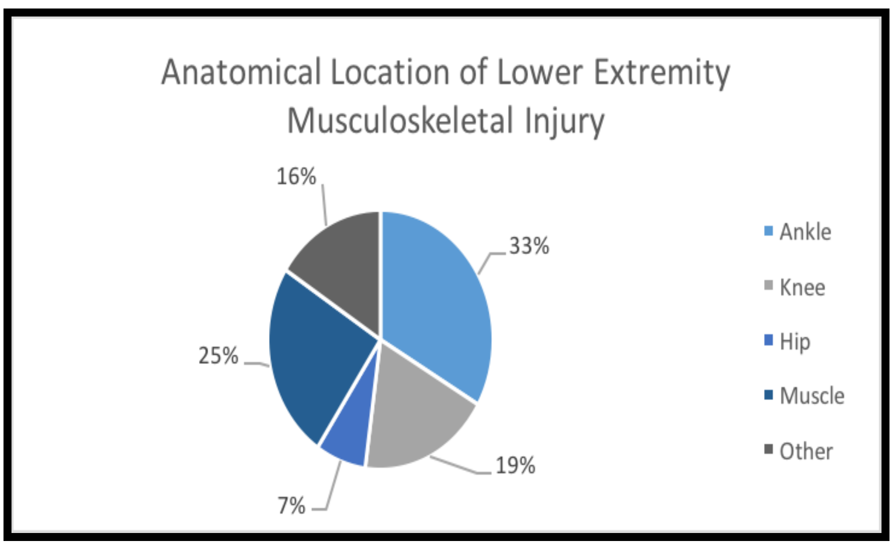

Figure 44. Anatomical Location of Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Lower Extremity Dominant Sport Athletes

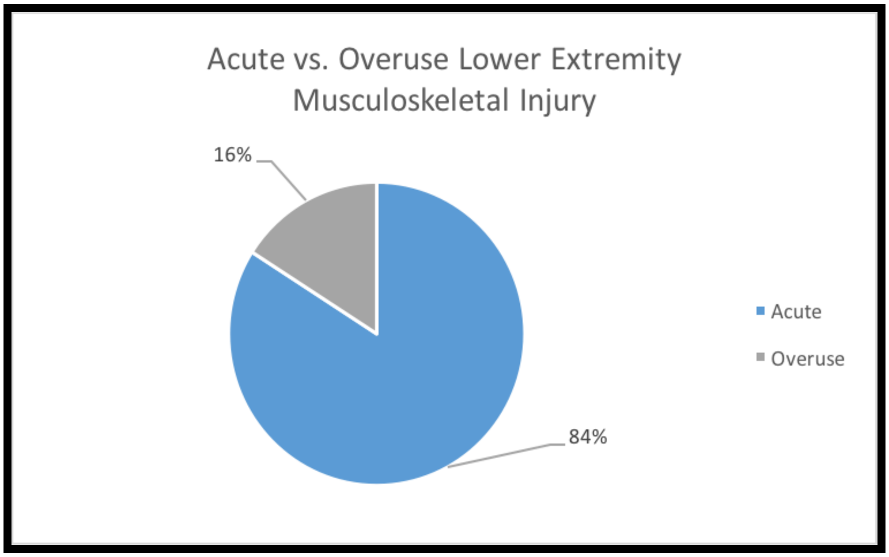

Figure 45. Acute vs. Overuse Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Lower Extremity Dominant Sport Athletes

The overall lower extremity musculoskeletal injury rate for the men's and women's collegiate athletic season was 6.13 injuries per 1,000 athlete exposures (95% CI: 4.69, 7.58). The pre-season lower extremity musculoskeletal injury rate was 8.12 injuries per 1,000 athlete exposures (95% CI: 4.87, 11.38). The competitive season lower extremity musculoskeletal injury rate was 5.35 injuries per 1,000 athlete exposures (95% CI: 3.71, 6.98). The post-season lower extremity musculoskeletal injury rate was 6.36 injuries per 1,000 athlete exposures (95% CI: 0.13, 12.59). The lower extremity musculoskeletal injury rate during practice participation was 6.59 injuries per 1,000 athlete exposures (95% CI: 4.91, 8.27); during participation in games the lower extremity musculoskeletal injury rate was 3.05 injuries per 1,000 athlete exposures (95% CI: 0.79, 5.31). The acute lower extremity musculoskeletal injury rate during the men's and women's collegiate athletic season was 5.15 injuries per 1,000 athlete exposures (95% CI: 3.83, 6.48); the overuse lower extremity musculoskeletal injury rate was 0.98 injuries per 1,000 athlete exposures (95% CI: 0.40, 1.56). The ankle had the highest number of injuries during the men's and women's collegiate athletic season, 2.04 injuries per 1,000 athlete exposures (95% CI: 1.21, 2.88), followed by knee with an injury rate of 1.16 injuries per 1,000 athlete exposures (95% CI: 0.53, 1.78). The injury rate for lower extremity musculoskeletal injuries categorized as other was 0.98 injuries per 1,000 athlete exposures (95% CI: 0.40, 1.56). The injury rate for lower extremity musculoskeletal injuries at the hip was 0.44 injuries per 1,000 athlete exposures (95% CI: 0.05, 0.83). The injury rate for lower extremity muscle injuries was 1.51 injuries per 1,000 athlete exposures (95% CI: 0.79, 2.23). Musculoskeletal injury rates are represented in Table 51.

Table 51. Overall Lower Extremity Dominant Sport Athletes Lower Extremity Musculoskeletal Injury Rates

	Number of Injuries	Number of Exposures	Injuries Per 1,000 Athlete Exposures	95% CI
Overall	69.00	11252.00	6.13	4.69, 7.58
Timing of Participation				
Pre-Season	24.00	2954.00	8.12	4.87, 11.38
Competitive Season	41.00	7669.00	5.35	3.71, 6.98
Post-Season	4.00	629.00	6.36	0.13, 12.59
Type of Participation				
Pratice	59.00	8959.00	6.59	4.91, 8.27
Game	7.00	2293.00	3.05	0.79, 5.31
Acute vs. Overuse				
Acute	58.00	11252.00	5.15	3.83, 6.48
Overuse	11.00	11252.00	0.98	0.40, 1.56
Injury Location				
Ankle	23.00	11252.00	2.04	1.21, 2.88
Knee	13.00	11252.00	1.16	0.53, 1.78
Hip	5.00	11252.00	0.44	0.05, 0.83
Muscle	17.00	11252.00	1.51	0.79, 2.23
Other	11.00	11252.00	0.98	0.40, 1.56

4.5.1.2 Men's Lower Extremity Musculoskeletal Injuries

Lower extremity musculoskeletal injuries were prospectively tracked in 78 men's lower extremity dominant athletes for one collegiate athletic season, following each athlete's test session. 36 out of 78 men's lower extremity dominant athletes prospectively tracked over the course of one collegiate athletic season suffered a lower extremity musculoskeletal injury (45.6%). Eleven of the men's lower extremity dominant athletes prospectively tracked suffered more than one lower extremity musculoskeletal injury; 48 total lower extremity musculoskeletal injuries were suffered over the course of the collegiate athletic season. Of the 48 total lower extremity musculoskeletal injuries suffered during the collegiate athletic season, 16 occurred during the pre-season (33.3%), 28 occurred during the competitive season (58.3%), and four occurred during the post-season (8.3%). 45 of the 48 lower extremity musculoskeletal injuries suffered over the course of the collegiate men's athletic season occurred during a practice (93.8%) and 3 occurred during a game (6.3%).

The lower extremity musculoskeletal injuries suffered by the men's lower extremity athletes were categorized by location, including, ankle, knee, hip, and other. There were 18 ankle injuries (37.5%), eight knee injuries (16.7%), 2 hip injuries (4.2%), 15 lower extremity muscle injuries (31.3%), and five injuries categorized as other (10.4%) out of the 48 total lower extremity musculoskeletal injuries suffered during the men's athletic season. There were 43 acute injuries (89.6%) and five overuse injuries (10.4%), of the 48 total lower extremity musculoskeletal injuries suffered. Lower extremity musculoskeletal injury data is presented in Figure 46, Figure 47, Figure 48, and Figure 49.

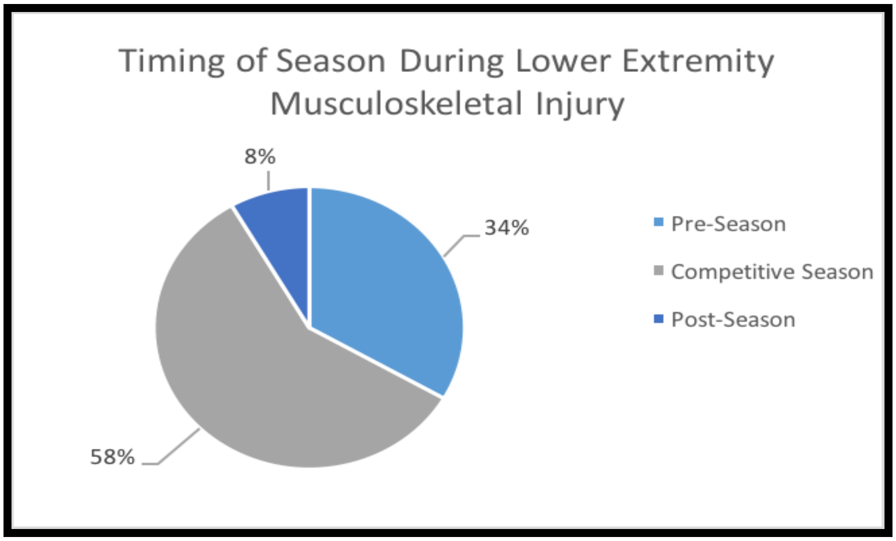

Figure 46. Timing of Season During Lower Extremity Musculoskeletal Injury – Overall Men's Lower Extremity Dominant Sport Athletes

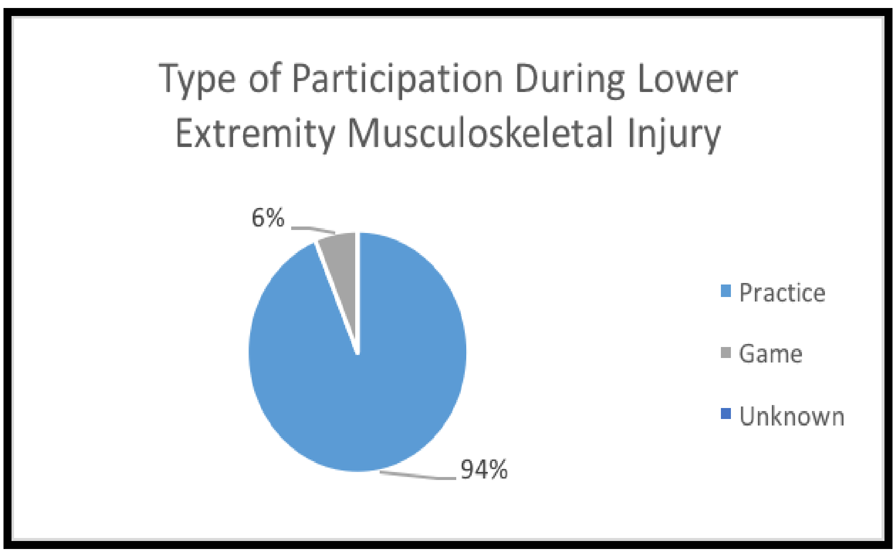

Figure 47. Type of Participation During Lower Extremity Musculoskeletal Injury – Overall Men's Lower Extremity Dominant Sport Athletes

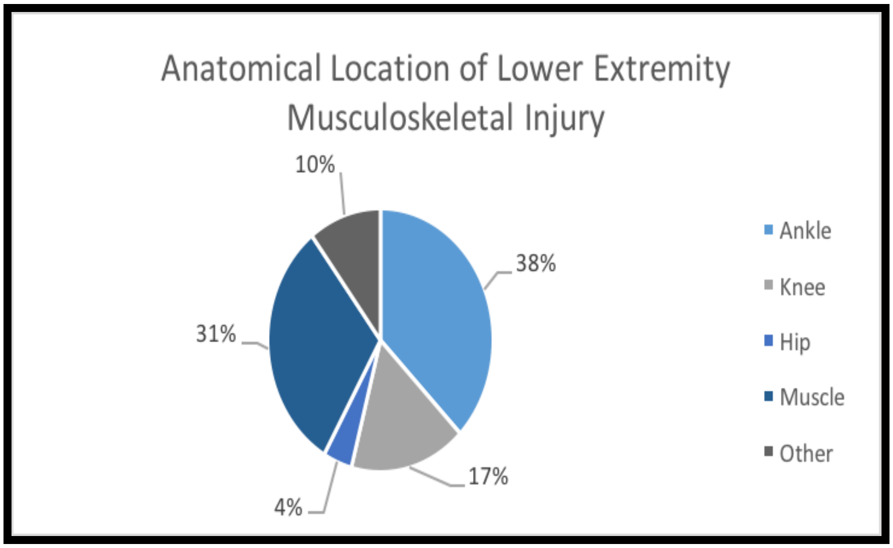

Figure 48. Anatomical Location of Lower Extremity Musculoskeletal Injury – Overall Men's Lower Extremity Dominant Sport Athletes

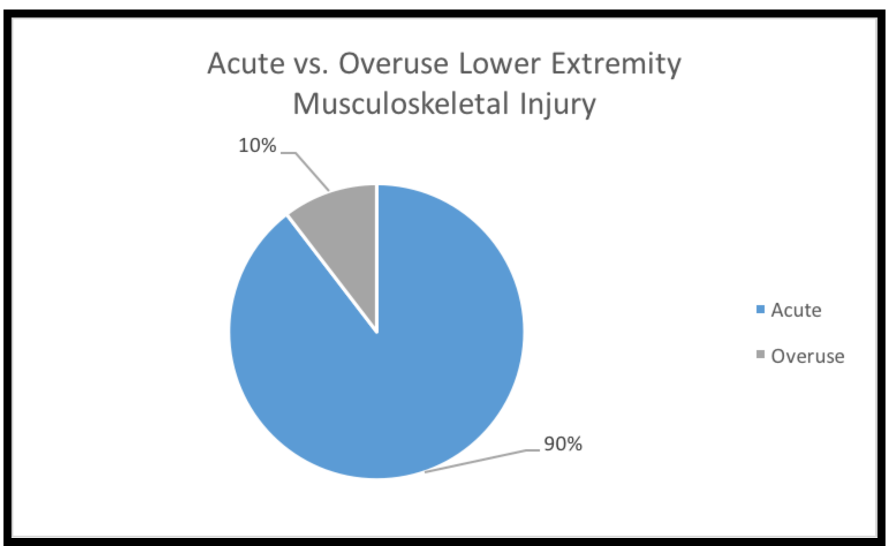

Figure 49. Acute vs. Overuse Lower Extremity Musculoskeletal Injury – Overall Men's Lower Extremity Dominant Sport Athletes

The overall lower extremity musculoskeletal injury rate for the men's collegiate athletic season was 7.43 injuries per 1,000 athlete exposures (95% CI: 5.32, 9.53). The pre-season lower extremity musculoskeletal injury rate was 10.24 injuries per 1,000 athlete exposures (95% CI: 5.22, 15.25). The competitive season lower extremity musculoskeletal injury rate was 6.42 injuries per 1,000 athlete exposures (95% CI: 4.04, 8.79). The post-season lower extremity musculoskeletal injury rate was 7.43 injuries per 1,000 athlete exposures (95% CI: 0.15, 14.72). The lower extremity musculoskeletal injury rate during practice participation was 8.52 injuries per 1,000 athlete exposures (95% CI: 6.03, 11.00); during participation in games the lower extremity musculoskeletal injury rate was 2.54 injuries per 1,000 athlete exposures (95% CI: -0.33, 5.42). The acute lower extremity musculoskeletal injury rate during the men's collegiate athletic season was 6.65 injuries per 1,000 athlete exposures (95% CI: 4.66, 8.64); the overuse lower extremity musculoskeletal injury rate was 0.77 injuries per 1,000 athlete exposures (95% CI: 0.10, 1.45). The ankle had the highest number of injuries during the men's collegiate athletic season, 2.78 injuries per 1,000 athlete exposures (95% CI: 1.50, 4.07), followed by knee with an injury rate of 1.24 injuries per 1,000 athlete exposures (95% CI: 0.38, 2.10). The injury rate for lower extremity musculoskeletal injuries categorized as other was 0.77 injuries per 1,000 athlete exposures (95% CI: 0.10, 1.45). The injury rate for lower extremity musculoskeletal injuries at the hip was 0.31 injuries per 1,000 athlete exposures (95% CI: -0.12, 0.74). The injury rate for lower extremity musculoskeletal injuries of the lower extremity muscles was 2.32 injuries per 1,000 athlete exposures (95% CI: 1.15, 3.49). Musculoskeletal injury rates are represented in Table 52.

Table 52. Overall Men's Lower Extremity Dominant Sport Athletes Lower Extremity Musculoskeletal Injury Rates

	Number of Injuries	Number of Exposures	Injuries Per 1,000 Athlete Exposures	95% CI
Overall	48.00	6464.00	7.43	5.32, 9.53
Timing of Participation				
Pre-Season	16.00	1563.00	10.24	5.22, 15.25
Competitive Season	28.00	4363.00	6.42	4.04, 8.79
Post-Season	4.00	538.00	7.43	0.15, 14.72
Type of Participation				
Pratice	45.00	5284.00	8.52	6.03, 11.00
Game	3.00	1180.00	2.54	-0.33, 5.42
Acute vs. Overuse				
Acute	43.00	6464.00	6.65	4.66, 8.64
Overuse	5.00	6464.00	0.77	0.10, 1.45
Injury Location				
Ankle	18.00	6464.00	2.78	1.50, 4.07
Knee	8.00	6464.00	1.24	0.38, 2.10
Hip	2.00	6464.00	0.31	-0.12, 0.74
Muscle	15.00	6464.00	2.32	1.15, 3.49
Other	5.00	6464.00	0.77	0.10, 1.45

4.5.1.3 Women's Lower Extremity Musculoskeletal Injuries

Lower extremity musculoskeletal injuries were prospectively tracked in 53 women's lower extremity dominant athletes for one collegiate athletic season, following each athlete's test session. 20 out of 53 women's lower extremity dominant athletes prospectively tracked over the course of one collegiate athletic season suffered a lower extremity musculoskeletal injury (37.7%). Only one of the women's lower extremity dominant athletes prospectively tracked suffered more than one lower extremity musculoskeletal injury; 21 total lower extremity musculoskeletal injuries were suffered over the course of the collegiate athletic season. Of the 21 total lower extremity musculoskeletal injuries suffered during the collegiate athletic season, eight occurred during the pre-season (38.1%), 13 occurred during the competitive season (61.9%), and zero occurred during the post-season (0.0%). 14 of the 21 lower extremity musculoskeletal injuries suffered over the course of the collegiate women's athletic season occurred during a practice (66.7%), four occurred during a game (19.0%), and three were unknown (14.3%).

The lower extremity musculoskeletal injuries suffered by the women's lower extremity athletes were categorized by location, including, ankle, knee, hip, and other. There were five ankle injuries (23.8%), five knee injuries (23.8%), three hip injuries (14.3%), two muscle injuries (9.5%), and six injuries categorized as other (28.6%) out of the 21 total lower extremity musculoskeletal injuries suffered during the women's athletic season. No hip injuries were reported. There were 15 acute injuries (71.4%) and 6 overuse injury (28.6%), of the 21 total lower extremity musculoskeletal injuries suffered. Lower extremity musculoskeletal injury data is presented in Figure 50, Figure 51, Figure 52, and Figure 53.

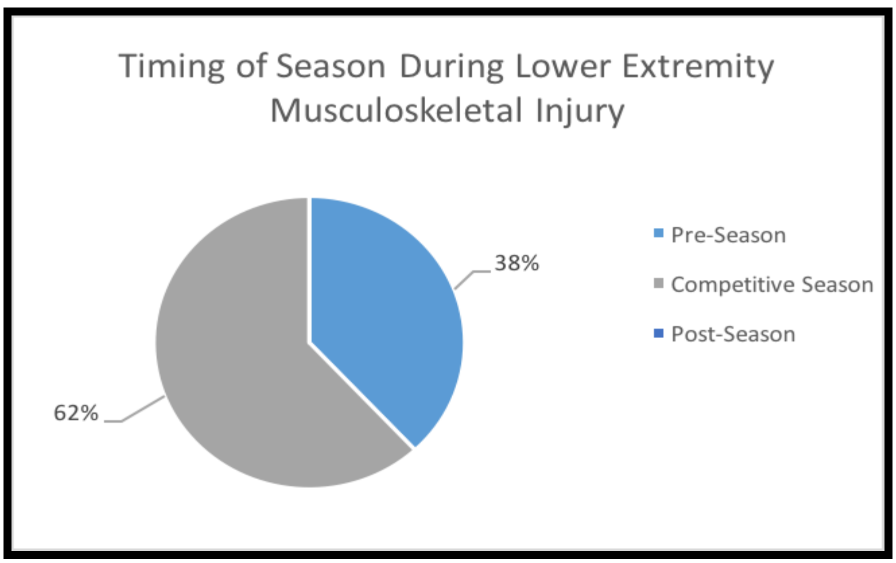

Figure 50. Timing of Season During Lower Extremity Musculoskeletal Injury – Overall Women's Lower Extremity Dominant Sport Athletes

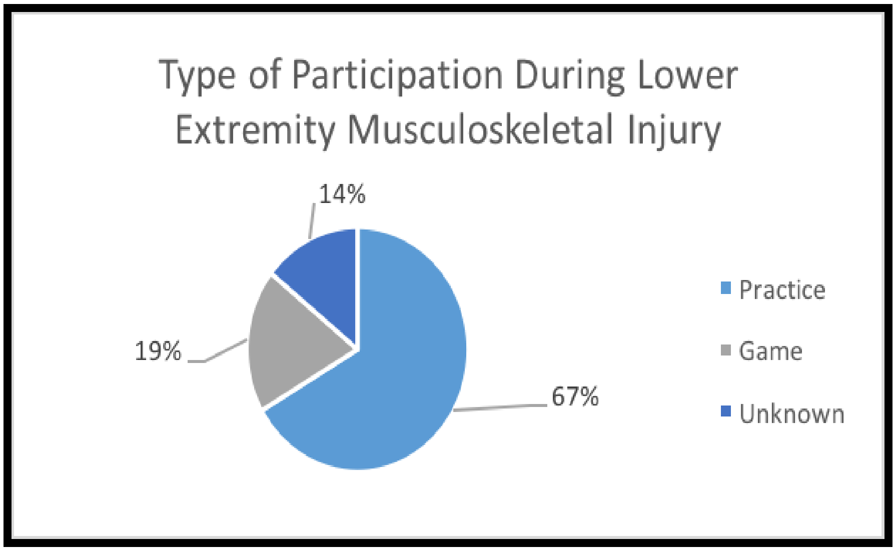

Figure 51. Type of Participation During Lower Extremity Musculoskeletal Injury – Overall Women's Lower Extremity Dominant Sport Athletes

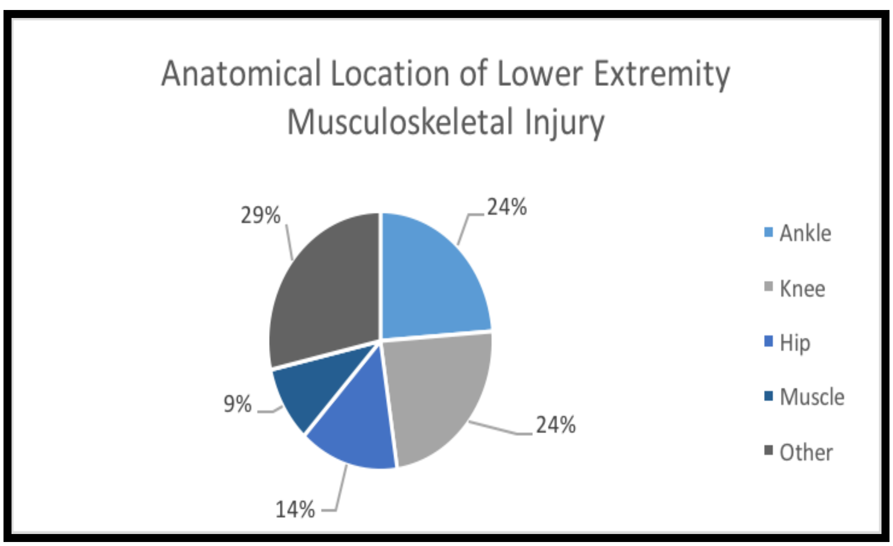

Figure 52. Anatomical Location of Lower Extremity Musculoskeletal Injury – Overall Women's Lower Extremity Dominant Sport Athletes

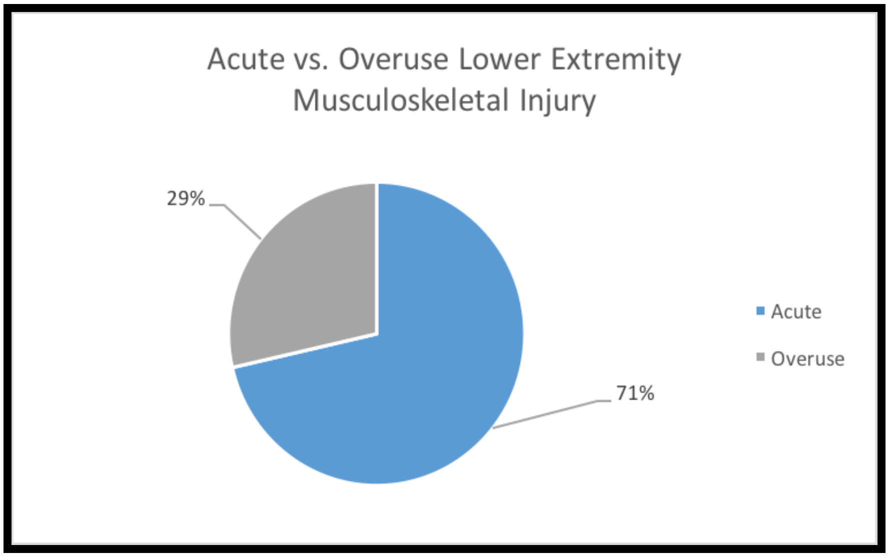

Figure 53. Acute vs. Overuse Lower Extremity Musculoskeletal Injury – Overall Women's Lower Extremity Dominant Sport Athletes

The overall lower extremity musculoskeletal injury rate for the women's collegiate athletic season was 4.39 injuries per 1,000 athlete exposures (95% CI: 2.51, 6.26). The pre-season lower extremity musculoskeletal injury rate was 5.75 injuries per 1,000 athlete exposures (95% CI: 1.77, 9.74). The competitive season lower extremity musculoskeletal injury rate was 3.93 injuries per 1,000 athlete exposures (95% CI: 1.79, 6.07). The lower extremity musculoskeletal injury rate during practice participation was 3.81 injuries per 1,000 athlete exposures (95% CI: 1.81, 5.81); during participation in games the lower extremity musculoskeletal injury rate was 3.59 injuries per 1,000 athlete exposures (95% CI: 0.07, 7.12). The acute lower extremity musculoskeletal injury rate during the women's collegiate athletic season was 3.13 injuries per 1,000 athlete exposures (95% CI: 1.55, 4.72); the overuse lower extremity musculoskeletal injury rate was 1.25 injuries per 1,000 athlete exposures (95% CI: 0.25, 2.26). The injury rate at the ankle during the women's collegiate athletic season was 1.04 injuries per 1,000 athlete exposures (95% CI: 0.13, 1.96), similar to the knee with an injury rate of 1.04 injuries per 1,000 athlete exposures (95% CI: 0.13, 1.96). The injury rate for lower extremity musculoskeletal injuries categorized as other was 1.25 injuries per 1,000 athlete exposures (95% CI: 0.25, 2.26). The injury rate for lower extremity musculoskeletal injuries at the hip was 0.63 injuries per 1,000 athlete exposures (95% CI: -0.08, 1.34). The injury rate for lower extremity muscle injuries was 0.42 injuries per 1,000 athlete exposures (95% CI: -0.16, 1.00). Musculoskeletal injury rates are represented in Table 53.

Table 53. Overall Women's Lower Extremity Dominant Sport Athletes Lower Extremity Musculoskeletal Injury Rates

	Number of Injuries	Number of Exposures	Injuries Per 1,000 Athlete Exposures	95% CI
Overall	21.00	4788.00	4.39	2.51, 6.26
Timing of Participation				
Pre-Season	8.00	1391.00	5.75	1.77, 9.74
Competitive Season	13.00	3306.00	3.93	1.79, 6.07
Type of Participation				
Pratice	14.00	3675.00	3.81	1.81, 5.81
Game	4.00	1113.00	3.59	0.07, 7.12
Acute vs. Overuse				
Acute	15.00	4788.00	3.13	1.55, 4.72
Overuse	6.00	4788.00	1.25	0.25, 2.26
Injury Location				
Ankle	5.00	4788.00	1.04	0.13, 1.96
Knee	6.00	4788.00	1.04	0.13, 1.96
Hip	3.00	4788.00	0.63	-0.08, 1.34
Muscle	2.00	4788.00	0.42	-0.16, 1.00
Other	6.00	4788.00	1.25	0.25, 2.26

4.5.2 Soccer

4.5.2.1 Overall Soccer Lower Extremity Musculoskeletal Injuries

Lower extremity musculoskeletal injuries were prospectively tracked in 48 (Men's: 24, Women's 24) soccer athletes for one collegiate fall soccer season, following each athlete's test session.

Eighteen out of 48 men's and women's soccer athletes prospectively tracked over the course of one collegiate fall soccer season suffered a lower extremity musculoskeletal injury (37.5%). None of the men's and women's soccer athletes prospectively tracked suffered more than one lower extremity musculoskeletal injury; 18 total lower extremity musculoskeletal injuries were suffered over the course of the collegiate fall men's and women's soccer season. Of the 18 total lower extremity musculoskeletal injuries suffered during the collegiate fall men's and women's soccer season, three occurred during the pre-season (16.7%), 12 occurred during the competitive season (66.7%), and three occurred during the post-season (16.7%). Ten of the 18 lower extremity musculoskeletal injuries suffered over the course of the collegiate men's and women's soccer fall season occurred during a practice (55.6%), five occurred during a game (27.8%), and three were unknown (16.7%). There were nine ankle injuries (50.0%), four knee injuries (22.2%), and four injuries categorized as other (22.2%) out of the 18 total lower extremity musculoskeletal injuries suffered during the men's and women's soccer fall collegiate season. There were 15 acute injuries (83.3%) and three overuse injuries (18.7%), of the 18 total lower extremity musculoskeletal injuries suffered. Lower extremity musculoskeletal injury data is presented in Figure 54, Figure 55, Figure 56, and Figure 57.

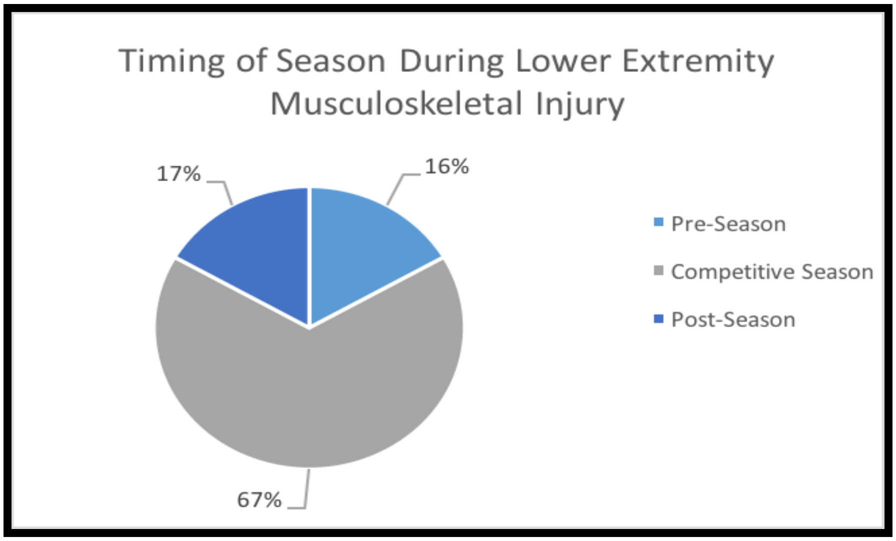

Figure 54. Timing of Season During Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Soccer Athletes

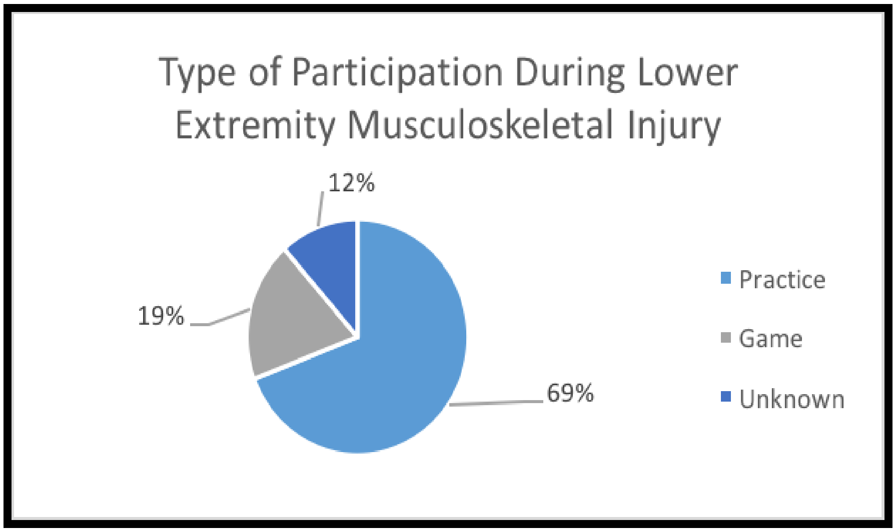

Figure 55. Type of Participation During Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Soccer Athletes

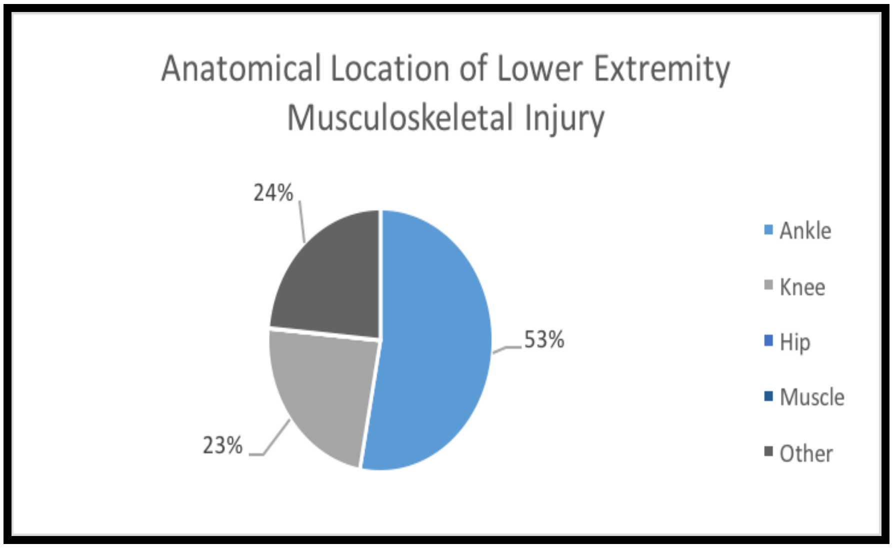

Figure 56. Anatomical Location of Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Soccer Athletes

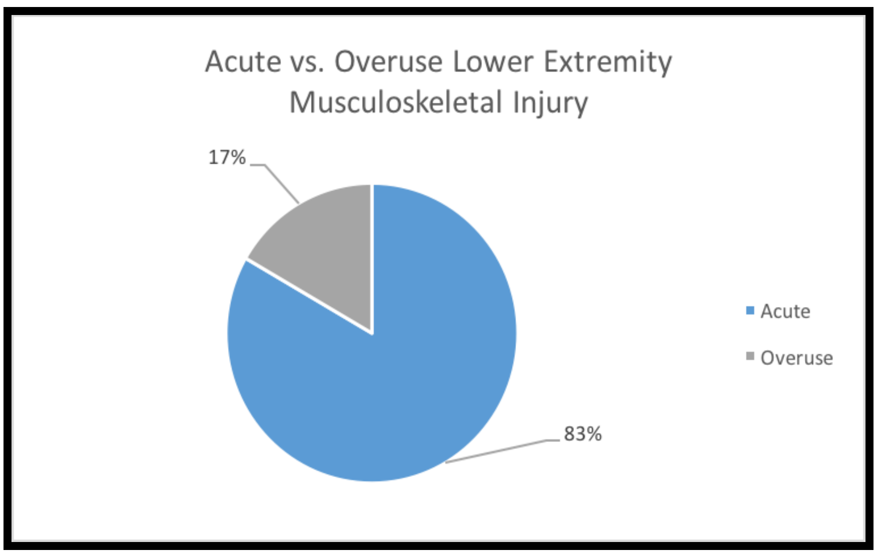

Figure 57. Acute vs. Overuse Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Soccer Athletes

The overall lower extremity musculoskeletal injury rate for the men's and women's soccer fall season was 5.22 injuries per 1,000 athlete exposures (95% CI: 2.81, 7.63). The pre-season lower extremity musculoskeletal injury rate was 4.06 injuries per 1,000 athlete exposures (95% CI: -0.53, 8.65). The competitive season lower extremity musculoskeletal injury rate was 4.58 injuries per 1,000 athlete exposures (95% CI: 1.99, 7.17). The lower extremity musculoskeletal injury rate during practice participation was 3.68 injuries per 1,000 athlete exposures (95% CI: 1.40, 5.97); during participation in games the lower extremity musculoskeletal injury rate was 6.80 injuries per 1,000 athlete exposures (95% CI: 0.84, 12.77). The acute lower extremity musculoskeletal injury rate during the men's and women's soccer fall season was 4.35 injuries per 1,000 athlete exposures (95% CI: 2.15, 6.55); the overuse lower extremity musculoskeletal injury rate was 0.87 injuries per 1,000 athlete exposures (95% CI: -0.11, 1.85). The ankle had the highest number of injuries during the men's and women's soccer fall season, 2.61 injuries per 1,000 athlete exposures (95% CI: 0.90, 4.31), followed by knee with an injury rate of 1.16 injuries per 1,000 athlete exposures (95% CI: 0.02, 2.30). The injury rate for lower extremity musculoskeletal injuries categorized as other was 1.16 injuries per 1,000 athlete exposures (95% CI: 0.02, 2.30). The overall ankle sprain injury rate during the men's and women's soccer fall season was 2.61 injuries per 1,000 athlete exposures (95% CI: 0.90, 4.31). Musculoskeletal injury rates are represented in Table 54.

Table 54. Overall Men's and Women's Soccer Athletes Lower Extremity Musculoskeletal Injury Rates

	Number of Injuries	Number of Exposures	Injuries Per 1,000 Athlete Exposures	95% CI
Overall	18.00	3449.00	5.22	2.81, 7.63
Timing of Participation				
Pre-Season	3.00	739.00	4.06	-0.53, 8.65
Competitive Season	12.00	2619.00	4.58	1.99, 7.17
Type of Participation				
Pratice	10.00	2714.00	3.68	1.40, 5.97
Game	5.00	735.00	6.80	0.84, 12.77
Acute vs. Overuse				
Acute	15.00	3449.00	4.35	2.15, 6.55
Overuse	3.00	3449.00	0.87	-0.11, 1.85
Injury Location				
Ankle	9.00	3449.00	2.61	0.90, 4.31
Knee	4.00	3449.00	1.16	0.02, 2.30
Other	4.00	3449.00	1.16	0.02, 2.30

4.5.2.2 Men's Soccer Lower Extremity Musculoskeletal Injuries

Lower extremity musculoskeletal injuries were prospectively tracked in 24 men's soccer athletes for one collegiate fall soccer season, following each athlete's test session. Eight out of 24 men's soccer athletes prospectively tracked over the course of one collegiate fall soccer season suffered a lower extremity musculoskeletal injury (33.3%). None of the men's soccer athletes prospectively tracked suffered more than one lower extremity musculoskeletal injury; eight total lower extremity musculoskeletal injuries were suffered over the course of the collegiate fall men's soccer season. Of the eight total lower extremity musculoskeletal injuries suffered during the collegiate fall men's soccer season, one occurred during the pre-season (12.5%), four occurred during the competitive season (50.0%), and three occurred during the post-season (37.5%). Six of the eight lower extremity musculoskeletal injuries suffered over the course of the collegiate men's soccer fall season occurred during a practice (75.0%) and two occurred during a game (25.0%).

The lower extremity musculoskeletal injuries suffered by the men's soccer athletes were categorized by location, including, ankle, knee, hip, and other. There were five ankle injuries (62.5%), one knee injuries (12.5%), and two injuries categorized as other (25.0%) out of the 8 total lower extremity musculoskeletal injuries suffered during the men's soccer fall collegiate season. No hip injuries were reported. When the lower extremity musculoskeletal injuries were categorized by injury type, five of the eight lower extremity musculoskeletal injuries suffered were ankle sprain (62.5%), one was a lateral collateral ligament sprain of the knee (12.5%), one injury was a sartorious muscle strain (12.5%), and one injury was tendinopathy of the posterior tibialis tendon insertion point (12.5%). There were seven acute injuries (87.5%) and one overuse injury (12.5%), of the eight total lower extremity musculoskeletal injuries suffered. Lower extremity musculoskeletal injury data is presented in Figure 58, Figure 59, Figure 60, and Figure 61.

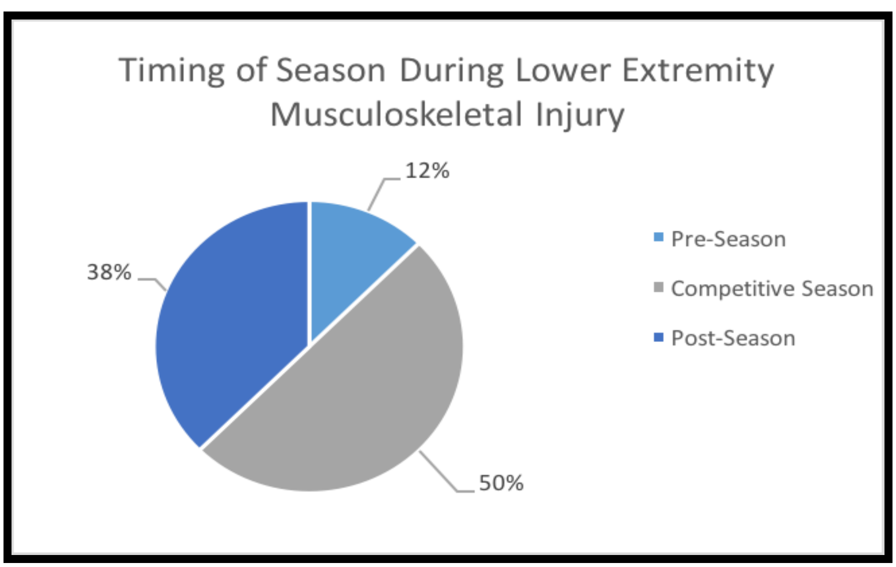

Figure 58. Timing of Season During Lower Extremity Musculoskeletal Injury – Men's Soccer Athletes

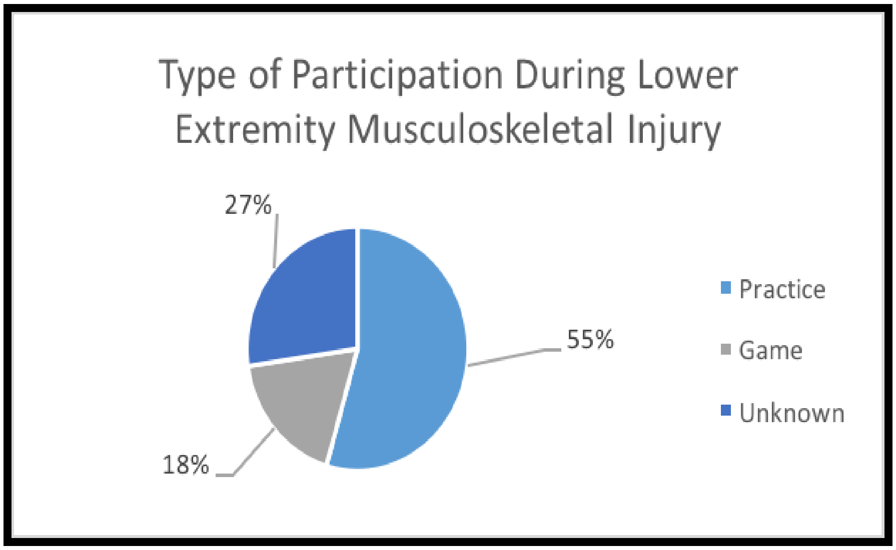

Figure 59. Type of Participation During Lower Extremity Musculoskeletal Injury – Men's Soccer Athletes

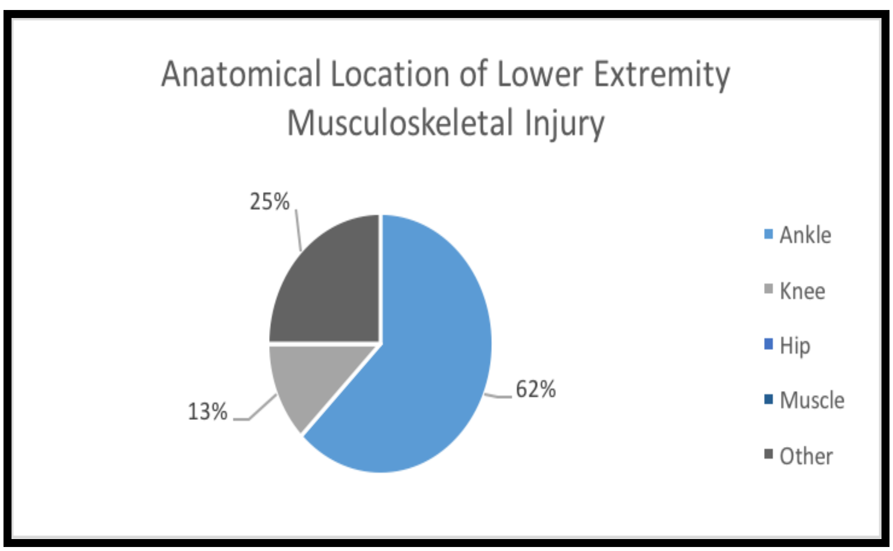

Figure 60. Anatomical Location of Lower Extremity Musculoskeletal Injury – Men's Soccer Athletes

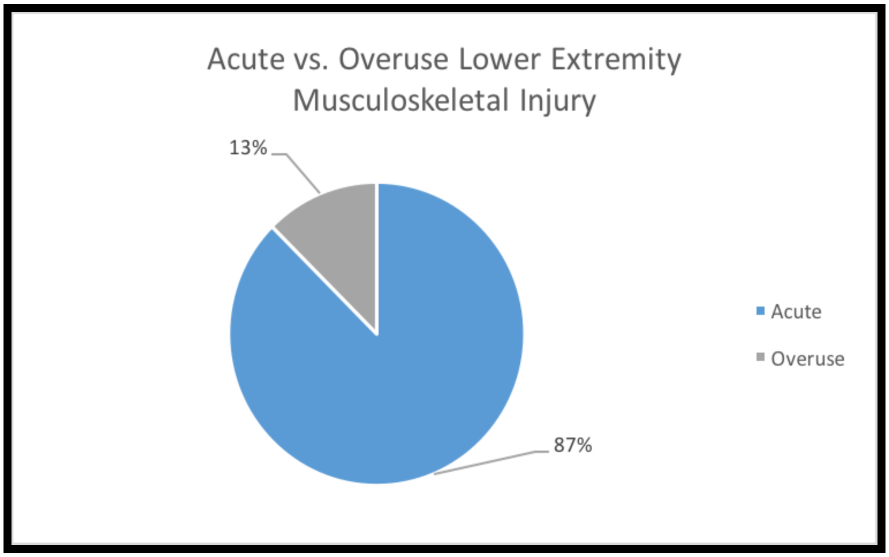

Figure 61. Acute vs. Overuse Lower Extremity Musculoskeletal Injury – Men's Soccer Athletes

The overall lower extremity musculoskeletal injury rate for the men's soccer fall season was 4.56 injuries per 1,000 athlete exposures (95% CI: 1.40, 7.72). The pre-season lower extremity musculoskeletal injury rate was 5.21 injuries per 1,000 athlete exposures (95% CI: -5.00, 15.42). The competitive season lower extremity musculoskeletal injury rate was 2.72 injuries per 1,000 athlete exposures (95% CI: 0.05, 5.38). Both the pre-season and competitive season lower extremity musculoskeletal injury rates were significantly less than the post-season lower extremity musculoskeletal injury rate, 32.97 injuries per 1,000 athlete-exposures (95% CI: -4.34, 70.27). The lower extremity musculoskeletal injury rate during practice participation was 4.52 injuries per 1,000 athlete exposures (95% CI: 0.90, 8.13); during participation in games the lower extremity musculoskeletal injury rate was 4.68 injuries per 1,000 athlete exposures (95% CI: 1.81, 11.18). The acute lower extremity musculoskeletal injury rate during the men's soccer fall season was 3.99 injuries per 1,000 athlete exposures (95% CI: 1.03, 6.94); the overuse lower extremity musculoskeletal injury rate was 0.57 injuries per 1,000 athlete exposures (95% CI: -0.55, 1.69). The ankle had the highest number of injuries during the men's soccer fall season, 2.85 injuries per 1,000 athlete exposures (95% CI: 0.35, 5.35), followed by other lower extremity musculoskeletal injuries with an injury rate of 1.14 injuries per 1,000 athlete exposures (95% CI: -0.44, 2.72). The injury rate for knee injuries was 0.57 injuries per 1,000 athlete exposures (95% CI: -0.55, 1.69). The overall ankle sprain injury rate during the men's soccer fall season was 2.85 injuries per 1,000 athlete exposures (95% CI: 0.35, 5.35). An injury rate of 0.57 injuries per 1,000 athlete exposures (95% CI: -0.55, 1.69) was noted for the following injuries: lateral collateral ligament sprain of the knee, sartorious muscle strain, and tendinopathy of the posterior tibialis tendon insertion. Musculoskeletal injury rates are represented in Table 55.

Table 55. Overall Men's Soccer Athletes Lower Extremity Musculoskeletal Injury Rates

	Number of Injuries	Number of Exposures	Injuries Per 1,000 Athlete Exposures	95% CI
Overall	8.00	1755.00	4.56	1.40, 7.72
Timing of Participation				
Pre-Season	1.00	192.00	5.21	5.00, 15.42
Competitive Season	4.00	1472.00	2.72	0.05, 5.38
Post-Season	3.00	91.00	32.97	-4.34, 70.27
Type of Participation				
Pratice	6.00	1328.00	4.52	0.90, 8.13
Game	2.00	427.00	4.68	1.81, 11.18
Acute vs. Overuse				
Acute	7.00	1755.00	3.99	1.03, 6.94
Overuse	1.00	1755.00	0.57	0.55, 1.69
Injury Location				
Ankle	5.00	1755.00	2.85	0.35, 5.35
Knee	1.00	1755.00	0.57	-0.55, 1.69
Other	2.00	1755.00	1.14	-0.44, 2.72
Injury Type				
Ankle Sprain	5.00	1755.00	2.85	0.35, 5.35

4.5.2.3 Women's Soccer Lower Extremity Musculoskeletal Injuries

Lower extremity musculoskeletal injuries were prospectively tracked in 24 women's soccer athletes for one collegiate fall soccer season, following each athlete's test session. Ten out of 24 women's soccer athletes prospectively tracked over the course of one collegiate fall soccer season suffered a lower extremity musculoskeletal injury (41.7%). None of the women's soccer athletes prospectively tracked suffered more than one lower extremity musculoskeletal injury; 10 total lower extremity musculoskeletal injuries were suffered over the course of the collegiate fall women's soccer season. Of the 10 total lower extremity musculoskeletal injuries suffered during the collegiate fall women's soccer season, two occurred during the pre-season (20.0%) and 8 occurred during the competitive season (80.0%). Four of the 10 lower extremity musculoskeletal injuries suffered over the course of the collegiate women's soccer fall season occurred during a practice (40.0%), three occurred during a game (30.0%), and three were unknown (30.0%).

Timing of the lower extremity musculoskeletal injury during participation in a practice or game was only able to be identified in five or the 10 lower extremity musculoskeletal injuries. All five of the lower extremity injuries where timing was able to be identified, occurred during the first half of the practice or game (50.0%), the timing of the remaining five lower extremity musculoskeletal injuries was not able to be identified (50.0%).

The lower extremity musculoskeletal injuries suffered by the women's soccer athletes were categorized by location, including, ankle, knee, hip, and other. There were four ankle injuries (40.0%), three knee injuries (30.0%), one hip injury (10.0%) and two injuries categorized as other (20.0%) out of the 10 total lower extremity musculoskeletal injuries suffered during the women's soccer fall collegiate season. When the lower extremity musculoskeletal injuries were categorized by injury type, four of the 10 lower extremity musculoskeletal injuries suffered were ankle sprain (40.0%), two were medial knee pain (20.0%), one injury was patellar tendonitis (10.0%), and one injury was IT band tightness (10.0%), one injury was a hamstring strain (10.0%), and one was Achilles tendonitis (10.0%). There were eight acute injuries (80.0%) and two overuse injury (20.0%), of the 10 total lower extremity musculoskeletal injuries suffered. Lower extremity musculoskeletal injury data is presented in Figure 62, Figure 63, Figure 64, and Figure 65.

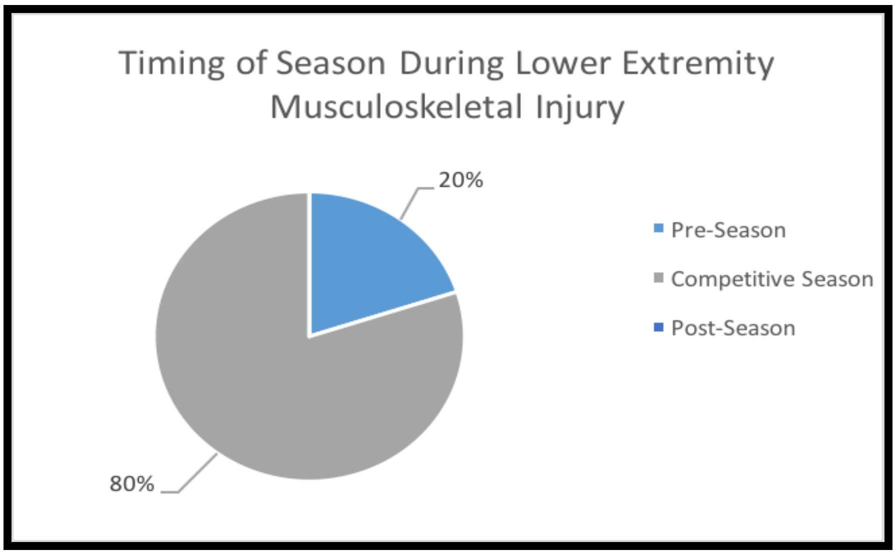

Figure 62. Timing of Season During Lower Extremity Musculoskeletal Injury – Women's Soccer Athletes

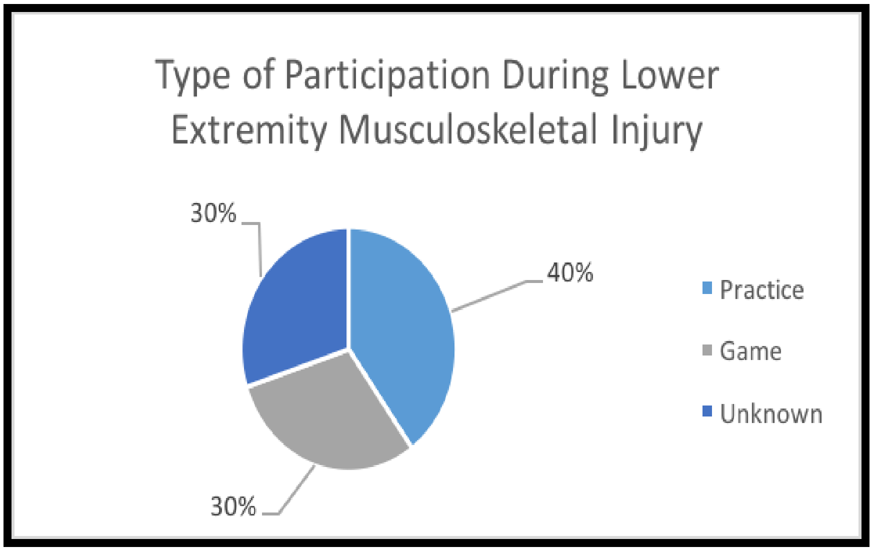

Figure 63. Type of Participation During Lower Extremity Musculoskeletal Injury – Women's Soccer Athletes

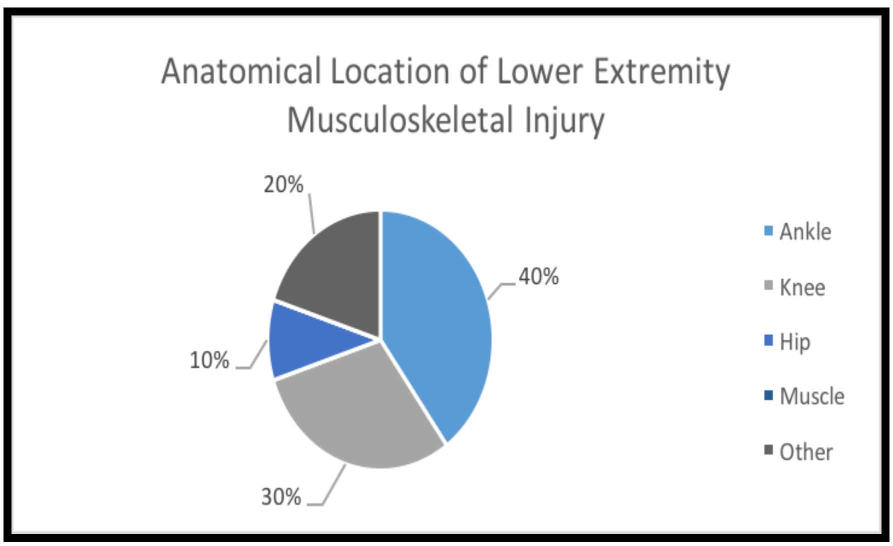

Figure 64. Anatomical Location of Lower Extremity Musculoskeletal Injury – Women's Soccer Athletes

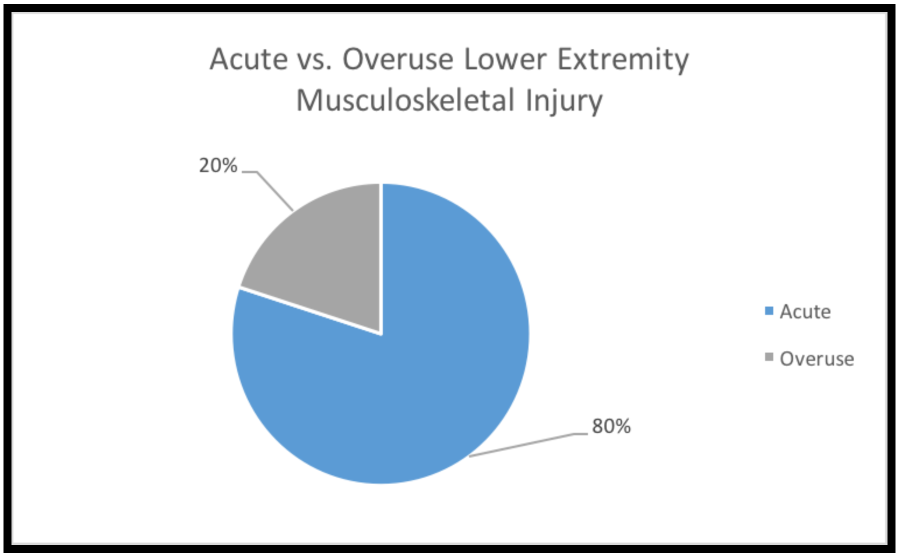

Figure 65. Acute vs. Overuse Lower Extremity Musculoskeletal Injury – Women's Soccer Athletes

The overall lower extremity musculoskeletal injury rate for the women's soccer fall season was 5.90 injuries per 1,000 athlete exposures (95% CI: 2.24, 9.56). The pre-season lower extremity musculoskeletal injury rate was 3.66 injuries per 1,000 athlete exposures (95% CI: -1.41, 8.72). The competitive season lower extremity musculoskeletal injury rate was 6.97 injuries per 1,000 athlete exposures (95% CI: 2.14, 11.81). The lower extremity musculoskeletal injury rate during practice participation was 2.89 injuries per 1,000 athlete exposures (95% CI: 0.06, 5.71); during participation in games the lower extremity musculoskeletal injury rate was 9.74 injuries per 1,000 athlete exposures (95% CI: -1.28, 20.76). The acute lower extremity musculoskeletal injury rate during the women's soccer fall season was 4.72 injuries per 1,000 athlete exposures (95% CI: 1.45, 8.00); the overuse lower extremity musculoskeletal injury rate was 1.18 injuries per 1,000 athlete exposures (95% CI: -0.46, 2.82). The ankle had the highest number of injuries during the women's soccer fall season, 2.36 injuries per 1,000 athlete exposures (95% CI: 0.05, 4.68), followed by knee injuries with an injury rate of 1.77 injuries per 1,000 athlete exposures (95% CI: -0.23, 3.77). The injury rate for hip injuries was 0.59 injuries per 1,000 athlete exposures (95% CI: -0.57, 1.75). The injury rate for other lower extremity musculoskeletal injuries was 1.18 injuries per 1,000 athlete exposures (95% CI: -0.46, 2.82). The overall ankle sprain injury rate during the women's soccer fall season was 2.36 injuries per 1,000 athlete exposures (95% CI: 0.05, 4.68). The medial knee pain injury rate during the women's soccer fall season was 1.18 injuries per 1,000 athlete exposures (95% CI: An injury rate of 0.59 injuries per 1,000 athlete exposures (95% CI: -0.46, 2.82) was noted for the following injuries: IT band tightness, hamstring muscle strain, and Achilles tendonitis. Musculoskeletal injury rates are represented in Table 56.

Table 56. Women's Soccer Athletes Lower Extremity Musculoskeletal Injury Rates

	Number of Injuries	Number of Exposures	Injuries Per 1,000 Athlete Exposures	95% CI
Overall	10.00	1694.00	5.90	2.24, 9.56
Timing of Participation				
Pre-Season	2.00	547.00	3.66	1.41, 8.72
Competitive Season	8.00	1147.00	6.97	2.14, 11.81
Type of Participation				
Pratice	4.00	1386.00	2.89	0.06, 5.71
Game	3.00	308.00	9.74	-1.28, 20.76
Acute vs. Overuse				
Acute	8.00	1694.00	4.72	1.45, 8.00
Overuse	2.00	1694.00	1.18	-0.46, 2.82
Injury Location				
Ankle	4.00	1694.00	2.36	0.05, 4.68
Knee	3.00	1694.00	1.77	-0.23, 3.77
Hip	1.00	1694.00	0.59	-0.57, 1.75
Other	2.00	1694.00	1.18	-0.46, 2.82
Injury Type				
Ankle Sprain	4.00	1694.00	2.36	0.05, 4.68

4.5.3 Football

4.5.3.1 Overall Football Lower Extremity Musculoskeletal Injuries

Lower extremity musculoskeletal injuries were prospectively tracked in 43 football athletes for one collegiate fall football season, following each athlete's test session. Twenty-three out of 43 football athletes prospectively tracked over the course of one collegiate fall football season suffered a lower extremity musculoskeletal injury (53.5%). Eleven of the 43 of the football athletes prospectively tracked suffered more than one lower extremity musculoskeletal injury; 35 total lower extremity musculoskeletal injuries were suffered over the course of the collegiate fall football season. Of the 35 total lower extremity musculoskeletal injuries suffered during the collegiate fall football season, 14 occurred during the pre-season (40.0%), 20 occurred during the competitive season (57.1%), and one occurred during the post-season (0.03%). Thirty-five of the 35 lower extremity musculoskeletal injuries suffered over the course of the collegiate football fall season occurred during a practice (100.0%), zero occurred during games. There were 12 ankle injuries (34.3%), six knee injuries (17.1%), two hip injuries (0.06%), and 15 injuries categorized injury to the lower extremity muscles (42.9%) out of the 35 total lower extremity musculoskeletal injuries suffered during the football fall collegiate season. There were 33 acute injuries (94.3%) and 2 overuse injuries (0.06%), of the 35 total lower extremity musculoskeletal injuries suffered. Lower extremity musculoskeletal injury data is presented in Figure 66, Figure 67, Figure 68, and Figure 69.

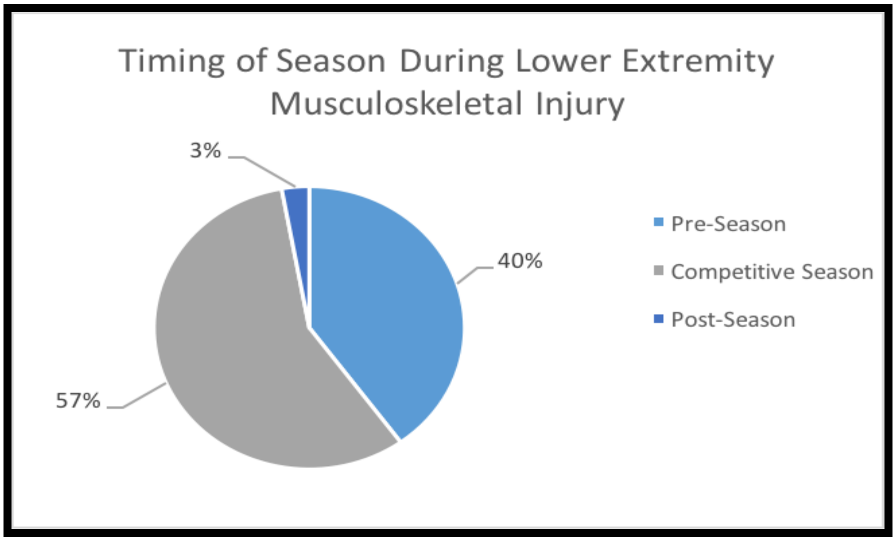

Figure 66. Timing of Season During Lower Extremity Musculoskeletal Injury – Football Athletes

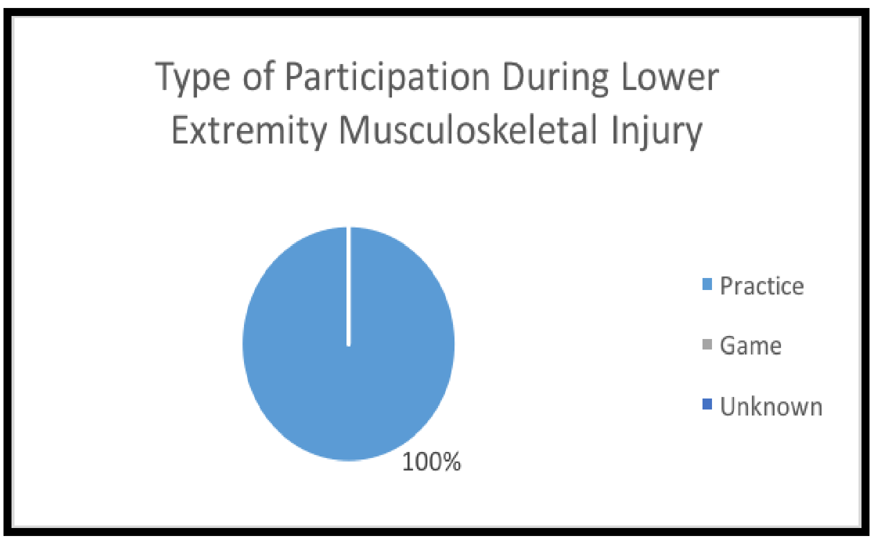

Figure 67. Type of Participation During Lower Extremity Musculoskeletal Injury – Football Athletes

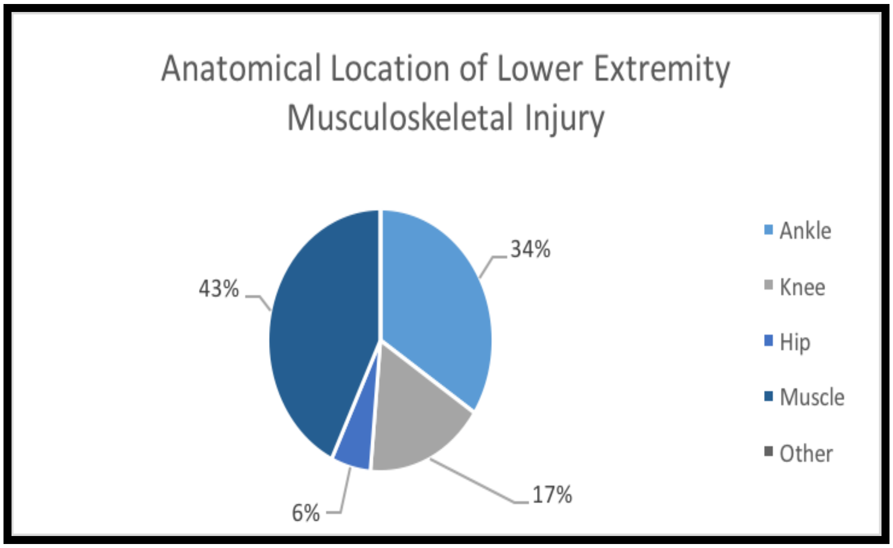

Figure 68. Anatomical Location of Lower Extremity Musculoskeletal Injury – Football Athletes

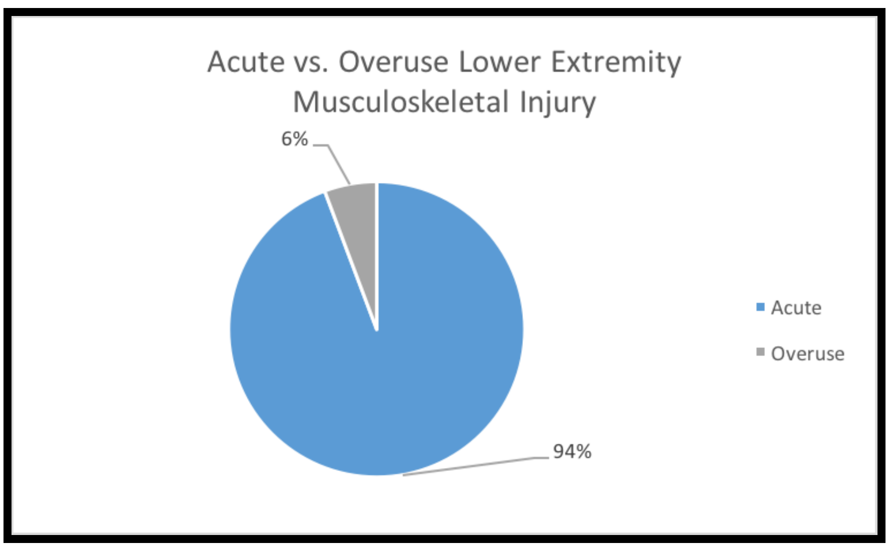

Figure 69. Acute vs. Overuse Lower Extremity Musculoskeletal Injury – Football Athletes

The overall lower extremity musculoskeletal injury rate for the football fall season was 10.19 injuries per 1,000 athlete exposures (95% CI: 6.81, 13.56). The pre-season lower extremity musculoskeletal injury rate was 4.70 injuries per 1,000 athlete exposures (95% CI: 2.24, 7.16).

The competitive season lower extremity musculoskeletal injury rate was 9.70 injuries per 1,000 athlete exposures (95% CI: 5.45, 13.96). The post-season lower extremity musculoskeletal injury rate was 2.44 injuries per 1,000 athlete exposures (95% CI: -2.34, 7.22). The lower extremity musculoskeletal injury rate during practice participation was 11.75 injuries per 1,000 athlete exposures (95% CI: 7.86, 15.64); during participation in games no lower extremity musculoskeletal injuries were suffered. The acute lower extremity musculoskeletal injury rate during the football fall season was 9.61 injuries per 1,000 athlete exposures (95% CI: 6.33, 12.88); the overuse lower extremity musculoskeletal injury rate was 0.58 injuries per 1,000 athlete exposures (95% CI: -0.22, 1.39). The overall injury rate for the muscles of the lower extremity during the football fall season was 4.37 injuries per 1,000 athlete exposures (95% CI: 2.16, 6.58). The ankle had the second highest number of injuries during the football fall season, 3.49 injuries per 1,000 athlete exposures (95% CI: 1.52, 5.47), followed by knee with an injury rate of 1.75 injuries per 1,000 athlete exposures (95% CI: 0.35, 3.14). The injury rate for lower extremity musculoskeletal injuries categorized at the hip was 0.58 injuries per 1,000 athlete exposures (95% CI: -0.22, 1.39). Musculoskeletal injury rates are represented in Table 57.

Table 57. Football Athletes Lower Extremity Musculoskeletal Injury Rates

	Number of Injuries	Number of Exposures	Injuries Per 1,000 Athlete Exposures	95% CI
Overall	35.00	3435.00	10.19	6.81, 13.56
Timing of Participation				
Pre-Season	14.00	964.00	4.7	2.24, 7.16
Competitive Season	20.00	2061.00	9.7	5.45, 13.96
Post-Season	1.00	410.00	2.44	-2.34, 7.22
Type of Participation				
Pratice	35.00	2979.00	11.75	7.86, 15.64
Acute vs. Overuse				
Acute	33.00	3435.00	9.61	6.33, 12.88
Overuse	2.00	3435.00	0.58	-0.22, 1.39
Injury Location				
Ankle	12.00	3435.00	3.49	1.52, 5.47
Knee	6.00	3435.00	1.75	0.35, 3.14
Hip	2.00	3435.00	0.58	-0.22, 1.39
Muscle	15.00	3435.00	4.37	2.16, 6.58

4.5.4 Volleyball

4.5.4.1 Overall Volleyball Lower Extremity Musculoskeletal Injuries

Lower extremity musculoskeletal injuries were prospectively tracked in 16 women's volleyball athletes for one collegiate fall women's volleyball season, following each athlete's test session. Four out of 16 women's volleyball athletes prospectively tracked over the course of one collegiate fall women's volleyball season suffered a lower extremity musculoskeletal injury (25.0%). One of the one of the women's volleyball athletes prospectively tracked suffered more than one lower extremity musculoskeletal injury; five total lower extremity musculoskeletal injuries were suffered over the course of the collegiate fall women's volleyball season. Of the 5 total lower extremity musculoskeletal injuries suffered during the collegiate fall women's volleyball season, none occurred during the pre-season (0.0%), five occurred during the competitive season (100.0%), and none occurred during the post-season (0.0%). Four of the five lower extremity musculoskeletal injuries suffered over the course of the collegiate women's volleyball fall season occurred during practice participation (80.0%) and one occurred during game participation (20.0%). There was one ankle injuries (20.0%), two hip injuries (40.0%), one injury categorized as an injury to the lower extremity muscles (20.0%), and one injury categorized as other (20.0%) out of the five total lower extremity musculoskeletal injuries suffered during the women's volleyball fall collegiate season. There were four acute injuries (80.0%) and one overuse injuries (20.0%), of the five total lower extremity musculoskeletal injuries suffered. Lower extremity musculoskeletal injury data is presented in Figure 70, Figure 71, Figure 72, and Figure 73.

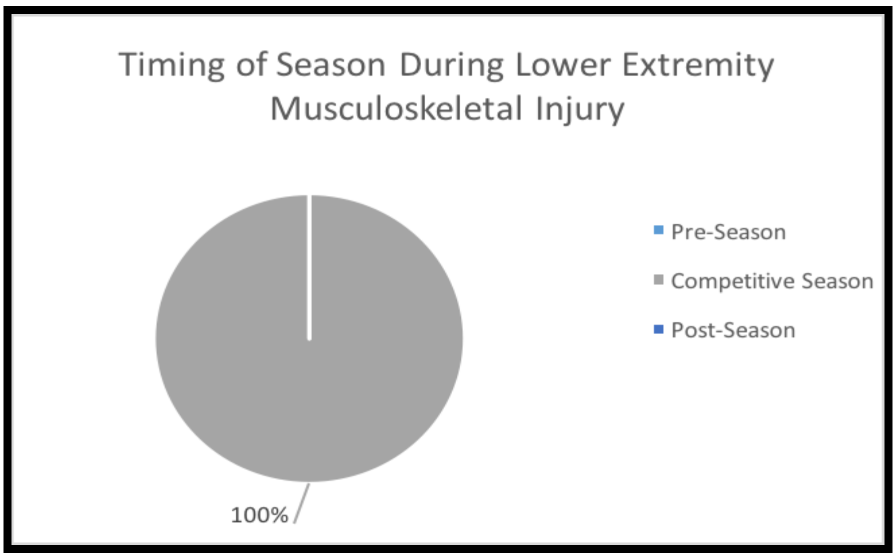

Figure 70. Timing of Season During Lower Extremity Musculoskeletal Injury – Women's Volleyball Athletes

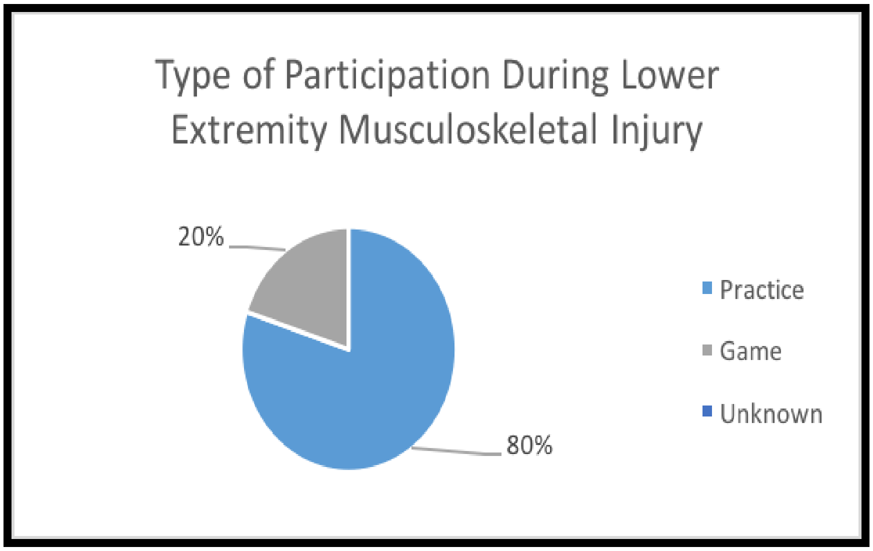

Figure 71. Type of Participation During Lower Extremity Musculoskeletal Injury – Women's Volleyball Athletes

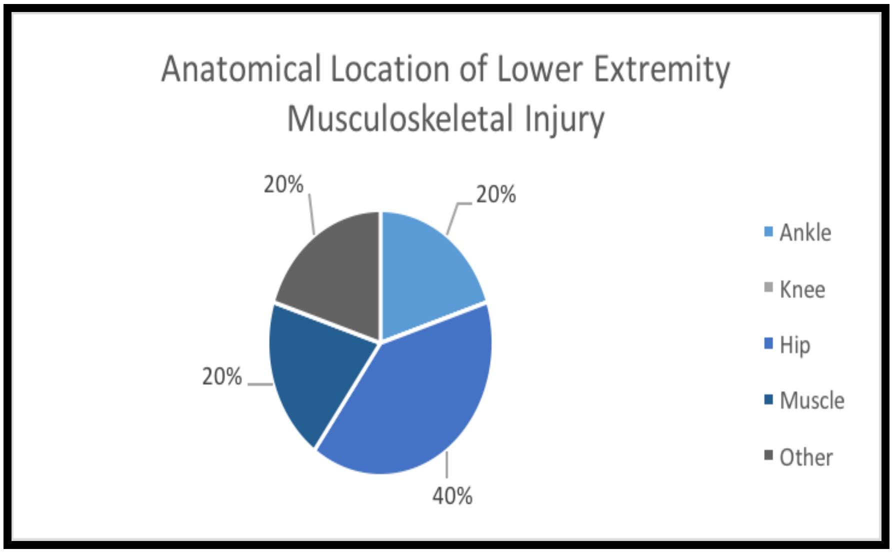

Figure 72. Anatomical Location of Lower Extremity Musculoskeletal Injury – Women's Volleyball Athletes

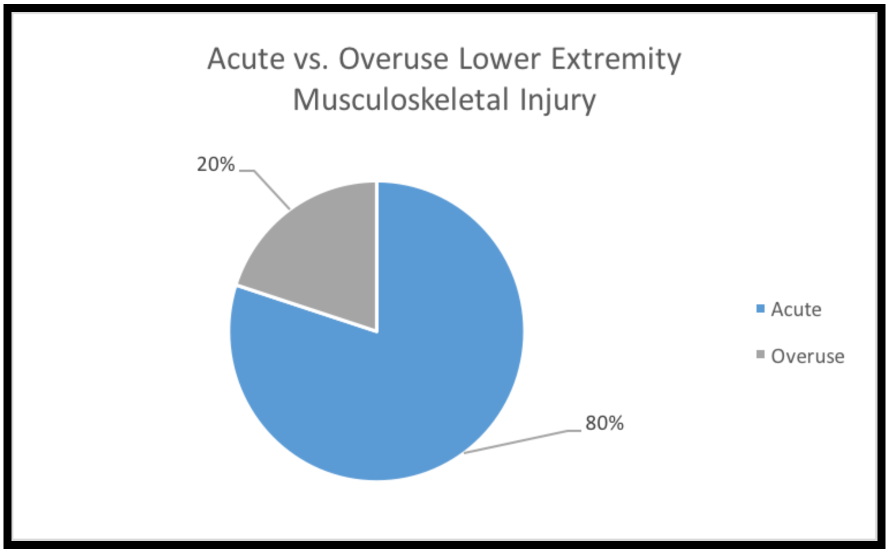

Figure 73. Acute vs. Overuse Lower Extremity Musculoskeletal Injury – Women's Volleyball Athletes

The overall lower extremity musculoskeletal injury rate for the women's volleyball fall season was 2.87 injuries per 1,000 athlete exposures (95% CI: 0.35, 5.38). The competitive season lower extremity musculoskeletal injury rate was 3.89 injuries per 1,000 athlete exposures (95% CI: 0.48, 7.30). The lower extremity musculoskeletal injury rate during practice participation was 3.28 injuries per 1,000 athlete exposures (95% CI: 0.07, 6.49); during participation in games the lower extremity musculoskeletal injury rate was 1.91 injuries per 1,000 athlete exposures (95% CI: -1.83, 5.65). The acute lower extremity musculoskeletal injury rate during the women's volleyball fall season was 2.29 injuries per 1,000 athlete exposures (95% CI: 0.05, 4.54); the overuse lower extremity musculoskeletal injury rate was 0.57 injuries per 1,000 athlete exposures (95% CI: -0.55, 1.70). The overall injury rate for the hip during the women's volleyball fall season was 1.15 injuries per 1,000 athlete exposures (95% CI: -0.44, 2.73). The ankle had the second highest number of injuries during the football fall season, 0.57 injuries per 1,000 athlete exposures (95% CI: -0.55, 1.70), tied with the muscles of the lower extremity and lower extremity musculoskeletal injuries categorized as other, with an injury rate of 0.57 injuries per 1,000 athlete exposures (95% CI: -0.55, 1.70). Musculoskeletal injury rates are represented in Table 58.

Table 58. Women's Volleyball Athletes Lower Extremity Musculoskeletal Injury Rates

	Number of Injuries	Number of Exposures	Injuries Per 1,000 Athlete Exposures	95% CI
Overall	5.00	1745.00	2.87	0.35, 5.38
Timing of Participation				
Competitive Season	5.00	1286.00	3.89	0.48, 7.30
Type of Participation				
Pratice	4.00	1121.00	3.28	0.07, 6.49
Game	1.00	524.00	1.91	-1.83, 5.65
Acute vs. Overuse				
Acute	4.00	1745.00	2.29	0.05, 4.54
Overuse	1.00	1745.00	0.57	-0.55, 1.70
Injury Location				
Ankle	1.00	1745.00	0.57	-0.55, 1.70
Hip	2.00	1745.00	1.15	-0.44, 2.73
Muscle	1.00	1745.00	0.57	-0.55, 1.70
Other	1.00	1745.00	0.57	-0.55, 1.70

4.5.5 Basketball

4.5.5.1 Overall Basketball Lower Extremity Musculoskeletal Injuries

Lower extremity musculoskeletal injuries were prospectively tracked in 24 (Men's: 11, Women's: 13) basketball athletes for one collegiate winter basketball season, following each athlete's test session. Eleven out of 24 men's and women's basketball athletes prospectively tracked over the course of one collegiate winter basketball season suffered a lower extremity musculoskeletal injury (45.8%). None of the men's and women's basketball athletes prospectively tracked suffered more than one lower extremity musculoskeletal injury; eleven total lower extremity musculoskeletal injuries were suffered over the course of the collegiate winter men's and women's basketball season. Of the 11 total lower extremity musculoskeletal injuries suffered during the collegiate fall men's and women's basketball season, seven occurred during the pre-season (63.6%), four occurred during the competitive season (36.4%), and none occurred during the post-season (0.0%). Ten of the 11 lower extremity musculoskeletal injuries suffered over the course of the collegiate men's and women's basketball winter season occurred during a practice (90.9%) and one occurred during a game (0.09%). There was one ankle injury (0.09%), three knee injuries (27.3%), one muscle injury (0.09%), and 6 injuries categorized as other (54.5%) out of the 11 total lower extremity musculoskeletal injuries suffered during the men's and women's basketball winter collegiate season. There were six acute injuries (54.5%) and five overuse injuries (45.5%), of the 11 total lower extremity musculoskeletal injuries suffered. Lower extremity musculoskeletal injury data is presented in Figure 74, Figure 75, Figure 76, and Figure 77.

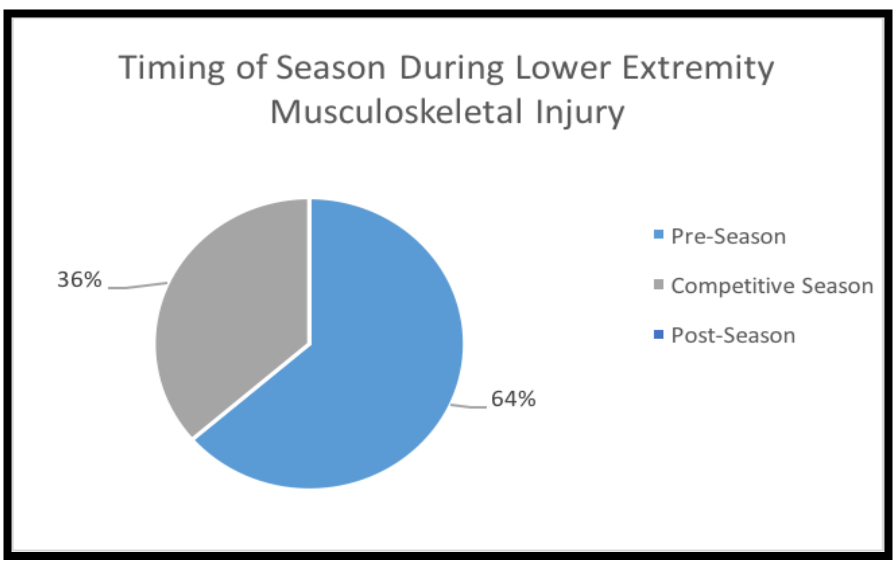

Figure 74. Timing of Season During Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Basketball Athletes

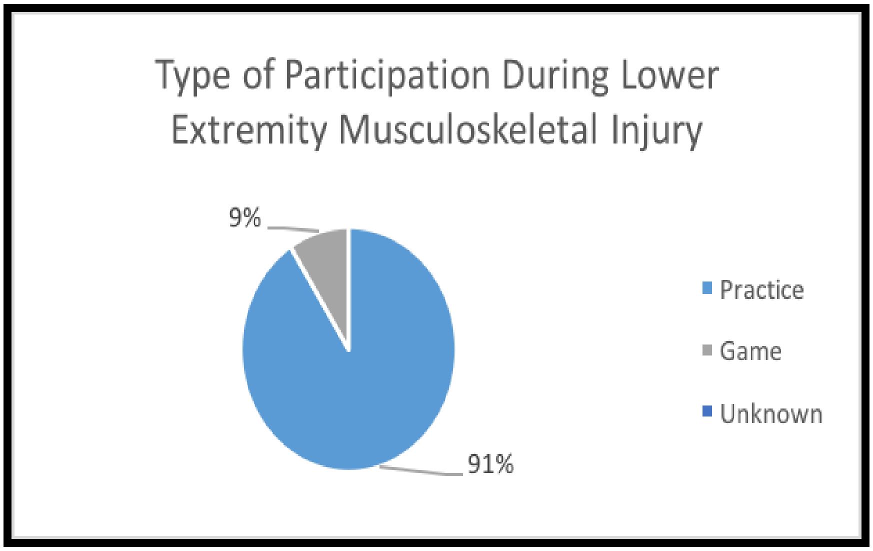

Figure 75. Type of Participation During Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Basketball Athletes

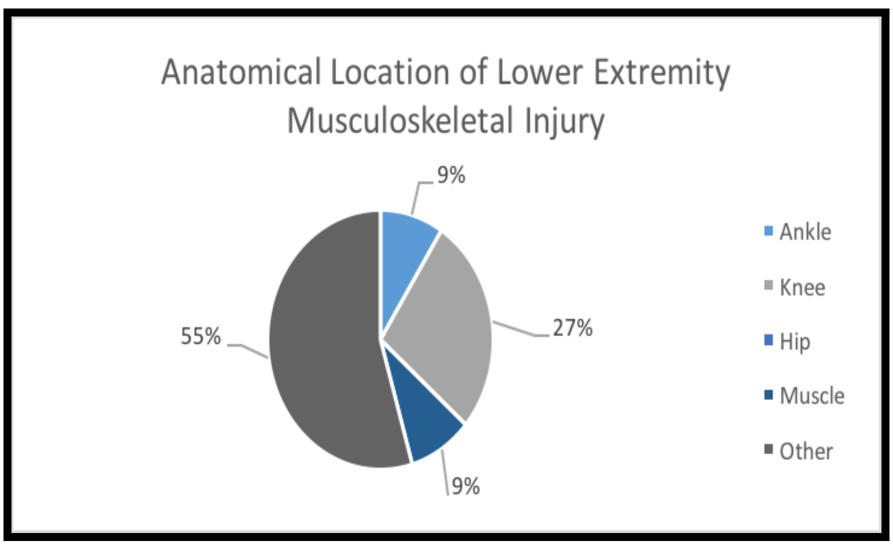

Figure 76. Anatomical Location of Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Basketball Athletes

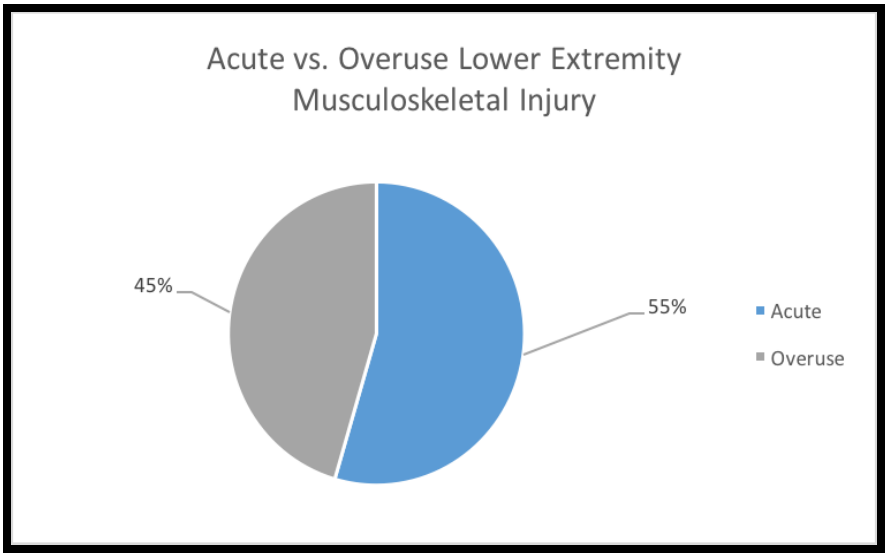

Figure 77. Acute vs. Overuse Lower Extremity Musculoskeletal Injury – Overall Men's and Women's Basketball Athletes

The overall lower extremity musculoskeletal injury rate for the men's and women's basketball fall season was 4.19 injuries per 1,000 athlete exposures (95% CI: 1.72, 6.67). The pre-season lower extremity musculoskeletal injury rate was 8.23 injuries per 1,000 athlete exposures (95% CI: 2.13, 14.32). The competitive season lower extremity musculoskeletal injury rate was 2.35 injuries per 1,000 athlete exposures (95% CI: 0.05, 4.65). The lower extremity musculoskeletal injury rate during practice participation was 4.89 injuries per 1,000 athlete exposures (95% CI: 1.86, 7.92); during participation in games the lower extremity musculoskeletal injury rate was 1.73 injuries per 1,000 athlete exposures (95% CI: -1.66, 5.12). The acute lower extremity musculoskeletal injury rate during the men's and women's basketball winter season was 2.29 injuries per 1,000 athlete exposures (95% CI: 0.46, 4.12); the overuse lower extremity musculoskeletal injury rate was 1.91 injuries per 1,000 athlete exposures (95% CI: 0.24, 3.58). The ankle had the lowest number of injuries during the men's and women's basketball winter season, 0.38 injuries per 1,000 athlete exposures (95% CI: -0.37, 1.13), followed by knee with an injury rate of 1.14 injuries per 1,000 athlete exposures (95% CI: -0.15, 2.44). The injury rate for lower extremity musculoskeletal injuries categorized as other was 2.29 injuries per 1,000 athlete exposures (95% CI: 0.46, 4.12). The overall muscle of the lower extremity injury rate during the men's and women's basketball winter season was 0.38 injuries per 1,000 athlete exposures (95% CI: -0.37, 1.13). Musculoskeletal injury rates are represented in Table 59.

Table 59. Men's and Women's Basketball Athletes Lower Extremity Musculoskeletal Injury Rates

	Number of Injuries	Number of Exposures	Injuries Per 1,000 Athlete Exposures	95% CI
Overall	11.00	2623.00	4.19	1.72, 6.67
Timing of Participation				
Pre-Season	7.00	851.00	8.23	2.13, 14.32
Competitive Season	4.00	1703.00	2.35	0.05, 4.65
Type of Participation				
Pratice	10.00	2045.00	4.89	1.86, 7.92
Game	1.00	578.00	1.73	-1.66, 5.12
Acute vs. Overuse				
Acute	6.00	2623.00	2.29	0.46, 4.12
Overuse	5.00	2623.00	1.19	0.24, 3.58
Injury Location				
Ankle	1.00	2623.00	0.38	-0.37, 1.13
Knee	3.00	2623.00	1.14	-0.15, 2.44
Muscle	1.00	2623.00	0.38	-0.37, 1.13
Other	6.00	2623.00	2.29	0.46, 4.12

4.5.5.2 Men's Basketball Lower Extremity Musculoskeletal Injuries

Lower extremity musculoskeletal injuries were prospectively tracked in 11 men's basketball athletes for one collegiate winter basketball season, following each athlete's test session. Five out of 11 men's basketball athletes prospectively tracked over the course of one collegiate winter basketball season suffered a lower extremity musculoskeletal injury (41.7%). None of the men's basketball athletes prospectively tracked suffered more than one lower extremity musculoskeletal injury; five total lower extremity musculoskeletal injuries were suffered over the course of the collegiate winter men's basketball season. Of the five total lower extremity musculoskeletal injuries suffered during the collegiate winter men's basketball season, one occurred during the pre-season (20.0%), four occurred during the competitive season (80.0%), and none occurred during the post-season (0.0%). Four of the five lower extremity musculoskeletal injuries suffered over the course of the collegiate men's basketball winter season occurred during a practice (80.0%) and one occurred during a game (20.0%).

The lower extremity musculoskeletal injuries suffered by the men's basketball athletes were categorized by location, including, ankle, knee, hip, and other. There was one ankle injury (20.0%), one knee injury (20.0%), and three injuries categorized as other (60.0%) out of the five total lower extremity musculoskeletal injuries suffered during the men's basketball winter collegiate season. No hip injuries were reported. When the lower extremity musculoskeletal injuries were categorized by injury type, one of the five lower extremity musculoskeletal injuries suffered were ankle sprain (20.0%), one was an anterior cruciate ligament tear of the knee (20.0%), two injuries were stress fractures of the foot (40.0%), and one injury was a midfoot sprain injury (20.0%). There were three acute injuries (60.0%) and two overuse injury (40.0%), of the five total lower extremity musculoskeletal injuries suffered. Lower extremity musculoskeletal injury data is presented in Figure 78, Figure 79, Figure 80, and Figure 81.

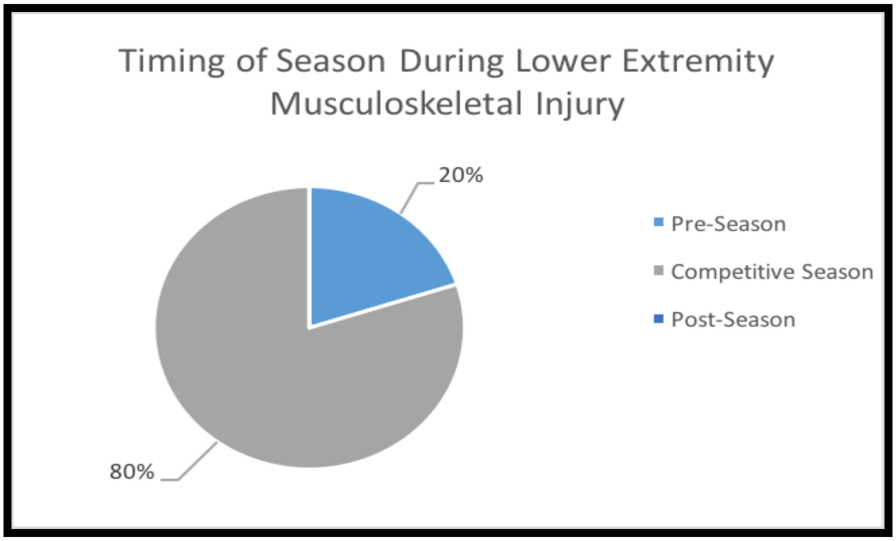

Figure 78. Timing of Season During Lower Extremity Musculoskeletal Injury – Men's Basketball Athletes

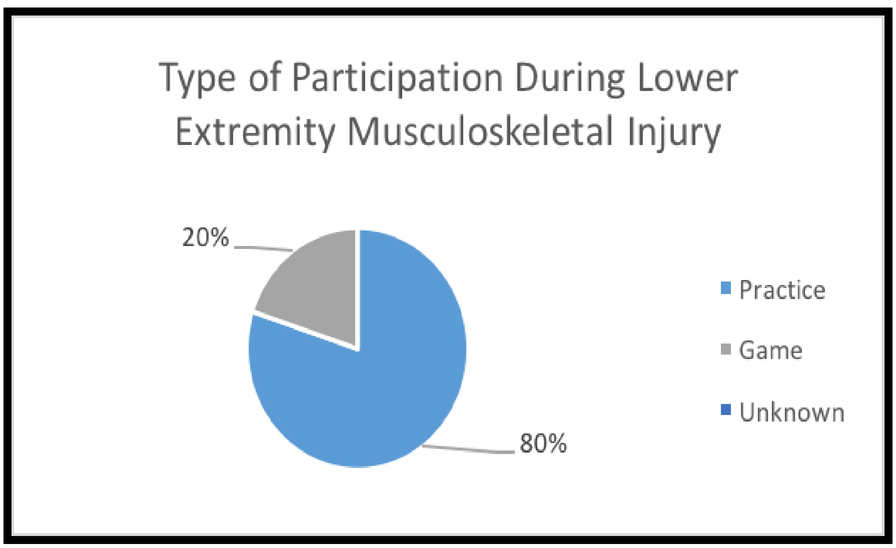

Figure 79. Type of Participation During Lower Extremity Musculoskeletal Injury – Men's Basketball Athletes

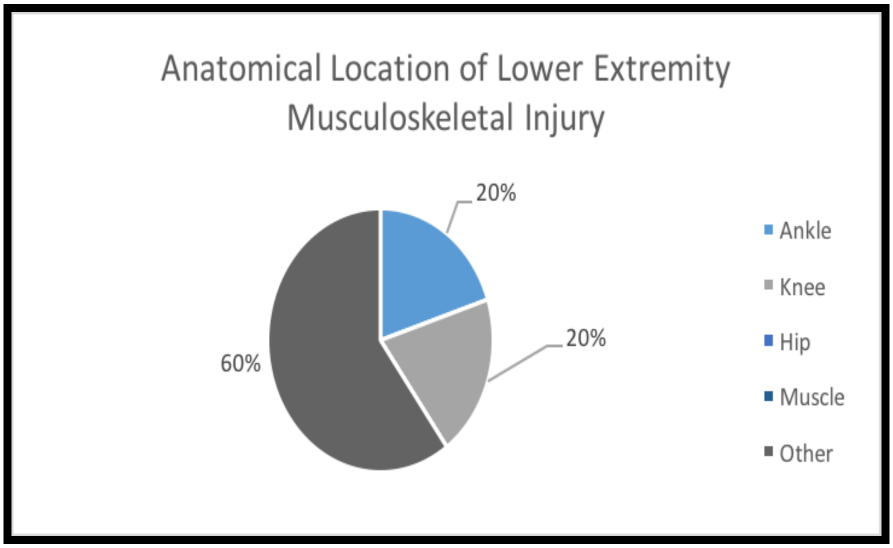

Figure 80. Anatomical Location of Lower Extremity Musculoskeletal Injury – Men's Basketball Athletes

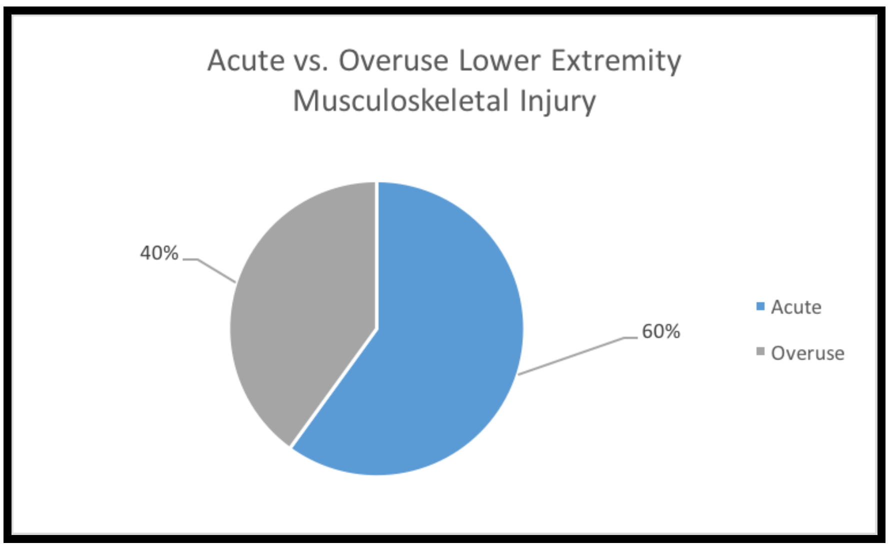

Figure 81. Acute vs. Overuse Lower Extremity Musculoskeletal Injury – Men's Basketball Athletes

The overall lower extremity musculoskeletal injury rate for the men's basketball winter season was 3.92 injuries per 1,000 athlete exposures (95% CI: 0.48, 7.36). The pre-season lower extremity musculoskeletal injury rate was 2.46 injuries per 1,000 athlete exposures (95% CI: -2.36, 7.27). The competitive season lower extremity musculoskeletal injury rate was 4.82

injuries per 1,000 athlete exposures (95% CI: 0.10, 9.54). The lower extremity musculoskeletal injury rate during practice participation was 4.09 injuries per 1,000 athlete exposures (95% CI: 0.08, 8.11); during participation in games the lower extremity musculoskeletal injury rate was 3.37 injuries per 1,000 athlete exposures (95% CI: -3.23, 9.97). The acute lower extremity musculoskeletal injury rate during the men's basketball winter season was 2.35 injuries per 1,000 athlete exposures (95% CI: -0.31, 5.02); the overuse lower extremity musculoskeletal injury rate was 1.57 injuries per 1,000 athlete exposures (95% CI: -0.61, 3.75). The ankle had the lowest number of injuries during the men's basketball winter season, 0.78 injuries per 1,000 athlete exposures (95% CI: -0.75, 2.32). The injury rate for other lower extremity musculoskeletal injuries was 2.35 injuries per 1,000 athlete exposures (95% CI: -0.31, 5.02). The injury rate for knee injuries was 0.78 injuries per 1,000 athlete exposures (95% CI: -0.75, 2.32). Musculoskeletal injury rates are represented in Table 60.

Table 60. Men's Basketball Athletes Lower Extremity Musculoskeletal Injury Rates

	Number of Injuries	Number of Exposures	Injuries Per 1,000 Athlete Exposures	95% CI
Overall	5.00	1274.00	3.92	0.48, 7.36
Timing of Participation				
Pre-Season	1.00	407.00	2.46	2.36, 7.27
Competitive Season	4.00	830.00	4.82	0.10, 9.54
Type of Participation				
Pratice	4.00	977.00	4.09	0.08, 8.11
Game	1.00	297.00	3.37	-3.23, 9.97
Acute vs. Overuse				
Acute	3.00	1274.00	2.35	-0.31, 5.02
Overuse	2.00	1274.00	1.57	-0.61, 3.75
Injury Location				
Ankle	1.00	1274.00	0.78	-0.75, 2.32
Knee	1.00	1274.00	0.78	-0.75, 2.32
Other	3.00	1274.00	2.35	-0.31, 5.02

4.5.5.3 Women's Basketball Lower Extremity Musculoskeletal Injuries

Lower extremity musculoskeletal injuries were prospectively tracked in 13 women's basketball athletes for one collegiate winter basketball season, following each athlete's test session. Six out of 13 women's basketball athletes prospectively tracked over the course of one collegiate winter basketball season suffered a lower extremity musculoskeletal injury (46.2%). None of the women's basketball athletes prospectively tracked suffered more than one lower extremity musculoskeletal injury; six total lower extremity musculoskeletal injuries were suffered over the course of the collegiate winter women's basketball season. Of the six total lower extremity musculoskeletal injuries suffered during the collegiate winter women's basketball season, six occurred during the pre-season (100.0%), none occurred during the competitive season (0.0%), and none occurred during the post-season (0.0%). Six of the six lower extremity musculoskeletal injuries suffered over the course of the collegiate women's basketball winter season occurred during a practice (100.0%) and none occurred during a game (0.0%).

The lower extremity musculoskeletal injuries suffered by the women's basketball athletes were categorized by location, including, ankle, knee, hip, and other. There were two knee injuries (33.3%), one muscle injury (16.7%), and three injuries categorized as other (50.0%) out of the six total lower extremity musculoskeletal injuries suffered during the women's basketball winter collegiate season. No ankle or hip injuries were reported. When the lower extremity musculoskeletal injuries were categorized by injury type, two of the six lower extremity musculoskeletal injuries suffered were midfoot sprains (33.3%), two were patellar tendonitis of the knee (33.3%), one injury was an adductor muscle strain (16.7%), and one injury was iliotibial band friction syndrome (16.7%). There were three acute injuries (50.0%) and three overuse injury (50.0%), of the six total lower extremity musculoskeletal injuries suffered. Lower extremity musculoskeletal injury data is presented in Figure 82, Figure 83, Figure 84, and Figure 85.

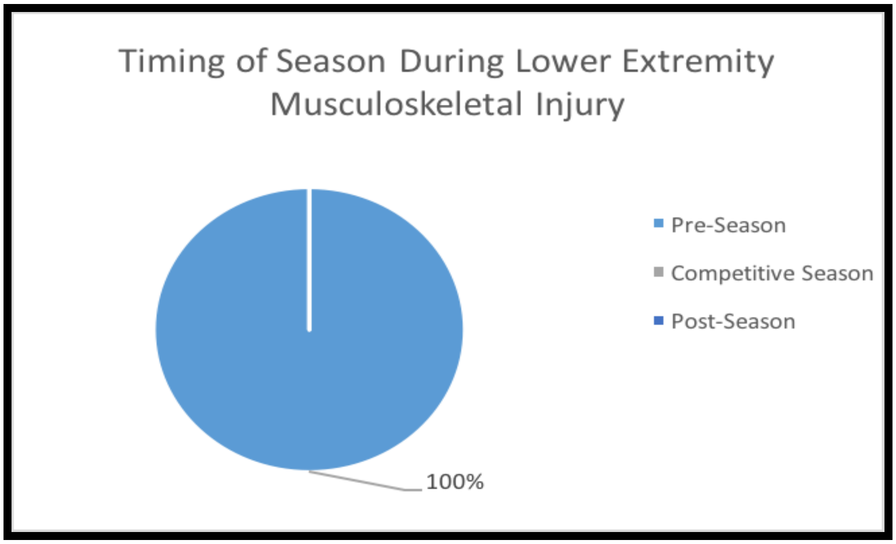

Figure 82. Timing of Season During Lower Extremity Musculoskeletal Injury – Women's Basketball Athletes

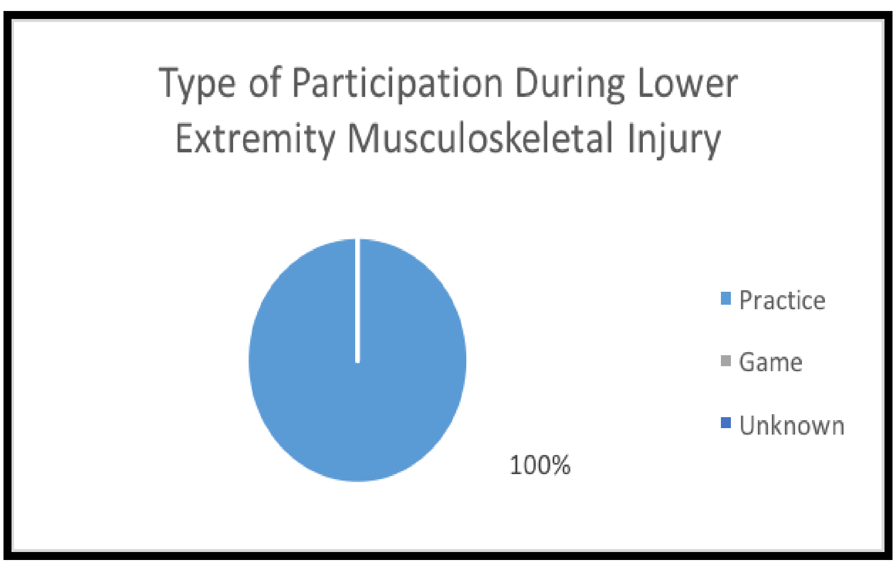

Figure 83. Type of Participation During Lower Extremity Musculoskeletal Injury – Women's Basketball Athletes

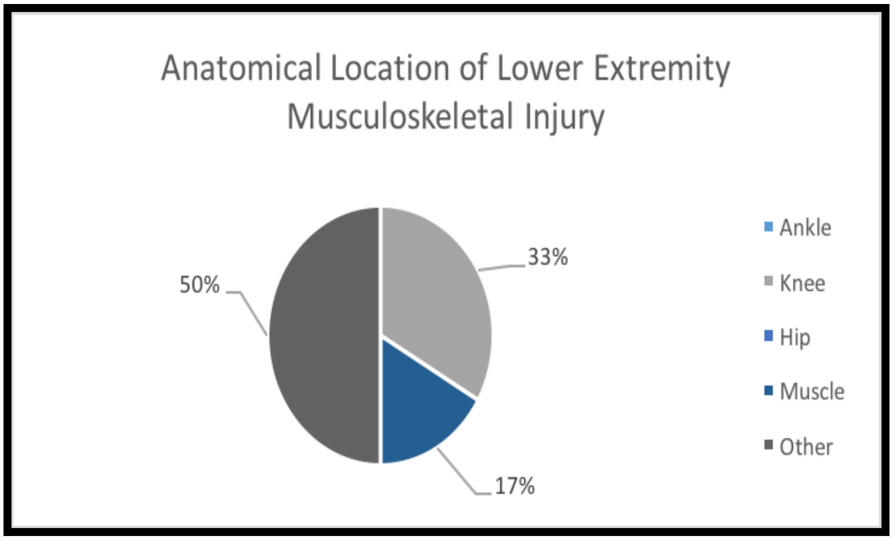

Figure 84. Anatomical Location of Lower Extremity Musculoskeletal Injury – Women's Basketball Athletes

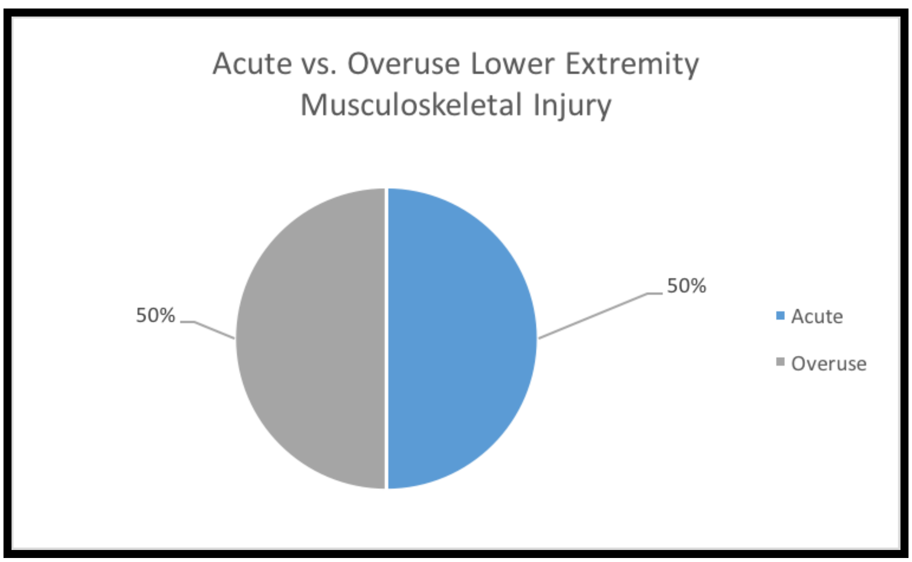

Figure 85. Acute vs. Overuse Lower Extremity Musculoskeletal Injury – Women's Basketball Athletes

The overall lower extremity musculoskeletal injury rate for the women's basketball winter season was 4.45 injuries per 1,000 athlete exposures (95% CI: 0.89, 8.01). The pre-season lower extremity musculoskeletal injury rate was 13.51 injuries per 1,000 athlete exposures (95% CI: 2.70, 24.33). The lower extremity musculoskeletal injury rate during practice participation was 5.62 injuries per 1,000 athlete exposures (95% CI: 1.12, 10.11). The acute lower extremity musculoskeletal injury rate during the women's basketball winter season was 2.22 injuries per 1,000 athlete exposures (95% CI: -0.29, 4.47); the overuse lower extremity musculoskeletal injury rate was 2.22 injuries per 1,000 athlete exposures (95% CI: -0.29, 4.47). The other lower extremity musculoskeletal injuries had the highest number of injuries during the women's basketball winter season, 2.22 injuries per 1,000 athlete exposures (95% CI: -0.29, 4.47), followed by knee lower extremity musculoskeletal injuries with an injury rate of 1.48 injuries per 1,000 athlete exposures (95% CI: -0.57, 3.54). The injury rate for lower extremity muscle injuries was 0.74 injuries per 1,000 athlete exposures (95% CI: -0.71, 2.19). Musculoskeletal injury rates are represented in Table 61.

Table 61. Women's Basketball Athletes Lower Extremity Musculoskeletal Injury Rates

	Number of Injuries	Number of Exposures	Injuries Per 1,000 Athlete Exposures	95% CI
Overall	6.00	1349.00	4.45	0.89, 8.01
Timing of Participation				
Pre-Season	6.00	444.00	13.51	2.70, 24.33
Type of Participation				
Pratice	6.00	1068.00	5.62	1.12, 10.11
Acute vs. Overuse				
Acute	3.00	1349.00	2.22	-0.29, 4.47
Overuse	3.00	1349.00	2.22	-0.29, 4.47
Injury Location				
Muscle	1.00	1349.00	0.74	-0.71, 2.19
Knee	2.00	1349.00	1.48	-0.57, 3.54
Other	3.00	1349.00	2.22	-0.29, 4.47

4.6 LOWER EXTREMITY MUSCULOSKELETAL INJURY RATE RATIOS

4.6.1 Sex

4.6.1.1 Men's and Women's Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the men's and women's athlete's collegiate seasons; the referent category was men's lower extremity dominant athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 1.69 (95% CI: 1.01, 2.83). The preseason lower extremity musculoskeletal injury incidence rate ratio for the men's and women's athlete's collegiate seasons was 1.78 (95% CI: 0.76, 4.16), while the competitive season lower extremity musculoskeletal injury incidence rate ratio was 1.63 (95% CI: 0.85, 3.15). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the men's and women's athlete's collegiate seasons was 2.24 (95% CI: 1.23, 4.07). The lower extremity musculoskeletal injury incidence rate ratio during participation in games for the men's and women's athlete's collegiate seasons was 0.71 (95% CI: 0.16, 3.16). The acute lower extremity musculoskeletal injury incidence rate ratio for the men's and women's athlete's collegiate seasons was 2.12 (95% CI: 1.18, 3.82), while the overuse injury incidence rate ratio was 0.62 (95% CI: 0.19, 2.02). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 2.67 (95% CI: 0.99, 7.18). The injury incidence rate ratio for musculoskeletal injuries at the knee was 1.19 (95% CI: 0.39, 3.62). The injury incidence rate ratio for musculoskeletal injuries at the hip was 0.49 (95% CI: 0.08, 3.00). The injury incidence rate ratio for musculoskeletal injuries of the lower extremity muscles was 5.56 (95% CI: 1.27, 24.29). The injury incidence rate ratio for musculoskeletal injuries categorized as other was 0.62 (95% CI: 0.19, 2.02). Lower extremity injury rate ratios are represented in Table 62.

Table 62. Overall Men's and Women's Lower Extremity Dominant Sport Athletes Injury Rate Ratios

	Injury Incidence Rate - Men's	Injury Incidence Rate - Women's	Injury Incidence Rate Ratio	95% CI
Overall	7.43	4.39	1.69	1.01, 2.83
Timing of Participation				
Pre-Season	10.24	5.75	1.78	0.76, 4.16
Competitive Season	6.42	3.93	1.63	0.85, 3.15
Type of Participation				
Pratice	8.52	3.81	2.24	1.23, 4.07
Game	2.54	3.59	0.71	0.16, 3.16
Acute vs. Overuse				
Acute	6.65	3.13	2.12	1.18, 3.82
Overuse	0.77	1.25	0.62	0.19, 2.02
Injury Location				
Ankle	2.78	1.04	2.67	0.99, 7.18
Knee	1.24	1.04	1.19	0.39, 3.62
Hip	0.31	0.63	0.49	0.08, 3.00
Muscle	2.32	0.42	5.56	1.27, 24.29
Other	0.77	1.25	0.62	0.19, 2.02

4.6.2 Lower Extremity Dominant Sport Type

4.6.2.1 Soccer and Football Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the soccer and football collegiate fall seasons; the referent category was overall men's and women's soccer athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 0.51 (95% CI: 0.29, 0.90). The preseason lower extremity musculoskeletal injury incidence rate ratio for the soccer and football collegiate seasons was 0.86 (95% CI: 0.25, 3.01), while the competitive season lower extremity musculoskeletal injury incidence rate ratio was 0.47 (95% CI: 0.23, 0.97). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the soccer and football collegiate fall seasons was 0.31 (95% CI: 0.16, 0.63). The acute lower extremity musculoskeletal injury incidence rate ratio for the soccer and football collegiate fall seasons was 0.45 (95% CI: 0.25, 0.83), while the overuse injury incidence rate ratio was 1.50 (95% CI: 0.25, 8.98). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 0.75 (95% CI: 0.32, 1.77), followed by the injury incidence rate ratio for musculoskeletal injuries at the knee which was 0.66 (95% CI: 0.19, 2.35). Lower extremity injury rate ratios are represented in Table 63.

Table 63. Overall Men's and Women's Soccer and Football Athletes Injury Rate Ratios

	Injury Incidence Rate - Soccer	Injury Incidence Rate - Football	Injury Incidence Rate Ratio	95% CI
Overall	5.22	10.19	0.51	0.29, 0.90
Timing of Participation				
Pre-Season	4.06	4.70	0.86	0.25, 3.01
Competitive Season	4.58	9.70	0.47	0.23, 0.97
Type of Participation				
Pratice	3.68	11.75	0.31	0.16, 0.63
Acute vs. Overuse				
Acute	4.35	9.61	0.45	0.25, 0.83
Overuse	0.87	0.58	1.5	0.25, 0.83
Injury Location				
Ankle	2.61	3.49	0.75	0.32, 1.77
Knee	1.16	1.75	0.66	0.19, 2.35

4.6.2.2 Soccer and Volleyball Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the soccer and volleyball collegiate fall seasons; the referent category was overall men's and women's soccer athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 0.55 (95% CI: 0.20, 1.48). The competitive season lower extremity musculoskeletal injury incidence rate ratio was 0.85 (95% CI: 0.30, 2.41). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the soccer and volleyball collegiate fall seasons was 0.89 (95% CI: 0.28, 2.84). The lower extremity musculoskeletal injury incidence rate ratio during participation in games is 0.28 (95% CI: 0.03, 2.40). The acute lower extremity musculoskeletal injury incidence rate ratio for the soccer and football collegiate fall seasons was 0.53 (95% CI: 0.17, 1.59), while the overuse injury incidence rate ratio was 0.66 (95% CI: 0.06, 7.23). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 0.22 (95% CI: 0.03, 1.72). Lower extremity injury rate ratios are represented in Table 64.

Table 64. Overall Men's and Women's Soccer and Women's Volleyball Athletes Injury Rate Ratios

	Injury Incidence Rate - Soccer	Injury Incidence Rate - Volleyball	Injury Incidence Rate Ratio	95% CI
Overall	5.22	2.87	0.55	0.20, 1.48
Timing of Participation				
Competitive Season	4.58	3.89	0.85	0.30, 2.41
Type of Participation				
Pratice	3.68	3.28	0.89	0.28, 2.84
Game	6.80	1.91	0.28	0.03, 2.40
Acute vs. Overuse				
Acute	4.35	2.29	0.53	0.17, 1.59
Overuse	0.87	0.57	0.66	0.06, 7.23
Injury Location				
Ankle	2.61	0.57	0.22	0.03, 1.72

4.6.2.3 Soccer and Basketball Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the soccer and basketball collegiate athletic seasons; the referent category was overall men's and women's soccer athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 1.33 (95% CI: 0.49, 3.58). The pre-season lower extremity musculoskeletal injury incidence rate ratio was 1.65 (95% CI: 0.17, 15.89). The competitive season lower extremity musculoskeletal injury incidence rate ratio was 0.95 (95% CI: 0.31, 2.95). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the soccer and basketball collegiate athletic seasons was 0.90 (95% CI: 0.28, 2.87). The lower extremity musculoskeletal injury incidence rate ratio during participation in games is 2.02 (95% CI: 0.24, 17.29). The acute lower extremity musculoskeletal injury incidence rate ratio for the soccer and basketball collegiate athletic seasons was 1.85 (95% CI: 0.53, 6.38), while the overuse injury incidence rate ratio was 0.55 (95% CI: 0.09, 3.32). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 3.33 (95% CI: 0.42, 26.25). The injury incidence rate ratio for musculoskeletal injuries at the knee was 1.48 (95% CI: 0.17, 13.22). The injury incidence rate ratio for musculoskeletal injuries categorized as other was 0.49 (95% CI: 0.11, 2.20). Lower extremity injury rate ratios are represented in Table 65.

Table 65. Overall Men's and Women's Soccer and Men's and Women's Basketball Athletes Injury Rate Ratios

	Injury Incidence Rate - Soccer	Injury Incidence Rate - Basketball	Injury Incidence Rate Ratio	95% CI
Overall	5.22	4.19	1.33	0.49, 3.58
Timing of Participation				
Pre-Season	4.06	8.23	1.65	0.17, 15.89
Competitive Season	4.58	2.35	0.95	0.31, 2.95
Type of Participation				
Pratice	3.68	4.89	0.9	0.28, 2.87
Game	6.80	1.73	2.02	0.24, 17.29
Acute vs. Overuse				
Acute	4.35	2.29	1.85	0.53, 6.38
Overuse	0.87	1.19	0.55	0.09, 3.32
Injury Location				
Ankle	2.61	0.38	3.33	0.42, 26.25
Knee	1.16	1.14	1.48	0.17, 13.22
Other	1.16	2.29	0.49	0.11, 2.20

4.6.2.4 Volleyball and Football Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the volleyball and football collegiate fall seasons; the referent category was women's volleyball athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 0.28 (95% CI: 0.11, 0.72). The competitive season lower extremity musculoskeletal injury incidence rate ratio was 0.40 (95% CI: 0.15, 1.07). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the volleyball and football collegiate fall seasons was 0.28 (95% CI: 0.10, 0.79). The acute lower extremity musculoskeletal injury incidence rate ratio for the volleyball and football collegiate fall seasons was 0.24 (95% CI: 0.08, 0.67), while the overuse injury incidence rate ratio was 0.98 (95% CI: 0.09, 10.84). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 0.16 (95% CI: 0.02, 1.26). The injury incidence rate ratio for the muscles of the lower extremity was 0.57 (95% CI: 0.02, 0.99). Lower extremity injury rate ratios are represented in Table 66.

Table 66. Women's Volleyball and Football Athletes Injury Rate Ratios

	Injury Incidence Rate - Volleyball	Injury Incidence Rate - Football	Injury Incidence Rate Ratio	95% CI
Overall	2.87	10.19	0.28	0.11, 0.72
Timing of Participation				
Competitive Season	3.89	9.70	0.4	0.15, 1.07
Type of Participation				
Pratice	3.28	11.75	0.28	0.10, 0.79
Acute vs. Overuse				
Acute	2.29	9.61	0.24	0.08, 0.67
Overuse	0.57	0.58	0.98	0.09, 10.84
Injury Location				
Ankle	0.57	3.49	0.16	0.02, 1.26
Muscle	0.57	4.37	0.57	0.02, 0.99

4.6.2.5 Volleyball and Basketball Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the volleyball and basketball collegiate athletic seasons; the referent category was women's volleyball athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 0.73 (95% CI: 0.21, 2.52). The competitive season lower extremity musculoskeletal injury incidence rate ratio was 0.81 (95% CI: 0.22, 3.00). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the volleyball and basketball collegiate athletic seasons was 0.80 (95% CI: 0.20, 3.20). The lower extremity musculoskeletal injury incidence rate ratio during participation in game for the volleyball and basketball collegiate athletic seasons was 0.57 (95% CI: 0.04, 9.06). The acute lower extremity musculoskeletal injury incidence rate ratio for the volleyball and basketball collegiate athletic seasons was 0.97 (95% CI: 0.22, 4.35), while the overuse injury incidence rate ratio was 0.37 (95% CI: 0.03, 4.03). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 0.73 (95% CI: 0.05, 11.67), followed by the injury incidence rate ratio for musculoskeletal injuries categorized as other which was 0.24 (95% CI: 0.03, 2.34). Lower extremity injury rate ratios are represented in Table 67.

Table 67. Women's Volleyball and Men's and Women's Basketball Athletes Injury Rate Ratios

	Injury Incidence Rate - Volleyball	Injury Incidence Rate - Basketball	Injury Incidence Rate Ratio	95% CI
Overall	2.87	4.19	0.73	0.21, 2.52
Timing of Participation				
Competitive Season	3.89	2.35	0.81	0.22, 3.00
Type of Participation				
Pratice	3.28	4.89	0.8	0.20, 3.20
Game	1.91	1.73	0.57	0.04, 9.06
Acute vs. Overuse				
Acute	2.29	2.29	0.97	0.22, 4.35
Overuse	0.57	1.19	0.37	0.03, 4.03
Injury Location				
Ankle	0.57	0.38	0.73	0.05, 11.67
Other	0.57	2.29	0.24	0.03, 2.34

4.6.2.6 Basketball and Football Lower Extremity Musculoskeletal Injury Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the basketball and football collegiate athletic seasons; the referent category was overall men's and women's basketball athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 0.39 (95% CI: 0.15, 0.98). The pre-season lower extremity musculoskeletal injury incidence rate ratio was 0.52 (95% CI: 0.07, 3.98). The competitive season lower extremity musculoskeletal injury incidence rate ratio was 0.50 (95% CI: 0.17, 1.45). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the basketball and football collegiate athletic seasons was 0.35 (95% CI: 0.12, 0.98). The acute lower extremity musculoskeletal injury incidence rate ratio for the basketball and football collegiate athletic seasons was 0.25 (95% CI: 0.08, 0.80), while the overuse injury incidence rate ratio was 2.70 (95% CI: 0.38, 19.14). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 0.22 (95% CI: 0.03, 1.73). The injury incidence rate ratio for musculoskeletal injuries at the knee which was 0.45 (95% CI: 0.05, 3.73). Lower extremity injury rate ratios are represented in Table 68.

Table 68. Men's and Women's Basketball and Football Athletes Injury Rate Ratios

	Injury Incidence Rate - Basketball	Injury Incidence Rate - Football	Injury Incidence Rate Ratio	95% CI
Overall	4.19	10.19	0.39	0.15, 0.98
Timing of Participation				
Pre-Season	8.23	4.70	0.52	0.07, 3.98
Competitive Season	2.35	9.70	0.5	0.17, 1.45
Type of Participation				
Pratice	4.89	11.75	0.35	0.12, 0.98
Acute vs. Overuse				
Acute	2.29	9.61	0.25	0.08, 0.80
Overuse	1.19	0.58	2.7	0.38, 19.14
Injury Location				
Ankle	0.38	3.49	0.22	0.03, 1.73
Knee	1.14	1.75	0.45	0.05, 3.73

4.6.3 Men's Lower Extremity Dominant Sports

4.6.3.1 Men's Soccer and Football Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the men's soccer and football collegiate fall seasons; the referent category was men's soccer athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 0.45 (95% CI: 0.21, 0.96). The preseason lower extremity musculoskeletal injury incidence rate ratio for the men's soccer and football collegiate seasons was 1.11 (95% CI: 0.15, 8.43), while the competitive season lower extremity musculoskeletal injury incidence rate ratio was 0.28 (95% CI: 0.10, 0.82). The post-season lower extremity musculoskeletal injury incidence rate ratio was 13.51 (95% CI: 1.41, 129.91). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the men's soccer and football collegiate fall seasons was 0.38 (95% CI: 0.16, 0.91). The acute lower extremity musculoskeletal injury incidence rate ratio for the men's soccer and football collegiate fall seasons was 0.42 (95% CI: 0.18, 0.94), while the overuse injury incidence rate ratio was 0.98 (95% CI: 0.09, 10.84). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 0.82 (95% CI: 0.29, 2.32), followed by the injury incidence rate ratio for musculoskeletal injuries at the knee which was 0.32 (95% CI: 0.04, 2.71). Lower extremity injury rate ratios are represented in Table 69.

Table 69. Men's Soccer and Football Athletes Injury Rate Ratios

	Injury Incidence Rate - Men's Soccer	Injury Incidence Rate - Football	Injury Incidence Rate Ratio	95% CI
Overall	4.56	10.19	0.45	0.21, 0.96
Timing of Participation				
Pre-Season	5.21	4.70	1.11	0.15, 8.43
Competitive Season	2.72	9.70	0.28	0.10, 0.82
Post-Season	32.97	2.44	13.51	1.41, 129.91
Type of Participation				
Pratice	4.52	11.75	0.38	0.16, 0.91
Acute vs. Overuse				
Acute	3.99	9.61	0.42	0.18, 0.94
Overuse	0.57	0.58	0.98	0.09, 10.84
Injury Location				
Ankle	2.85	3.49	0.82	0.29, 2.32
Knee	0.57	1.75	0.32	0.04, 2.71

4.6.3.2 Men's Soccer and Men's Basketball Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the men's soccer and men's basketball collegiate athletic seasons; the referent category was men's soccer athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 1.16 (95% CI: 0.38, 3.55). The pre-season lower extremity musculoskeletal injury incidence rate ratio was 2.12 (95% CI: 0.13, 33.90). The competitive season lower extremity musculoskeletal injury incidence rate ratio was 0.56 (95% CI: 0.14, 2.26). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the men's soccer and men's basketball collegiate athletic seasons was 1.10 (95% CI: 0.31, 3.91). The lower extremity musculoskeletal injury incidence rate ration during participation in game for the men's soccer and men's basketball collegiate athletic seasons was 1.39 (95% CI: 0.13, 15.33). The acute lower extremity musculoskeletal injury incidence rate ratio for the men's soccer and men's basketball collegiate athletic seasons was 1.69 (95% CI: 0.44, 6.55), while the overuse injury incidence rate ratio was 0.36 (95% CI: 0.03, 4.00). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 3.63 (95% CI: 0.42, 31.08), followed by the injury incidence rate ratio for musculoskeletal injuries at the knee which was 0.73 (95% CI: 0.05, 11.61). The injury incidence rate ratio for musculoskeletal injuries categorized as other was 0.48 (95% CI: 0.08, 2.90). Lower extremity injury rate ratios are represented in Table 70.

Table 70. Men's Soccer and Men's Basketball Athletes Injury Rate Ratios

	Injury Incidence Rate - Men's Soccer	Injury Incidence Rate - Men's Basketball	Injury Incidence Rate Ratio	95% CI
Overall	4.56	3.92	1.16	0.38, 3.55
Timing of Participation				
Pre-Season	5.21	2.46	2.12	0.13, 33.90
Competitive Season	2.72	4.82	0.56	0.14, 2.26
Type of Participation				
Pratice	4.52	4.09	1.1	0.31, 3.91
Game	4.68	3.37	1.39	0.13, 15.33
Acute vs. Overuse				
Acute	3.99	2.35	1.69	0.44, 6.55
Overuse	0.57	1.57	0.36	0.03, 4.00
Injury Location				
Ankle	2.85	0.78	3.63	0.42, 31.08
Knee	0.57	0.78	0.73	0.05, 11.61
Other	1.14	2.35	0.48	0.08, 2.90

4.6.3.3 Football and Men's Basketball Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the football and men's basketball collegiate athletic seasons; the referent category was football athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 2.60 (95% CI: 1.02, 6.63). The pre-season lower extremity musculoskeletal injury incidence rate ratio was 1.91 (95% CI: 0.0.25, 14.55). The competitive season lower extremity musculoskeletal injury incidence rate ratio was 2.01 (95% CI: 0.69, 5.89). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the football and men's basketball collegiate athletic seasons was 2.87 (95% CI: 1.02, 8.07). The acute lower extremity musculoskeletal injury incidence rate ratio for the football and men's basketball collegiate athletic seasons was 4.08 (95% CI: 1.25, 13.30), while the overuse injury incidence rate ratio was 0.37 (95% CI: 0.05, 2.63). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 4.45 (95% CI: 0.58, 34.23), followed by the injury incidence rate ratio for musculoskeletal injuries at the knee which was 2.23 (95% CI: 0.27, 18.48). Lower extremity injury rate ratios are represented in Table 71.

Table 71. Football and Men's Basketball Athletes Injury Rate Ratios

	Injury Incidence Rate - Football	Injury Incidence Rate - Men's Basketball	Injury Incidence Rate Ratio	95% CI
Overall	10.19	3.92	2.60	1.02, 6.63
Timing of Participation				
Pre-Season	4.70	2.46	1.91	0.25, 14.55
Competitive Season	9.70	4.82	2.01	0.69, 5.89
Type of Participation				
Pratice	11.75	4.09	2.87	1.02, 8.07
Acute vs. Overuse				
Acute	9.61	2.35	4.08	1.25, 13.30
Overuse	0.58	1.57	0.37	0.05, 2.63
Injury Location				
Ankle	3.49	0.78	4.45	0.58, 34.23
Knee	1.75	0.78	2.23	0.27, 18.48

4.6.4 Women's Lower Extremity Dominant Sports

4.6.4.1 Women's Soccer and Volleyball Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the volleyball and women's soccer collegiate fall seasons; the referent category was women's soccer athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 0.49 (95% CI: 0.11, 2.08). The competitive season lower extremity musculoskeletal injury incidence rate ratio was 0.56 (95% CI: 0.15, 2.10). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the volleyball and women's soccer collegiate fall seasons was 1.13 (95% CI: 0.26, 4.89). The lower extremity musculoskeletal injury incidence rate ratio during participation in games was 0.20 (95% CI: 0.02, 2.20). The acute lower extremity musculoskeletal injury incidence rate ratio for the volleyball and women's soccer collegiate fall seasons was 0.49 (95% CI: 0.10, 2.46), while the overuse injury incidence rate ratio was 0.48 (95% CI: 0.02, 12.49). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 0.24 (95% CI: 0.01, 6.25). Lower extremity injury rate ratios are represented in Table 72.

Table 72. Women's Soccer and Women's Volleyball Athletes Injury Rate Ratios

	Injury Incidence Rate - Women's Soccer	Injury Incidence Rate - Women's Volleyball	Injury Incidence Rate Ratio	95% CI
Overall	5.90	2.87	0.49	0.11 2.08
Timing of Participation				
Competitive Season	6.97	3.89	0.56	0.15, 2.10
Type of Participation				
Pratice	2.89	3.28	1.13	0.26, 4.89
Game	9.74	1.91	0.2	0.02, 2.20
Acute vs. Overuse				
Acute	4.72	2.29	0.49	0.10, 2.46
Overuse	1.18	0.57	0.48	0.02, 12.49
Injury Location				
Ankle	2.36	0.57	0.24	0.01, 6.25

4.6.4.2 Women's Soccer and Women's Basketball Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the women's soccer and women's basketball collegiate athletic seasons; the referent category was women's soccer athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 1.33 (95% CI: 0.48, 3.65). The pre-season lower extremity musculoskeletal injury incidence rate ratio was 0.27 (95% CI: 0.05, 1.34). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the women's soccer and women's basketball collegiate athletic seasons was 0.51 (95% CI: 0.14, 1.82). The acute lower extremity musculoskeletal injury incidence rate ratio for the women's soccer and women's basketball collegiate athletic seasons was 2.12 (95% CI: 0.56, 8.00), while the overuse injury incidence rate ratio was 0.53 (95% CI: 0.09, 3.18). The injury incidence rate ratio for musculoskeletal injuries at the knee was 1.19 (95% CI: 0.20, 7.15), followed by the injury incidence rate ratio for musculoskeletal injuries categorized as other which was 0.53 (95% CI: 0.09, 3.18). Lower extremity injury rate ratios are represented in Table 73.

Table 73. Women's Soccer and Women's Basketball Athletes Injury Rate Ratios

	Injury Incidence Rate - Women's Soccer	Injury Incidence Rate - Women's Basketball	Injury Incidence Rate Ratio	95% CI
Overall	5.90	4.45	1.33	0.48, 3.65
Timing of Participation				
Pre-Season	3.66	13.51	0.27	0.05, 1.34
Type of Participation				
Pratice	2.89	5.62	0.51	0.14, 1.82
Acute vs. Overuse				
Acute	4.72	2.22	2.12	0.56, 8.00
Overuse	1.18	2.22	0.53	0.09, 3.18
Injury Location				
Knee	1.77	1.48	1.19	0.20, 7.15
Other	1.18	2.22	0.53	0.09, 3.18

4.6.4.3 Volleyball and Women's Basketball Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the women's soccer and women's basketball collegiate athletic seasons; the referent category was women's volleyball athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 0.64 (95% CI: 0.20, 2.11). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the women's soccer and women's basketball collegiate athletic seasons was 0.58 (95% CI: 0.16, 2.07). The acute lower extremity musculoskeletal injury incidence rate ratio for the women's soccer and women's basketball collegiate athletic seasons was 1.03 (95% CI: 0.23, 4.61), while the overuse injury incidence rate ratio was 0.26 (95% CI: 0.03, 2.48). The injury incidence rate ratio for musculoskeletal injuries of the lower extremity muscles was 0.77 (95% CI: 0.05, 12.36), followed by the injury incidence rate ratio for musculoskeletal injuries categorized as other which was 0.26 (95% CI: 0.03, 2.48). Lower extremity injury rate ratios are represented in Table 74.

Table 74. Women's Volleyball and Women's Basketball Athletes Injury Rate Ratios

	Injury Incidence Rate - Women's Volleyball	Injury Incidence Rate - Women's Basketball	Injury Incidence Rate Ratio	95% CI
Overall	2.87	4.45	0.64	0.20, 2.11
Type of Participation				
Pratice	3.28	5.62	0.58	0.16, 2.07
Acute vs. Overuse				
Acute	2.29	2.22	1.03	0.23, 4.61
Overuse	0.57	2.22	0.26	0.03, 2.48
Injury Location				
Muscle	0.57	0.74	0.77	0.05, 12.36
Other	0.57	2.22	0.26	0.03, 2.48

4.6.5 Soccer and Basketball Stratified by Sex

4.6.5.1 Men's and Women's Soccer Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for men's and women's collegiate fall soccer season; the referent category was men's soccer athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 0.77 (95% CI: 0.31, 1.96). The preseason lower extremity musculoskeletal injury incidence rate ratio for the men's and women's collegiate soccer season was 1.42 (95% CI: 0.13, 15.70), while the competitive season lower extremity musculoskeletal injury incidence rate ratio was 0.39 (95% CI: 0.12, 1.30). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the men's and women's collegiate fall soccer season was 1.56 (95% CI: 0.44, 5.54); the injury incidence rate ratio during game participation was was 0.48 (95% CI: 0.08, 2.88). The acute lower extremity musculoskeletal injury incidence rate ratio for the men's and women's soccer collegiate fall season was 0.85 (95% CI: 0.31, 2.33), while the overuse injury incidence rate ratio was 0.48 (95% CI: 0.04, 5.33). The injury incidence rate ratio for musculoskeletal injuries at the ankle was 1.21 (95% CI: 0.32, 4.50), followed by the injury incidence rate ratio for other lower extremity musculoskeletal injury which was 0.97 (95% CI: 0.14, 6.86). The lowest musculoskeletal injury incidence rate ratio was at the knee which was 0.32 (95% CI: 0.03, 3.10). The ankle sprain injury incidence rate ratio was 1.21 (95% CI: 0.32, 4.50) for the men's and women's collegiate fall soccer season. Lower extremity injury rate ratios are represented in Table 75.

Table 75. Men's Soccer and Women's Soccer Athletes Injury Rate Ratios

	Injury Incidence Rate - Men's Soccer	Injury Incidence Rate - Women's Soccer	Injury Incidence Rate Ratio	95% CI
Overall	4.56	5.90	0.77	0.31, 1.96
Timing of Participation				
Pre-Season	5.21	3.66	1.42	0.13, 15.7
Competitive Season	2.72	6.97	0.39	0.12, 1.30
Type of Participation				
Pratice	4.52	2.89	1.56	0.44, 5.54
Game	4.68	9.74	0.48	0.08, 2.88
Acute vs. Overuse				
Acute	3.99	4.72	0.85	0.31, 2.33
Overuse	0.57	1.18	0.48	0.04, 5.33
Injury Location				
Ankle	2.85	2.36	1.21	0.32, 4.50
Knee	0.57	1.77	0.32	0.03, 3.10
Other	1.14	1.18	0.97	0.14, 6.86

4.6.5.2 Men's and Women's Basketball Lower Extremity Musculoskeletal Injury Rate Ratios

The lower extremity musculoskeletal injury rate ratios were calculated for the men's basketball and women's basketball collegiate athletic seasons; the referent category was men's basketball athletes. The overall lower extremity musculoskeletal injury incidence rate ratio was 0.88 (95% CI: 0.27, 2.89). The pre-season lower extremity musculoskeletal injury incidence rate ratio was 0.18 (95% CI: 0.02, 1.51). The lower extremity musculoskeletal injury incidence rate ratio during participation in practice for the men's basketball and women's basketball collegiate athletic seasons was 0.73 (95% CI: 0.21, 2.58). The acute lower extremity musculoskeletal injury incidence rate ratio for the men's basketball and women's basketball collegiate athletic seasons was 1.06 (95% CI: 0.21, 5.24), while the overuse injury incidence rate ratio was 0.71 (95% CI: 0.12, 4.22). The injury incidence rate ratio for musculoskeletal injuries at the knee was 0.53 (95% CI: 0.05, 5.84). The injury incidence rate ratio for musculoskeletal injuries categorized as other which was 1.06 (95% CI: 0.21, 5.25). Lower extremity injury rate ratios are represented in Table 76.

Table 76. Men's Basketball and Women's Basketball Athletes Injury Rate Ratios

	Injury Incidence Rate - Men's Basketball	Injury Incidence Rate - Women's Basketball	Injury Incidence Rate Ratio	95% CI
Overall	3.92	4.45	0.88	0.27, 2.89
Timing of Participation				
Pre-Season	2.46	13.51	0.18	0.02, 1.51
Type of Participation				
Pratice	4.09	5.62	0.73	0.21, 2.58
Acute vs. Overuse				
Acute	2.35	2.22	1.06	0.21, 5.24
Overuse	1.57	2.22	0.71	0.12, 4.22
Injury Location				
Knee	0.78	1.48	0.53	0.05, 5.84
Other	2.35	2.22	1.06	0.21, 5.25

4.7 LOWER EXTREMITY DOMINANT SPORT RISK FACTOR ANALYSIS

The third specific aim of this study was to evaluate the association between lower extremity musculoskeletal characteristics including range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability and the rate of lower extremity musculoskeletal injury in NCAA Division I University of Pittsburgh male and female athletes. It was hypothesized that the rate of lower extremity musculoskeletal injury would be higher among NCAA Division I University of Pittsburgh male and female athletes who demonstrated decreased lower extremity range of motion, flexibility, and isometric strength, as well as deficits in static and dynamic postural stability compared to NCAA Division I University of Pittsburgh male and female athletes who did not demonstrate decreases in these musculoskeletal characteristics. Separate simple Poison regression analysis were conducted to assess the association between the predictor variables including, range of motion, flexibility, strength, static postural stability, and dynamic postural stability, and lower extremity musculoskeletal injury rates in NCAA Division I male and female athletes participating in lower extremity dominant sports at the University of Pittsburgh. The risk factor analysis was performed for the following groups, all subjects, sport type (soccer, football, volleyball, etc.), and sex.

4.7.1 Risk Factor Analysis Overall

4.7.1.1 Overall

Separate simple Poison regressions were performed in order to allow for a better understanding of the relationship between the predictor variables chosen for the present study (lower extremity range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability) and the dependent variable of lower extremity musculoskeletal injury. Lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury. Separate simple Poison regressions demonstrated that multiple predictor variables were significant predictors of lower extremity musculoskeletal injury in athletes who participate in lower extremity dominant sports. When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity range of motion and flexibility demonstrated significance on the dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a lower extremity dominant sport season based on straight leg raise flexibility and the number of exposures. For every unit increase in straight leg raise flexibility the risk of lower extremity musculoskeletal injury increases by 105.90% (95% CI, 1.003 to 1.119), $p = 0.038$. Significant simple Poison regressions are represented in Table 77.

Table 77. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Dominant Lower Extremity for All Sport Types

	Number of Observations	IRR	P-Value	95% CI
Straight Leg Raise Flexibility	132	1.059	0.038	1.003, 1.119

When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity strength demonstrated significance on the non-dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a lower extremity dominant sport season based on dominant/non-dominant knee flexion strength ratio and the number of exposures. For every unit increase in dominant/non-dominant knee flexion strength ratio the risk of lower extremity musculoskeletal injury decreases by 4.20% (95% CI, 0.004 to 0.401), $p = 0.007$. Significant simple Poison regressions are represented in Table 78.

Table 78. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Non-Dominant Lower Extremity for All Sport Types

	Number of Observations	IRR	P-Value	95% CI
Dominant/Non-Dominant Knee Flexion Strength Ratio	131	0.042	0.007	0.004, 0.401

4.7.1.2 Sex

4.7.1.2.1 Men's Athletes

Separate simple Poison regressions were performed in order to allow for a better understanding of the relationship between the predictor variables chosen for the present study (lower extremity range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability) and the dependent variable of lower extremity musculoskeletal injury. Lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury. Separate simple Poison regressions demonstrated that multiple predictor variables were significant predictors of lower extremity musculoskeletal injury in men's athletes who participate in lower extremity dominant sports. When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity isometric strength demonstrated significance on the dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a men's lower extremity dominant sport season based on dominant/non-dominant hip external rotation strength ratio and the number of exposures. For every unit increase in dominant/non-dominant hip external rotation strength ratio the risk of lower extremity musculoskeletal injury increases by 2432.60% (95% CI, 1.224 to 483.274), $p = 0.036$. Significant simple Poison regressions are represented in Table 79.

Table 79. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Dominant Lower Extremity for All Men's Sport Types

	Number of Observations	IRR	P-Value	95% CI
Dominant/Non-Dominant Hip External Rotation Ratio	80	24.326	0.036	1.224, 483.274

When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity isometric strength demonstrated significance on the non-dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a men's lower extremity dominant sport season based on knee flexion strength and the number of exposures. For every unit increase in knee flexion strength the risk of lower extremity musculoskeletal injury increases by 103.20% (95% CI, 1.001 to 1.063), p = 0.049. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a men's lower extremity dominant sport season based on dominant/non-dominant knee flexion strength ratio and the number of exposures. For every unit increase in dominant/non-dominant knee flexion strength ratio the risk of lower extremity musculoskeletal injury decreases by 5.40% (95% CI, 0.005 to 0.607), p = 0.049. Significant simple Poison regressions are represented in Table 80.

Table 80. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Non-Dominant Lower Extremity for All Men's Sport Types

	Number of Observations	IRR	P-Value	95% CI
Knee Flexion Strength	79	1.032	0.049	1.001, 1.063
Dominant/Non-Dominant Knee Flexion Strength Ratio	79	0.054	0.019	0.005, 0.607

4.7.1.2.2 Women's Athletes

Separate simple Poison regressions were performed in order to allow for a better understanding of the relationship between the predictor variables chosen for the present study (lower extremity range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability) and the dependent variable of lower extremity musculoskeletal injury. Lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, additionally being stratified by injury location and type, as applicable. Separate simple Poison regressions demonstrated that multiple predictor variables were significant predicts of lower extremity musculoskeletal injury in overall women's lower extremity dominant sport athletes. When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity isometric strength demonstrated significance on the dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's lower extremity dominant sport season based on ankle dorsiflexion strength and the number of exposures. For every unit increase in ankle dorsiflexion strength the risk of lower extremity musculoskeletal injury decreases by 92.30% (95% CI, 0.854 to 0.998), $p = 0.027$. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's lower extremity dominant sport season based on ankle inversion strength and the number of exposures. For every unit increase in ankle inversion strength the risk of lower extremity musculoskeletal injury decreases by 89.80% (95% CI, 0.820 to 0.992), $p = 0.018$. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's lower extremity dominant sport season based on hip abduction strength and the number of exposures. For every unit increase in hip abduction strength the risk of lower extremity musculoskeletal injury decreases by 85.40% (95% CI, 0.745 to 0.978), $p = 0.017$. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's lower extremity dominant sport season based on hip adduction strength and the number of exposures. For every unit increase in hip adduction strength the risk of lower extremity musculoskeletal injury increases by 84.10% (95% CI, 0.728 to 0.971), $p = 0.014$. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's lower extremity dominant sport season based on knee flexion strength and the number of exposures. For every unit increase in knee flexion strength the risk of lower extremity musculoskeletal injury decreases by 86.90% (95% CI, 0.794 to 0.952), p = 0.001. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's lower extremity dominant sport season based on knee extension strength and the number of exposures. For every unit increase in knee extension strength the risk of lower extremity musculoskeletal injury decreases by 95.40% (95% CI, 0.911 to 0.998), p = 0.037. Significant simple Poison regressions are represented in Table 81.

Table 81. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Dominant Lower Extremity for All Women's Sport Types

	Number of Observations	IRR	P-Value	95% CI
Ankle Dorsiflexion Strength	52	0.923	0.027	0.854, 0.998
Ankle Inversion Strength	52	0.898	0.018	0.820, 0.992
Hip Abduction Strength	52	0.854	0.017	0.745, 0.978
Hip Adduction Strength	52	0.841	0.014	0.728, 0.971
Knee Flexion Strength	52	0.869	0.001	0.794, 0.952
Knee Extension Strength	52	0.954	0.037	0.911, 0.998

4.7.2 Risk Factor Analysis by Sport

4.7.2.1 Soccer

Separate simple Poison regressions were performed in order to allow for a better understanding of the relationship between the predictor variables chosen for the present study (lower extremity range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability) and the dependent variable of lower extremity musculoskeletal injury. Lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, as well as being stratified by injury location and type, as applicable. Separate simple Poison regressions demonstrated that multiple predictor variables were significant predicts of lower extremity musculoskeletal injury in overall men's and women's soccer athletes. When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity range of motion and flexibility, as well as isometric strength demonstrated significance on the non-dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a men's and women's soccer season based on straight leg raise flexibility and the number of exposures. For every unit increase in straight leg raise flexibility the risk of lower extremity musculoskeletal injury decreases by 85.60% (95% CI, 0.740 to 0.990), $p = 0.035$. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a men's and women's soccer season based on dominant/non-dominant straight leg raise flexibility ratio and the number of exposures. For every unit increase in dominant/non-dominant straight leg raise flexibility ratio the risk of lower extremity musculoskeletal injury increases by 19100000000.00% (95% CI, 10.716 to 3.390e+15), $p = 0.014$. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a men's and women's soccer season based on dominant/non-dominant hip adduction strength ratio and the number of exposures. For every unit increase in dominant/non-dominant hip adduction strength ratio the risk of lower extremity musculoskeletal injury decreases by 0.02% (95% CI, 6.320e-08 to 0.522), $p = 0.019$. Significant simple Poison regressions are represented in Table 82.

Table 82. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Non-Dominant Lower Extremity for All Men's and Women's Soccer Athletes

	Number of Observations	IRR	P-Value	95% CI
Straight Leg Raise Flexibility	48	0.856	0.035	0.740, 0.990
Dominant/Non-Dominant Straight Leg Raise Flexibility Ratio	48	191000000.000	0.014	10.716, 3.390e+15
Dominant/Non-Dominant Hip Adduction Strength Ratio	48	0.000	0.019	6.320e-08, 0.522

4.7.2.1.1 Men's Soccer

Separate simple Poison regressions were performed in order to allow for a better understanding of the relationship between the predictor variables chosen for the present study (lower extremity range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability) and the dependent variable of lower extremity musculoskeletal injury. Lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury. When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, none of the predictor variables demonstrated significance on the dominant or non-dominant lower extremity.

4.7.2.1.2 Women's Soccer

Separate simple Poison regressions were performed in order to allow for a better understanding of the relationship between the predictor variables chosen for the present study (lower extremity range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability) and the dependent variable of lower extremity musculoskeletal injury. Lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury. Separate simple Poison regressions demonstrated that multiple predictor variables were significant predicts of lower extremity musculoskeletal injury in women's soccer athletes. When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity isometric strength demonstrated significance on the dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's soccer season based on knee flexion strength and the number of exposures. For every unit increase in knee flexion strength the risk of lower extremity musculoskeletal injury decreases by 71.60% (95% CI, 0.511 to 1.002), p = 0.003. Significant simple Poison regressions are represented in Table 83.

Table 83. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Dominant Lower Extremity for All Women's Soccer Athletes

	Number of Observations	IRR	P-Value	95% CI
Knee Flexion Strength	24	0.716	0.003	0.511, 1.002

When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, only lower extremity range of motion and flexibility demonstrated significance on the non-dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's soccer season based on straight leg raise flexibility and the number of exposures. For every unit increase in straight leg raise flexibility the risk of lower extremity musculoskeletal injury decreases by 75.10% (95% CI, 0.569 to 0.991), p = 0.012. Significant simple Poison regressions are represented in Table 84.

Table 84. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Non-Dominant Lower Extremity for All Women's Soccer Athletes

	Number of Observations	IRR	P-Value	95% CI
Straight Leg Raise Flexibility	24	0.751	0.012	0.569, 0.991

4.7.2.2 Football

Separate simple Poison regressions were performed in order to allow for a better understanding of the relationship between the predictor variables chosen for the present study (lower extremity range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability) and the dependent variable of lower extremity musculoskeletal injury. Lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury. Separate simple Poison regressions demonstrated that multiple predictor variables were significant predicts of lower extremity musculoskeletal injury in football athletes. When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity flexibility and static balance demonstrated significance on the non-dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a football season based on straight leg raise flexibility and the number of exposures. For every unit increase in straight leg raise flexibility the risk of lower extremity musculoskeletal injury increases by 106.70% (95% CI, 0.999 to 1.204), p = 0.039. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a football season based on eyes-closed static balance medial/lateral ground reaction forces and the number of exposures. For every unit increase in eyes-closed static balance medial/lateral ground reaction forces the risk of lower extremity musculoskeletal injury decreases by 91.30% (95% CI, 0.829 to 1.006), p = 0.038. Significant simple Poison regressions are represented in Table 85.

Table 85. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Non-Dominant Lower Extremity for All Football Athletes

	Number of Observations	IRR	P-Value	95% CI
Straight Leg Raise Flexibility	45	1.067	0.039	0.999, 1.204
Eyes-Closed Static Balance Medial/Lateral Ground Reaction Force	44	0.913	0.038	0.829, 1.006

4.7.2.3 Volleyball

Separate simple Poison regressions were performed in order to allow for a better understanding of the relationship between the predictor variables chosen for the present study (lower extremity range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability) and the dependent variable of lower extremity musculoskeletal injury. Lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury. Separate simple Poison regressions demonstrated that multiple predictor variables were significant predicts of lower extremity musculoskeletal injury in women's volleyball athletes. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on ankle dorsiflexion strength and the number of exposures. For every unit increase in ankle dorsiflexion strength the risk of lower extremity musculoskeletal injury decreases by 72.00% (95% CI, 0.545 to 0.952), p = 0.010. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on ankle inversion strength and the number of exposures. For every unit increase in ankle inversion strength the risk of lower extremity musculoskeletal injury decreases by 72.50% (95% CI, 0.511 to 1.028), p = 0.042. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on ankle eversion strength and the number of exposures. For every unit increase in ankle eversion strength the risk of lower extremity musculoskeletal injury decreases by 72.40% (95% CI, 0.548 to 0.957), p = 0.009. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on hip abduction strength and the number of exposures. For every unit increase in hip abduction strength the risk of lower extremity musculoskeletal injury decreases by 67.50% (95% CI, 0.461 to 0.987), p = 0.023. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on hip adduction strength and the number of exposures. For every unit increase in hip adduction strength the risk of lower extremity musculoskeletal injury decreases by 73.50% (95% CI, 0.533 to 1.014), p = 0.041. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on hip internal rotation strength and the number of exposures. For every unit increase in hip internal rotation strength the risk of lower extremity musculoskeletal injury decreases by 64.10% (95% CI, 0.387 to 1.063), p = 0.020. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on knee flexion strength and the number of exposures. For every unit increase in knee flexion strength the risk of lower extremity musculoskeletal injury decreases by 76.60% (95% CI, 0.596 to 0.985), p = 0.015. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on dominant/non-dominant ankle inversion strength ratio and the number of exposures. For every unit increase in dominant/non-dominant ankle inversion strength ratio the risk of lower extremity musculoskeletal injury increases by 18817.70% (95% CI, 0.154 to 30696.000), p = 0.038. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on ankle eversion/inversion strength ratio and the number of exposures. For every unit increase in ankle ankle eversion/inversion strength ratio the risk of lower extremity musculoskeletal injury decreases by 0.40% (95% CI, 8.620e-06 to 1.584), p = 0.046. Significant simple Poison regressions are represented in Table 86.

Table 86. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Dominant Lower Extremity for All Women's Volleyball Athletes

	Number of Observations	IRR	P-Value	95% CI
Ankle Dorsiflexion Strength	16	0.720	0.010	0.545, 0.952
Ankle Inversion Strength	16	0.725	0.042	0.511, 1.028
Ankle Eversion Strength	16	0.724	0.009	0.548, 0.957
Hip Abduction Strength	16	0.675	0.023	0.461, 0.987
Hip Adduction Strength	16	0.735	0.041	0.533, 1.014
Hip Internal Rotation Strength	16	0.641	0.020	0.387, 1.063
Knee Flexion Strength	16	0.766	0.015	0.596, 0.985
Dominant/Non-Dominant Ankle Inversion Strength Ratio	16	188.177	0.038	0.154, 30696.820
Ankle Eversion/Inversion Strenght Ratio	16	0.004	0.046	8.620e-06, 1.584

When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity isometric strength demonstrated significance on the non-dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on ankle dorsiflexion strength and the number of exposures. For every unit increase in ankle dorsiflexion strength the risk of lower extremity musculoskeletal injury decreases by 69.40% (95% CI, 0.485 to 0.992), p = 0.024. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on ankle plantarflexion strength and the number of exposures. For every unit increase in ankle plantarflexion strength the risk of lower extremity musculoskeletal injury decreases by 70.70% (95% CI, 0.487 to 1.027), p = 0.031. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on knee flexion strength and the number of exposures. For every unit increase in knee flexion strength the risk of lower extremity musculoskeletal injury decreases by 72.80% (95% CI, 0.515 to 1.028), p = 0.037. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on hip external rotation strength and the number of exposures. For every unit increase in hip external rotation strength the risk of lower extremity musculoskeletal injury decreases by 62.40% (95% CI, 0.339 to 1.149), p = 0.045. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on knee extension strength and the number of exposures. For every unit increase in knee extension strength the risk of lower extremity musculoskeletal injury decreases by 86.50% (95% CI, 0.746 to 1.003), p = 0.038. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's volleyball season based on dominant/non-dominant ankle eversion strength ratio and the number of exposures. For every unit increase in dominant/non-dominant ankle eversion strength ratio the risk of lower extremity musculoskeletal injury decreases by 0.00% (95% CI, 4.680e-79 to 4.060e+30), p = 0.005. Significant simple Poison regressions are represented in Table 87.

Table 87. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Non-Dominant Lower Extremity for All Women's Volleyball Athletes

	Number of Observations	IRR	P-Value	95% CI
Ankle Dorsiflexion Strength	16	0.694	0.024	0.485, 0.992
Ankle Plantarflexion Strength	16	0.707	0.031	0.487, 1.027
Knee Flexion Strength	16	0.728	0.037	0.515, 1.028
Hip External Rotation Strength	16	0.624	0.045	0.339, 1.149
Knee Extension Strength	16	0.865	0.038	0.746, 1.003
Dominant/Non-Dominant Ankle Eversion Strength Ratio	16	0.000	0.005	4.680e-79, 4.060e+30

4.7.2.4 Basketball

Separate simple Poison regressions were performed in order to allow for a better understanding of the relationship between the predictor variables chosen for the present study (lower extremity range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability) and the dependent variable of lower extremity musculoskeletal injury. Lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury. Separate simple Poison regressions demonstrated that multiple predictor variables were significant predicts of lower extremity musculoskeletal injury in men's and women's basketball athletes. When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity range of motion and flexibility, as well as isometric strength demonstrated significance on the dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a overall men's and women's basketball season based on straight leg raise flexibility and the number of exposures. For every unit increase in straight leg raise flexibility the risk of lower extremity musculoskeletal injury increases by 115.70% (95% CI, 1.028 to 1.302), p = 0.022. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a overall men's and women's basketball season based on hip adduction strength and the number of exposures. For every unit increase in hip abduction strength the risk of lower extremity musculoskeletal injury decreases by 85.10% (95% CI, 0.712 to 1.016), p = 0.046. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a overall men's and women's basketball season based on hip abduction strength and the number of exposures. For every unit increase in hip adduction strength the risk of lower extremity musculoskeletal injury decreases by 79.50% (95% CI, 0.629 to 1.007), p = 0.024. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a overall men's and women's basketball season based on knee flexion strength and the number of exposures. For every unit increase in knee flexion strength the risk of lower extremity musculoskeletal injury decreases by 90.00% (95% CI, 0.808 to 1.004), p = 0.036. Significant simple Poison regressions are represented in Table 88.

Table 88. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Dominant Lower Extremity for All Men's and Women's Basketball Athletes

	Number of Observations	IRR	P-Value	95% CI
Straight Leg Raise Flexibility	23	1.157	0.022	1.028, 1.302
Hip Abduction Strength	23	0.851	0.046	0.712, 1.016
Hip Adduction Strength	23	0.795	0.024	0.629, 1.007
Knee Flexion Strength	23	0.900	0.036	0.808, 1.004

When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity isometric strength demonstrated significance on the non-dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during an overall men's and women's basketball season season based on dominant/non-dominant ankle dorsiflexion strength ratio and the number of exposures. For every unit increase in dominant/non-dominant ankle dorsiflexion strength ratio the risk of lower extremity musculoskeletal injury decreases by 0.004% (95% CI, 5.340e-10 to 2.619), p = 0.028. Significant simple Poison regressions are represented in Table 89.

Table 89. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Non-Dominant Lower Extremity for All Men's and Women's Basketball Athletes

	Number of Observations	IRR	P-Value	95% CI
Dominant/Non-Dominant Ankle Dorsiflexion Strenght Ratio	23	0.000	0.028	5.340e-10, 2.619

4.7.2.4.1 Men's Basketball

Separate simple Poison regressions were performed in order to allow for a better understanding of the relationship between the predictor variables chosen for the present study (lower extremity range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability) and the dependent variable of lower extremity musculoskeletal injury. Lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury. Separate simple Poison regressions demonstrated that multiple predictor variables were significant predicts of lower extremity musculoskeletal injury in men's basketball athletes. When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, lower extremity range of motion and flexibility, as well as isometric strength demonstrated significance on the dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a men's basketball season season based on straight leg raise flexibility and the number of exposures. For every unit increase in straight leg raise flexibility the risk of lower extremity musculoskeletal injury increases by 118.50% (95% CI, 1.021 to 1.374), p = 0.021. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a men's basketball season season based on dominant/non-dominant hip external rotation strength ratio and the number of exposures. For every unit increase in dominant/non-dominant hip external rotation ratio the risk of lower extremity musculoskeletal injury increases by 632993.80% (95% CI, 1.550 to 2.590e+07), p = 0.025. Significant simple Poison regressions are represented in Table 90.

Table 90. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Dominant Lower Extremity for All Men's Basketball Athletes

	Number of Observations	IRR	P-Value	95% CI
Straight Leg Raise Flexibility	11	1.185	0.021	1.021, 1.374
Dominant/Non-Dominant Hip External Rotation Strength Ratio	11	6329.938	0.025	1.550, 2.590e+07

4.7.2.4.2 Women's Basketball

Separate simple Poison regressions were performed in order to allow for a better understanding of the relationship between the predictor variables chosen for the present study (lower extremity range of motion, flexibility, isometric strength, static postural stability, and dynamic postural stability) and the dependent variable of lower extremity musculoskeletal injury. Lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury. Separate simple Poison regressions demonstrated that none of the predictor variables were significant predicts of lower extremity musculoskeletal injury in women's basketball athletes. When lower extremity musculoskeletal injuries were calculated as any lower extremity musculoskeletal injury, regardless of location and/or type, isometric strength demonstrated significance on the dominant lower extremity. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's basketball season season based on hip adduction strength and the number of exposures. For every unit increase in hip adduction strength the risk of lower extremity musculoskeletal injury decreases by 62.50% (95% CI, 0.365 to 1.069), p = 0.020. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's basketball season season based on knee flexion strength and the number of exposures. For every unit increase in knee flexion strength the risk of lower extremity musculoskeletal injury decreases by 83.80% (95% CI, 0.684 to 1.028), p = 0.042. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's basketball season season based on dominant/non-dominant ankle inversion strength ratio and the number of exposures. For every unit increase in dominant/non-dominant ankle inversion strength ratio the risk of lower extremity musculoskeletal injury decreases by 0.00% (95% CI, 1.050e-08 to 2.052), p = 0.070. A simple Poisson regression was run to predict the number of lower extremity musculoskeletal injuries that occur during a women's basketball season season based on ankle eversion/inversion strength ratio and the number of exposures. For every unit increase in ankle eversion/inversion strength ratio the risk of lower extremity musculoskeletal injury increases by 570560.60% (95% CI, 0.028 to 1.180e+09), p = 0.011. Significant simple Poison regressions are represented in Table 91.

Table 91. Significant Simple Poison Regressions – All Lower Extremity Musculoskeletal Injuries on the Dominant Lower Extremity for All Women's Basketball Athletes

	Number of Observations	IRR	P-Value	95% CI
Hip Adduction Strength	12	0.625	0.020	0.365, 1.069
Knee Flexion Strength	12	0.838	0.042	0.684, 1.028
Dominant/Non-Dominant Ankle Inversion Strength Ratio	12	0.000	0.070	1.050e-08, 2.052
Ankle Eversion/Inversion Strength Ratio	12	5705.606	0.011	0.028, 1.180e+09

5.0 DISCUSSION

Lower extremity musculoskeletal injury is a serious and persistent concern for collegiate athletes, who participate in lower extremity dominant sports which require cutting, jumping, and landing.[3-5, 28, 29, 31, 47] Lower extremity musculoskeletal injury can have significant short-term and long-term consequences, including disability, re-current injuries, and the development of post-traumatic osteoarthritis.[3-5, 28, 29, 31, 47] An examination of the modifiable musculoskeletal risk factors for lower extremity musculoskeletal injury may lead to the avoidance of these injuries, with proper implementation of risk factor-specific injury prevention programs. The injury prevention process calls for the examination of modifiable risk factors for musculoskeletal injury.[60] Therefore, the purpose of this study was to identify the incidence of lower extremity musculoskeletal injury in NCAA Division I athletes participating in lower extremity dominant sports at the University of Pittsburgh, describe the musculoskeletal characteristics of the lower extremity, and identify the association between musculoskeletal characteristics of the lower extremity and the rate of lower extremity musculoskeletal injury in NCAA Division I athletes at the University of Pittsburgh. It was hypothesized that the rate of lower extremity musculoskeletal injury would be higher among NCAA Division I University of Pittsburgh athletes who demonstrate decreased lower extremity range of motion, flexibility, and isometric strength, as well as deficits in static and dynamic postural stability compared to athletes who did not demonstrate decreases in lower extremity range of motion, flexibility, and isometric strength, as well as deficits in static and dynamic postural stability. The findings of the present study demonstrated that football had the highest rate of LE MSI, followed by women's soccer and men's soccer, as well as women's basketball and men's basketball. Women's volleyball had the lowest rate of LE MSI. Range of motion, flexibility, and strength of the LE were determined to be modifiable risk factors for LE MSI in all sport types excluding football and men's basketball. Each sport type displayed a different profile of modifiable risk factors for LE MSI.

5.1 SUBJECT CHARACTERISTICS

Men's and women's Division I NCAA University of Pittsburgh athletes who participate in lower extremity dominant sports were recruited to participate in this study. Athletes participating in lower extremity dominant sports face similar demands; these demands include running, cutting, and jumping, although the musculoskeletal characteristics necessary for peak performance in their respective sport may be different.[47] Sport participation represented by this study included: men's soccer, women's soccer, football, women's volleyball, men's basketball, and women's basketball. The intent behind including all six of these sports was to include a variety of lower extremity dominant sports, as well as include sports which both sexes participate in. Although there are a number of other sports which may be considered lower extremity dominant sport, including field hockey and lacrosse, the University of Pittsburgh does not field varsity teams in these sport types, therefore they were excluded from the present study.

5.2 LOWER EXTREMITY MUSCULOSKELETAL INJURY IN COLLEGIATE ATHLETES

5.2.1 Soccer

Overall, our study examined the lower extremity musculoskeletal injury rate in 48 men’s and women’s Division I soccer athletes at the University of Pittsburgh (Men’s: 24, Women’s: 24). Eighteen of the 48 men’s and women’s soccer athletes examined throughout the present study suffered a lower extremity musculoskeletal injury. None of the 48 men’s and women’s soccer athletes suffered more than one lower extremity musculoskeletal injury over the course of the collegiate fall men’s and women’s soccer season. The overall lower extremity musculoskeletal injury rate for the men’s and women’s soccer collegiate fall soccer season was 5.22 injuries per 1,000 athlete exposures. For men’s and women’s soccer athletes the acute lower extremity musculoskeletal injury rate for the fall collegiate soccer season was 4.35 injuries per 1,000 athlete exposures; the overuse injury rate was 0.87 injuries per 1,000 athlete exposures. The lower extremity musculoskeletal injury rate for men’s and women’s soccer athletes during participation in games was 6.80, followed by the injury rate for participation in practices which was 3.68 injuries per 1,000 athlete exposures. The pre-season injury rate for men’s and women’s soccer athletes was 4.06 injuries per 1,000 athlete exposures. The competitive season lower extremity musculoskeletal injury rate was 4.58 injuries per 1,000 athlete exposures. The injury rate for injuries occurring at the ankle in men’s and women’s soccer athletes was 2.61 injuries per 1,000 athlete exposures; the knee injury rate was 1.16 injuries per 1,000 athlete exposures.

Twenty-four men's soccer athletes were tested as a part of the present study, eight of these men's soccer athletes suffered a lower extremity musculoskeletal injury. None of the men's soccer athletes tested suffered more than one lower extremity musculoskeletal injury. The overall lower extremity musculoskeletal injury rate for men's soccer athletes during the fall collegiate season was 4.56 injuries per 1,000 athlete exposures. The acute lower extremity musculoskeletal injury rate were 3.99 injuries per 1,000 athlete exposures for the men's soccer athletes during the fall collegiate season. The overuse injury rate for men's soccer athletes was 0.57 injuries per 1,000 athlete exposures. The lower extremity musculoskeletal injury rate during practice participation for men's soccer athletes was 4.52 injuries per 1,000 athlete exposures. The injury rate during participation in games was 4.68 injuries per 1,000 athlete exposures. The pre-season lower extremity musculoskeletal injury rate for men's soccer athletes during the fall collegiate season was 5.21 injuries per 1,000 athlete exposures. The competitive season lower extremity musculoskeletal injury rate was lower for men's soccer athletes at 2.72 injuries per 1,000 athlete exposures. The post-season lower extremity musculoskeletal injury rate for men's soccer athletes was the highest at 32.97 injuries per 1,000 athlete exposures. Lower extremity musculoskeletal injuries at the ankle occurred at a rate of 2.85 injuries per 1,000 athlete exposures in men's soccer athletes. The knee had a lower rate of musculoskeletal injury at 0.57 injuries per 1,000 athlete exposures.

The NCAA Injury Surveillance System collected musculoskeletal injury data for men's soccer athletes over a 15-year period.[3] The lower extremity musculoskeletal injury rate during practice was similar to the musculoskeletal injury rate during games for the men's soccer athletes who participated in the present study (4.52 injuries per 1,000 athlete exposures vs. 4.68 injuries per 1,000 athlete exposures).[3] In contrast, the NCAA Injury Surveillance System reported a greater gap, larger differences, in the injury rate for men's soccer athletes during participation in practice compared to participation in games.[3] The musculoskeletal injury rate during game participation was greater than the musculoskeletal injury rate during practice participation according to the NCAA Injury Surveillance System.[3] When lower extremity musculoskeletal injury rates were examined throughout the phases of the fall men's soccer season, the pre-season musculoskeletal injury rate recorded during practices through the NCAA Injury Surveillance System, was 7.89 injuries per 1,000 athlete exposures.[3] The competitive season musculoskeletal injury rate during participation in practices was 2.43 injuries per 1,000 athlete exposures over the 15-year period in which data was collected as a part of the NCAA Injury Surveillance System.[3] The lower extremity musculoskeletal injury rate for the men's soccer athletes tested as a part of the present study followed a similar pattern, with the pre-season having a greater rate of lower extremity musculoskeletal injuries than the competitive season (5.21 injuries per 1,000 athlete exposures vs. 2.72 injuries per 1,000 athlete exposures). The post-season musculoskeletal injury rate for men's soccer during practice according to the NCAA Injury Surveillance System was 1.62 injuries per 1,000 athlete exposures.[3] Game musculoskeletal injury rates were much greater than practice musculoskeletal injury rates during the time period of the NCAA Injury Surveillance System data collection.[3] The competitive season musculoskeletal injury rate for men's soccer during game participation was 18.91 injuries per 1,000 athlete exposures and the post-season musculoskeletal injury rate during game participation was 14.58 injuries per 1,000 athlete exposures for men's soccer.[3] The men's soccer athletes in the present study had a much greater musculoskeletal injury rate than reported by the NCAA Injury Surveillance System for post-season participation. The lower extremity musculoskeletal injury rate for the present study was 32.97 injuries per 1,000 athlete exposures during the men's soccer post-season, including both practice and game participation. The highest post-season musculoskeletal injury rate the NCAA Injury Surveillance System reported was 14.58 injuries per 1,000 athlete exposures, which represented the post-season musculoskeletal injury rate for participation in games.[3] The large amount of post-season musculoskeletal injuries suffered by the men's soccer athletes in the present study is potentially concerning. This concern is related to the fact that the NCAA Injury Surveillance System includes not only lower extremity musculoskeletal injuries, it includes any musculoskeletal injury and/or concussion.[3] It has been previously reported that about two thirds of the musculoskeletal injuries recorded as a part of the 15-year NCAA Injury Surveillance System occurred at the lower extremity.[3] Therefore, removing all musculoskeletal injuries that did not occur to the lower extremity from the NCAA Injury Surveillance System data would likely decrease the musculoskeletal injury rate, further increasing the vast difference between the NCAA Injury Surveillance System's post-season injury rate and the post-season injury rate reported in the present study.[3]

Twenty-four women's soccer athletes were tested as a part of the present study, ten of these women's soccer athletes suffered a lower extremity musculoskeletal injury. None of the women's soccer athletes tested suffered more than one lower extremity musculoskeletal injury. The overall lower extremity musculoskeletal injury rate for women's soccer during the fall collegiate season was 5.90 injuries per 1,000 athlete exposures. The acute lower extremity musculoskeletal injury rate was 4.72 injuries per 1,000 athlete exposures for the women's soccer fall collegiate season. The overuse injury rate for women's soccer athletes was 1.18 injuries per 1,000 athlete exposures. The lower extremity musculoskeletal injury rate during practice participation for women's soccer athletes was 2.89 injuries per 1,000 athlete exposures. The injury rate during participation in games was 9.74 injuries per 1,000 athlete exposures for women’s soccer athletes. The pre-season lower extremity musculoskeletal injury rate for women’s soccer athletes during the fall collegiate season was 3.66 injuries per 1,000 athlete exposures. The competitive season lower extremity musculoskeletal injury rate was higher for women’s soccer athletes at 6.97 injuries per 1,000 athlete exposures, compared to the pre-season musculoskeletal injury rate. Lower extremity musculoskeletal injuries at the ankle occurred at a rate of 2.36 injuries per 1,000 athlete exposures in women’s soccer athletes. The knee had a lower rate of musculoskeletal injury at 1.77 injuries per 1,000 athlete exposures for women’s soccer athletes.

The NCAA Injury Surveillance System reported similar musculoskeletal injury rate patterns to the present study for women’s soccer athletes during the 15-year data collection period.[31] The NCAA Injury Surveillance System reported a practice musculoskeletal injury rate of 5.2 injuries per 1,000 athlete exposures for women’s soccer athletes.[31] The game injury rate for women’s soccer athletes according to the NCAA Injury Surveillance System was 16.4 injuries per 1,000 athlete exposures.[31] The lower extremity musculoskeletal injury rate for women’s soccer athletes during the present study followed a similar pattern for practice and game participation; practice participation had a lower musculoskeletal injury rate than the musculoskeletal injury rate during games (2.89 injuries per 1,000 athlete exposures vs. 9.74 injuries per 1,000 athlete exposures). The NCAA Injury Surveillance System reported higher rates of musculoskeletal injury for pre-season game participation compared competitive season game participation (19.65 injuries per 1,000 athlete exposures vs. 16.56 injuries per 1,000 athlete exposures).[31] The competitive season injury rates were higher than the post-season injury rate (16.56 injuries per 1,000 athlete exposures vs. 11.67 injuries per 1,000 athlete exposures) for participation in games according to the NCAA Injury Surveillance System.[31] Practice injury rates followed a similar trend to the game injury rates reported by the NCAA Injury Surveillance System for both the competitive season and the post-season.[31] The present study had opposing results for women's soccer musculoskeletal injury rates; competitive season musculoskeletal injury rates were greater than pre-season musculoskeletal injury rates (6.97 injuries per 1,000 athlete exposures vs. 3.66 injuries per 1,000 athlete exposures). 70% of all musculoskeletal injuries reported over the 15-year data collection period of the NCAA Injury Surveillance System were lower extremity musculoskeletal injuries.[31] This would indicate that it can be expected that the musculoskeletal injury rates calculated for the presented study should be slightly lower than the musculoskeletal injury rates calculated for the NCAA Injury Surveillance System, due to the exclusion of all musculoskeletal injuries not to the lower extremity in the present study.

When men's and women's soccer athletes are examined as a group the overall musculoskeletal injury rate is less than football athletes, but greater than women's volleyball athletes. This is in agreeance with the general trend noted by the NCAA Injury Surveillance System.[3, 31] Generally, football is considered a collision sport, the demands of this sport are therefore increased because of the constant purposeful contact (collision) that occurs between players of opposing teams.[28] This constant purposeful collision can significantly increase risk of lower extremity musculoskeletal injury, leading to increased injury rates when comparing to other sport types, which have significantly less purposeful collision associated with them.[28] Women's volleyball has the least likelihood of a purposeful athlete collision; therefore, it would be excepted that their musculoskeletal injury rates are lower than that of other sport types.[5] One of the most notable differences in the musculoskeletal injury rates of the present study between sport types as compared to soccer is that men's and women's soccer athletes had an injury rate of

6.80 injuries per 1,000 athlete exposures when participating in games, while football had no injury occurrences during participation in games. This may be indicative of the differences in training between men's and women's soccer and football. Training during practice participation in men's and women's soccer is very similar to game participation, meaning the structure and intensity is similar between practices and games; this is the often achieved through periodization and tracking of athletes through GPS devices.[3, 31] Training during practice participation in football is often very different from game play.[28] Football game play is regulated by certain rules and regulations that have been set forth by the NCAA.[28] There is also care given to following these rules and regulations, with referees enforcing these rules during football game participation.[28] The ability to match intensity between practice participation to game participation in football is much harder than in men's and women's soccer.[28] Often times this lack of ability to match intensity leads to greater intensity practices, with a lack of rules and regulations, as well as decreased oversight of these rules and regulations.[28] The lower extremity musculoskeletal injury rates between practice and game participation in men's and women's soccer athletes are mirrored in women's volleyball athletes. These two sport types are very similar in the ability to mimic intensity between game and practice participation.

Comparison of the rate of lower extremity musculoskeletal injury in men's soccer and women's soccer athletes demonstrates more similarities than differences between the two sexes participating in the same sport type. The overall lower extremity musculoskeletal injury rates are very similar, with men's soccer athletes having a lower extremity musculoskeletal injury rate just slightly lower than women's soccer athletes. There is no difference between practice and game injury rates in men's soccer athletes, whereas there is a large discrepancy between the injury rate during practice participation and game participation in the women's soccer athletes. Additional results of the present study agree with the results of previous research. Epidemiological studies have demonstrated that women's soccer athletes are at greater risk of suffering knee injury when compared to men's soccer athletes.[3, 31] The women's soccer athletes tested as a part of the present study had a greater incidence of musculoskeletal injury at the knee than the men's soccer athletes.[3, 31] The differences in lower extremity musculoskeletal injury risk attributed to sex have been well researched.[72] These sex differences may be due to a number of different reasons, which may include changes in body composition, joint laxity, strength, and hormonal changes.[72] Generally, women tend to have greater joint laxity and less strength in the lower extremity compared to their male counterparts; these changes in musculoskeletal characteristics of the lower extremity are modifiable risk factors that increase risk of musculoskeletal injury of the lower extremity.[77] These changes may also explain why the women's soccer athletes in the present study demonstrate a greater incidence of lower extremity musculoskeletal injury compared to the men's soccer athletes.

5.2.2 Football

Overall, the present study examined the lower extremity musculoskeletal injury rate in 43 Division I football athletes at the University of Pittsburgh. Twenty-three of the 43 football athletes examined in the present study suffered a lower extremity musculoskeletal injury. Eleven of the 43 football athletes suffered more than one lower extremity musculoskeletal injury over the course of the collegiate fall football season. Total, 35 lower extremity musculoskeletal injuries were suffered over the course of the collegiate fall football season. The overall lower extremity musculoskeletal injury rate for the football collegiate fall season was 10.19 injuries per

1,000 athlete exposures. For football athletes the acute lower extremity musculoskeletal injury rate for the fall collegiate football season was 9.61 injuries per 1,000 athlete exposures; the overuse injury rate was 0.58 injuries per 1,000 athlete exposures. The lower extremity musculoskeletal injury rate for football during participation in practice was 11.75 injuries per 1,000 athlete exposures, no lower extremity musculoskeletal injuries were suffered during game participation. The pre-season injury rate for football athletes was 4.70 injuries per 1,000 athlete exposures. The competitive season lower extremity musculoskeletal injury rate was 9.70 injuries per 1,000 athlete exposures for football athletes. The post-season lower extremity musculoskeletal injury rate for football athletes was 2.44 injuries per 1,000 athlete exposures. The injury rate for injuries occurring at the ankle in the football athletes was 3.49 injuries per 1,000 athlete exposures; the knee injury rate was 1.75 injuries per 1,000 athlete exposures.

The NCAA Injury Surveillance System reported that over the 15-year data collection period, football had the greatest rate of musculoskeletal injury in all lower extremity dominant sports.[28, 47] Game musculoskeletal injury rates in football were as high as 35.90 injuries per 1,000 athlete exposures, as reported by the NCAA Injury Surveillance System.[28, 47] Practice musculoskeletal injury rates were 3.80 injuries per 1,000 athlete exposures according to the NCAA Injury Surveillance System.[28, 47] The football athletes in the present study suffered no lower extremity musculoskeletal injuries during game participation and the musculoskeletal injury rate during participation in practice was 11.75 injuries per 1,000 athlete exposures. This is in opposition to the NCAA Injury Surveillance System results; the game musculoskeletal injury rate is greater than the practice musculoskeletal injury rate.[28, 47] 42,355 musculoskeletal injuries were reported over the 15-year data collection period of the NCAA Injury Surveillance System during participation in collegiate football.[28, 47] Pre-season practice musculoskeletal injury rates were much higher than the competitive season for collegiate football according to the NCAA Injury Surveillance System (36.11 injuries per 1,000 athlete exposures vs. 23.71 injuries per 1,000 athlete exposures).[28, 47] The results of the present study had greater rates of lower extremity musculoskeletal injury during the competitive season than the pre-season for football athletes (9.70 injuries per 1,000 athlete exposures vs. 4.70 injuries per 1,000 athlete exposures).

Football has the greatest incidence of lower extremity musculoskeletal injury compared to the remainder of the sport types tested as a part of the present study. Football is a collision sport by nature, which generally increases the lower extremity musculoskeletal injury risk.[28, 47] During participation in collision sports athletes are exposed to a greater number of opportunities for musculoskeletal injury.[28, 47] Although football had the greatest incidence of overall lower extremity musculoskeletal injury, there were no musculoskeletal injuries which occurred during game play. This is likely due to the strict rules and regulations that are enforced during football game play.[28, 47] Football athletes demonstrated the greatest number of muscle strain injuries compared to the remaining sport types represented in the present study. Many of the motions football athletes must perform, in order to be successful force athletes into a position of vulnerability.[28, 47] For example, linemen are continually placed in extreme ankle dorsiflexion which very quickly turns into a forceful contraction of the posterior lower extremity muscles when the athletes move into a tackle or collision with an athlete of the opposing team. This quick and forceful contraction, which is repeated numerous times during both practice and game participation, increases a football athletes risk of lower extremity muscle strain.

5.2.3 Volleyball

Overall, the present study examined the lower extremity musculoskeletal injury rate in 16 Division I women's volleyball athletes at the University of Pittsburgh. Four of the 16 women's volleyball athletes examined in the present study suffered a lower extremity musculoskeletal injury. One of the 16 women's volleyball athletes suffered more than one lower extremity musculoskeletal injury over the course of the collegiate fall women's volleyball season. In total 5 lower extremity musculoskeletal injuries were suffered over the course of the collegiate fall women's volleyball season. The overall lower extremity musculoskeletal injury rate for the collegiate fall women's volleyball season was 2.87 injuries per 1,000 athlete exposures. For women's volleyball, the acute lower extremity musculoskeletal injury rate for the fall collegiate women's volleyball season was 2.29 injuries per 1,000 athlete exposures; the overuse injury rate was 0.57 injuries per 1,000 athlete exposures. The lower extremity musculoskeletal injury rate for women's volleyball athletes during participation in practice was 3.28 injuries per 1,000 athlete exposures, during game participation the lower extremity musculoskeletal injury rate was 1.91 injuries per 1,000 athlete exposures. The competitive season lower extremity musculoskeletal injury rate was 3.89 injuries per 1,000 athlete exposures; no injuries were suffered during the pre-season or post-season. The injury rate for injuries occurring at the ankle and the muscles of the lower extremity in the women's volleyball athletes was 0.57 injuries per 1,000 athlete exposures; the hip injury rate was 1.15 injuries per 1,000 athlete exposures.

The NCAA Injury Surveillance System reported that over the 15-year data collection period, the game musculoskeletal injury rates in women's volleyball athletes is 4.58 injuries per 1,000 athlete exposures.[5, 47] Practice musculoskeletal injury rates were similar at 4.10 injuries per 1,000 athlete exposures, according to the NCAA Injury Surveillance System.[5, 47] The women's volleyball athletes in the present study suffered 1.91 injuries per 1,000 athlete exposures during game participation and the musculoskeletal injury rate during participation in practice was 3.28 injuries per 1,000 athlete exposures. This is in opposition to the NCAA Injury Surveillance System results; the game musculoskeletal injury rate was greater than the practice musculoskeletal injury rate. 2,216 musculoskeletal injuries were reported over the 15-year data collection period of the NCAA Injury Surveillance System during participation in collegiate women's volleyball.[5, 47] Pre-season practice musculoskeletal injury rates were two times higher than the competitive season for collegiate women's volleyball athletes, according to the NCAA Injury Surveillance System (6.19 injuries per 1,000 athlete exposures vs. 2.82 injuries per 1,000 athlete exposures).[5, 47] The results of the present study had greater rates of lower extremity musculoskeletal injury during the competitive season than the pre-season for women's volleyball athletes (3.89 injuries per 1,000 athlete exposures vs. 0.00 injuries per 1,000 athlete exposures).

Volleyball has the lowest lower extremity musculoskeletal injury rate of all the sport types tested as a part of the present study. This may be due to the demand that volleyball athletes must endure compared to the remainder of the athletes in the present study.[5, 47] Volleyball has the lowest demand out of all the sport types tested, as well as having the smallest likelihood that contact or collision between athletes would occur during practice and game participation.[5, 47] The rate of muscle strain injury in the volleyball athletes is greater than the soccer athletes, but less than the football athletes.[5, 47] It may be expected that the rate of muscle injury, including muscle strain injury, in volleyball athletes would be greater than all of the other sport types tested as a part of the present study.[5, 47] The plyometric nature of volleyball places a greater demand on the muscles of the lower extremity. This demand is often times eccentric, which means the muscle is lengthening while simultaneously providing a force. Eccentric contractions result in lower extremity musculoskeletal injury more often than concentric contractions. Often the cumulative and repetitive jumping that occurs as a part of volleyball participation results in a greater number of lower extremity musculoskeletal injuries. In the population of volleyball athletes tested as a part of the present study, this cumulative of micro-trauma due to repetitive jumping did not result in lower extremity musculoskeletal injury rates greater than the other sport types tested, excluding muscle strain injury.

5.2.4 Basketball

Overall, the present study examined the lower extremity musculoskeletal injury rate in 11 Division I men's basketball athletes at the University of Pittsburgh. Five of the 11 men's basketball athletes examined in the present study suffered a lower extremity musculoskeletal injury. None of the 11 men's basketball athletes suffered more than one lower extremity musculoskeletal injury over the course of the collegiate winter men's basketball season. In total 5 lower extremity musculoskeletal injuries were suffered over the course of the collegiate winter men's basketball season. The overall lower extremity musculoskeletal injury rate for the collegiate winter men's basketball season was 3.92 injuries per 1,000 athlete exposures. For men's basketball, the acute lower extremity musculoskeletal injury rate for the winter collegiate men's basketball season was 2.35 injuries per 1,000 athlete exposures; the overuse injury rate was 1.57 injuries per 1,000 athlete exposures. The lower extremity musculoskeletal injury rate for men's basketball athletes during participation in practice was 4.09 injuries per 1,000 athlete exposures, during game participation the lower extremity musculoskeletal injury rate was 3.37 injuries per 1,000 athlete exposures. The pre-season lower extremity musculoskeletal injury rate was 2.46 injuries per 1,000 athlete exposures. The competitive season lower extremity musculoskeletal injury rate was 4.82 injuries per 1,000 athlete exposures; no injuries were suffered during the post-season. The injury rate for injuries occurring at the ankle and the knee in the men's basketball athletes was 0.78 injuries per 1,000 athlete exposures; the other injury rate was 2.35 injuries per 1,000 athlete exposures.

The NCAA Injury Surveillance system demonstrated injury rates two times higher in game play compared to practice situations for men's basketball athletes; game play has a reported injury rate of 9.9 injuries per 1,000 athlete-exposures, while practice has an injury rate of 4.3 injuries per 1,000 athlete-exposures.[29] The gap between lower extremity musculoskeletal injury rates during practice participation and game participation in the present study was much less (4.09 injuries per 1,000 athlete exposures vs. 3.37 injuries per 1,000 athlete exposures). Pre-season injury rates, as measured by the NCAA Injury Surveillance System were three times higher than injury rates during the competitive season (7.5 injuries per 1,000 athlete-exposures vs. 2.8 injuries per 1,000 athlete-exposures; $p < 0.01$).[29] The present study demonstrated the opposite, with the competitive season lower extremity musculoskeletal injury rate being greater than the pre-season lower extremity musculoskeletal injury rate. The NCAA Injury Surveillance System reported a small number of injuries during the post-season 1.5 injuries per 1,000 athlete-exposures.[29] The present study demonstrated that regardless of playing two post-season games, there were no lower extremity musculoskeletal injuries reported.

Overall, the present study examined the lower extremity musculoskeletal injury rate in 13 Division I women's basketball athletes at the University of Pittsburgh. Six of the 13 women's basketball athletes examined in the present study suffered a lower extremity musculoskeletal injury. None of the 13 women's basketball athletes suffered more than one lower extremity musculoskeletal injury over the course of the collegiate winter women's basketball season. In total six lower extremity musculoskeletal injuries were suffered over the course of the collegiate winter women's basketball season. The overall lower extremity musculoskeletal injury rate for the collegiate winter women's basketball season was 4.45 injuries per 1,000 athlete exposures. For women's basketball, the acute lower extremity musculoskeletal injury rate for the winter collegiate women's basketball season was 2.22 injuries per 1,000 athlete exposures; the overuse injury rate was 2.22 injuries per 1,000 athlete exposures. The lower extremity musculoskeletal injury rate for women's basketball athletes during participation in practice was 5.62 injuries per 1,000 athlete exposures, during game participation no lower extremity musculoskeletal injuries were suffered. The pre-season lower extremity musculoskeletal injury rate was 13.51 injuries per 1,000 athlete exposures. No injuries were suffered during the competitive season or the post-season. The injury rate for injuries occurring at the knee in the women's basketball athletes was 1.48 injuries per 1,000 athlete exposures; the other injury rate was 2.22 injuries per 1,000 athlete exposures. The injury rate to the muscles of the lower extremity was 0.74 injuries per 1,000 athlete exposures.

Women's basketball follows similar trends to men's basketball in that the injury rate during game play is two times higher than that of practice according to the data collected during for the NCAA Injury Surveillance System.[4] In the present study the women's basketball athletes suffered no injuries during the competitive season; all lower extremity musculoskeletal injuries suffered in the present study were during the pre-season. The game injury rate for women's basketball is 7.68 injuries per 1,000 athlete-exposures while the practice injury rate is 3.99 injuries per 1,000 athlete-exposures.[4] The lower extremity musculoskeletal injury rate during practice participation for the women's basketball athletes in the present study is 5.62 injuries per

1,000 athlete exposures. For the present study the lower extremity musculoskeletal injury rate for women's basketball athletes during practice participation is greater than the injury rate reported by the NCAA Injury Surveillance System.[4] This is of interest because the NCAA Injury Surveillance System collects musculoskeletal injury at all joints, not just the lower extremity.[4] The present study collected only musculoskeletal injuries that occurred at the lower extremity, and still demonstrated greater injury rates during practice participation.[4] Over the 16-year period that the NCAA Injury Surveillance System was collecting data, 3,556 injuries were collected in women's basketball athletes.[4] Pre-season practice injury rates were 6.75 injuries per 1,000 athlete exposures according to the NCAA Injury Surveillance System. [4] Collecting only lower extremity musculoskeletal injuries, the present study demonstrated almost two times the pre-season injury rate at 13.51 injuries per 1,000 athlete exposures.

5.3 RISK FACTORS FOR LOWER EXTREMITY MUSCULOSKELETAL INJURY IN COLLEGIATE ATHLETES

5.3.1 Body Composition

Overall, in the present study, the variables collected to represent body composition are not predictive of lower extremity musculoskeletal injury in men's and women's athletes who participate in lower extremity dominant sports at the University of Pittsburgh. Previous research has identified the extreme ends of the Body Mass Index as a risk factor for lower extremity musculoskeletal injury, as well as shorter height, and greater overall body mass.[9, 16, 48, 54, 71, 76] Increases in height and overall body mass are often times desirable traits for participation in sport, due to the advantage that both height and body mass can provide for optimal athletic performance.[41, 54] This height and body mass increase is of specific importance in women's volleyball and football, two sports included in the present study.[41, 54] Although increases in overall body mass is often indicated in sport, it has been linked to increased risk for lower extremity musculoskeletal injury, as well as being linked to decreased agility and flexibility, and increased joint loading.[41] Sport type is indicative of the performance characteristics necessary to be successful and perform at an optimal level.[41, 54] Proper clinical care of athletes should include an understanding of sport type in order to determine the effects of body composition on risk of lower extremity musculoskeletal injury.

The present study tracked 48 men's and women's soccer athletes who demonstrated that body composition was not a significant predictor of lower extremity musculoskeletal injury. This inability for body composition to predict lower extremity musculoskeletal injury is true for all men's and women's soccer athletes, as well as when the soccer athletes are stratified by sex. The body composition variables examined in the present study, which proved not to be significant predictors of lower extremity musculoskeletal injury in men's and women's soccer athletes included body fat percentage, percent lean mass, fat mass in kilograms, fat free mass in kilograms, body weight in kilograms, and height in centimeters. Although desirable for some sport types, increased body mass can negatively effect athletes.[41] Increased total body mass has been linked to lower levels of physical activity, agility, and flexibility.[41] When these performance characteristics are negatively effected there is a greater risk of lower extremity musculoskeletal injury. Increased body fat levels have also been linked to increased joint loading.[41] When joint loading increases there is a decrease in physical activity levels, which again, lead to increased lower extremity musculoskeletal injury risk.[41] The men's and women's soccer athletes in the present study did not demonstrate any significant relationships between body composition and risk of lower extremity musculoskeletal injury. This may indicate that in soccer athletes body composition is neither a desirable trait or a non-desirable trait for optimal performance and risk of lower extremity musculoskeletal injury.

Similar to the men's and women's soccer athletes, the 43 football athletes and the 16 women's volleyball athletes tested as a part of this study, demonstrated that body composition was not predictive of lower extremity musculoskeletal injury. In addition to the changes in body mass placing athletes at increased risk of lower extremity musculoskeletal injury, height is also an important risk factor for lower extremity musculoskeletal injury.[54] Height is of specific importance to the population of volleyball athletes tested as a part of the present study. Height is generally a desirable trait for volleyball, the greater the athlete's height, the greater their ability to successfully participate in volleyball. Height has been previously demonstrated as a predictor of lower extremity musculoskeletal injury.[54] But, this does not hold true in any of the sport types, including volleyball, presented in the present study. Previous studies have demonstrated that female military recruits of shorter height have a greater risk of lower extremity musculoskeletal injury when compared to female military recruits of taller height.[54] Quadriceps muscle strain has also demonstrated links to athletes of shorter height, specifically in Australian football athletes.[76] The results of previous research may indicate that taller height is a protective factor against lower extremity musculoskeletal injury.[76] This may explain the lack of significance of height as a risk factor for lower extremity musculoskeletal injury in the present study. The mean height of the athlete tested as a part of the present study is likely greater than the average of many sport types, due to the sport types included. The sport types included tend to have athletes who are of greater height, including basketball and volleyball, driving the average height up, and decreasing the risk of lower extremity musculoskeletal injury in these populations of athletes.

5.3.2 Flexibility

Flexibility as a risk factor for lower extremity musculoskeletal injury is gradient, both excessive joint laxity and excessive tightness within the joint can increase the risk of lower extremity musculoskeletal injury risk in athletes who participate in lower extremity dominant sports.[77, 94] Too much joint laxity has been demonstrated to increase the risk of lower extremity musculoskeletal injury by up to five times in women's soccer athletes at the knee and ankle joint.[77] Laxity in the ankle joint has been linked to increased risk of ankle sprain, while medial joint laxity at the knee joint has been linked to lower extremity musculoskeletal injury.[77, 94] Tightness and decreased range of motion has been previously linked to overuse injury to the lower extremity.[67] This risk is significantly altered by regular stretching and warm up prior to participate in sport.[67] Generally, in the sport types represented in the present study, increased flexibility increased the risk of lower extremity musculoskeletal injury. This was particularly evident in the hamstring muscle, as represented by the straight leg raise flexibility test.

The men's and women's soccer athletes, as a group, tested as a part of the present study did demonstrate significant predictions between hamstring flexibility as measured by the straight leg raise and lower extremity musculoskeletal injury. This is in agreement with previous research, which has proven that individual measures of lower extremity range of motion and flexibility can be predictors for both hip and muscle injury in soccer athletes.[16, 55, 94] The overall group of lower extremity dominant sport athletes tested as a part of the present study, as well as the basketball athletes also demonstrated significance between hamstring flexibility and lower extremity musculoskeletal injury; straight leg raise flexibility was predictive of lower extremity musculoskeletal injury. Men's and women's soccer athletes, as a group, did demonstrate that dominant to non-dominant range of motion and flexibility ratios significantly predicted lower extremity musculoskeletal injury. Dominant to non-dominant lower extremity flexibility ratios are only a risk factor for lower extremity musculoskeletal injury in men's and women's soccer athletes, none of the other sports tested as a part of the present study demonstrated no connection between lower extremity range of motion and flexibility ratios and lower extremity musculoskeletal injury. Hamstring flexibility is measured with the active knee extension flexibility test and the straight leg raise flexibility test. In previous research an overabundance of hamstring flexibility has been predictive of lower extremity musculoskeletal injury.[94] In the men's and women's soccer athletes, as hamstring flexibility increased the risk of lower extremity musculoskeletal injury increased. This may indicate that there is a point in which too much flexibility is damaging as opposed to helpful in putting athletes at risk for lower extremity musculoskeletal injury. It would be expected that an athlete has balanced flexibility side to side, which would be indicated by a value of 1.00 for the ratio. When the value goes above the 1.00 the dominant side has increased flexibility compared to the non-dominant side, when the number is below 1.00 the non-dominant side has increased flexibility compared to the non-dominant side. Clinically, it may be expected that if the lower extremities are not balanced, the dominant side may be more flexible than the non-dominant side.

In the 16 collegiate women's volleyball athlete's tested as a part of the present study, lower extremity range of motion and flexibility was not significantly predictive of lower extremity musculoskeletal injury. Previous studies have demonstrated that side to side differences in ankle dorsiflexion range of motion and hamstring flexibility have been linked to increased risk of overuse lower extremity musculoskeletal injury.[94] In the current study population of 16 women's volleyball athletes, no increased risk of lower extremity musculoskeletal injury was noted as a result of increased dominant/non-dominant range of motion and flexibility ratios for ankle dorsiflexion range of motion and/or hamstring flexibility. Increased ankle joint laxity, as diagnosed with an anterior drawer test, has been associated with ankle injury.[94]

5.3.3 Strength

Both overall strength and strength ratios are modifiable musculoskeletal characteristics which have been previously demonstrated to be risk factors for lower extremity musculoskeletal injury.[12, 35, 94] Overall deficits in strength and imbalances between agonist and antagonist muscle groups have been linked to musculoskeletal injury at both the knee and ankle.[12, 35, 94] The ratio of ankle dorsiflexion to plantarflexion isometric strength and ankle eversion to inversion isometric strength have been linked to the increased occurrence of ankle sprain injuries in athletes who participate in lower extremity dominant sports.[12] Hamstring to quadriceps strength ratio has been linked to overuse musculoskeletal injury in the lower extremity as well as knee injury.[94] Side to side differences were of particular importance for risk of lower extremity musculoskeletal injury in the present study.[94] Overall, when all athletes who participate in lower extremity dominant sports were grouped, side to side differences in strength changed the risk of lower extremity musculoskeletal injury. This is also true for the description of only the men's lower extremity dominant athletes included in the present study, as well as the soccer, volleyball, and basketball sport types. Individually, weaknesses at the hip, including weaknesses in the internal rotators and external rotators, have been linked to pelvis weakness and decreased stability in the pelvis.[77] The pelvis is the foundation of movement for the distal joints, therefore decreased pelvis stability can increase the risk of lower extremity musculoskeletal injury for the entire kinetic chain.[77] The female athletes in the present study demonstrated that the muscles surrounding the pelvis and hip were linked to changes in risk of lower extremity musculoskeletal injury. Weaknesses in the musculature of the lower extremity may lead to or be indicative of a loss of pelvic stability.[77] Female athletes are often more susceptible to this because of the mobile nature of the bones that form the pelvis; the musculature needs to compensate for the increased mobility, leading to an increased risk of lower extremity musculoskeletal injury with strength weaknesses.[77]

Weaknesses in the hip can contribute significantly to change in pelvic stability.[77] When the hip external rotator muscles and the hip adductor muscles are performing at a suboptimal level, pelvic stability is lost.[77] This loss of pelvic stability leads to increased medial femoral rotation, knee valgus moments, and gluteus medius gait patterns.[77] Traditionally agonist/antagonist muscle pairs are predictors of lower extremity musculoskeletal injury.[12, 35, 94] The women's athletes who participated in lower extremity dominant sports who participated in the present study demonstrated a significant relationship between knee flexion strength and risk of lower extremity musculoskeletal injury. This may be demonstrative of the focus that injury prevention and rehabilitation programs have on maintaining and increasing hamstring strength in an effort to curb risk of musculoskeletal injury at the knee, specifically ACL injury. Women's athletes who participate in lower extremity dominant sports have one of the highest incidence in ACL injury among athletes who participate in lower extremity dominant sport.[94] This high incidence of ACL injury in women's athletes who participate in lower extremity dominant sports has lead to a great focus on strengthening of the hamstring muscle in order to prevent against this musculoskeletal injury.[94] Our results demonstrate that there is importance in having greater hamstring strength, due to reduced risk of all lower extremity musculoskeletal injuries.

5.3.3 Postural Stability

Postural stability was only demonstrated as a risk factor for lower extremity musculoskeletal injury in one sport type represented in the present study, football. Only one variable for eyes-closed static balance was significant, medial/lateral ground reaction force component score. Altered neuromuscular control strategies, increased joint forces, and increased forces in articular, ligamentous, and musculoskeletal characteristics have all been attributed to diminished postural stability.[85, 86, 92] When these characteristics are altered, the risk of musculoskeletal injury is increased.[85, 86, 92] Poor postural stability increases the sway of an individual away from the center of mass, increasing movement away from a stable base of support.[85, 86, 92] These altered movement patterns about a base of support have been associated with increased risk of lower extremity musculoskeletal injury in a wide variety of sport types, including soccer and basketball.[85, 86, 92] Poor dynamic postural stability has also been demonstrated as a risk factor for lower extremity musculoskeletal injury in athletes with a history of chronic ankle instability.[85, 86, 92]

The variables used to represent postural stability in the present study may not have provided enough of a range to detect changes in postural stability that may be associated with lower extremity musculoskeletal injury risk. The athletes tested as a part of the present study all had very similar scores between the static balance task and the dynamic postural stability task;

this may be due to the exclusion of athletes who had suffered a lower extremity musculoskeletal injury within the four weeks prior to testing. Healthy athletes may not have altered postural stability that reflect large enough changes to increase the risk of lower extremity musculoskeletal injury. If an athlete tested as a part of the present study had a lower extremity musculoskeletal injury outside of the required 4-week injury free period, they likely participated in a rehabilitation program that changed their postural stability; returning the athletes postural stability to a normal level and/or increasing their postural stability and/or in respect to that athletes. These factors may influence the ability for postural stability increase risk of lower extremity musculoskeletal injury in athletes who participate in lower extremity dominant sports.

5.4 LIMITATIONS

There are inherent limitations associated with the present study. These inherent limitations may depreciate the ability for the results of this study to be generalized. The first limitation of the present study is that all of the athletes who participated in the study were Division I NCAA athletes participating in lower extremity dominant sports at the University of Pittsburgh. This population is very specific and has the potential to be different than athletes at different institutions who participate in different levels of competition, including NCAA Division II and NCAA Division III. Because the study participants were only Division I NCAA athletes participating in lower extremity dominant sports at the University of Pittsburgh the generalization of these results should be made with caution.

A second limitation of the present study is that in order for each athlete to meet the inclusion/exclusion criteria for the study, each athlete had to be free of lower extremity musculoskeletal injury within the four week prior to their testing session. Previous lower extremity musculoskeletal injury is a known risk factor for lower extremity musculoskeletal injury. Although this is a risk factors for lower extremity musculoskeletal injury, it is non-modifiable; there is no ability to change a history of lower extremity musculoskeletal injury through an intervention. Lower extremity musculoskeletal injury history and/or prospective lower extremity musculoskeletal injury may significantly affect the musculoskeletal characteristics measured in the present study. An examination of the potential differences in the musculoskeletal characteristics tested during this study in athletes with and without a history of injuries may be necessary to understand the connection between lower extremity musculoskeletal injury history and these musculoskeletal characteristics.

Sample size for the present study was calculated based on that assumption that the mean exposure time per athlete would be 120. The exposure time for each athlete in the present study was slightly lower than the estimated exposure time of 120. For the purposes of the present study exposures were collected for one collegiate season; between the first day of pre-season for each sport, respectively, through the last game of the competitive season. If the team was invited to participate in the post-season, exposures were collected through the last game of the post-season. A majority of the teams tested for the purposes of the present study were not invited to participate in the post-season, therefore the actual exposure time for each athlete was less than the excepted exposure time. Sample size may have also had implications on the clinical implications of the lower extremity musculoskeletal injury risk factor analysis. The clinical implications of our risk factor analysis are limited due to the small number of lower extremity musculoskeletal injuries sustained by the study sample. In addition, when the data is stratified by sport type and sex, our lower extremity musculoskeletal injury risk factor analysis is limited because of the very small number of athletes in each sport type and the number of lower extremity musculoskeletal injuries sustained by each sport type and sex. For the present study both preventable and non-preventable lower extremity musculoskeletal injuries were included in the risk factor analysis. This increases the number of lower extremity musculoskeletal injuries suffered by our sample, but may also effect the clinical applications of the risk factor analysis portion of the present study.

5.5 STUDY SIGNIFICANCE

The present study provides a description of the burden of lower extremity musculoskeletal injury in men's and women's NCAA Division I athletes participating in lower extremity dominant sports at the University of Pittsburgh. The lower extremity musculoskeletal injury incidence rate was identified, according to sport type, injury location, and injury type. The identification of the modifiable intrinsic risk factors for the lower extremity musculoskeletal injury identified in the present study will assist in informing clinicians on appropriate injury prevention initiatives. These injury prevention initiatives may be more targeted than previously developed injury prevention initiatives, because they are based on the identification of the modifiable risk factors for lower extremity musculoskeletal injury. By targeting the specific differences in modifiable risk factors for lower extremity musculoskeletal injury identified in the present study, clinicians can provide more comprehensive care for lower extremity musculoskeletal injuries. By providing more complete and targeted care, clinicians have a greater opportunity to decrease the duration of missed participation and risk of re-injury. The results of the present study provide information that can be employed for the improvement of overall musculoskeletal heath, longevity of an athlete's career, and success of an athlete living a healthy lifestyle following the end of their athletic career. Clinicians, coaches, and policy makers can all benefit from targeted strategies for prevention of lower extremity musculoskeletal injuries, focused on modifiable intrinsic risk factors.

5.6 FUTURE DIRECTIONS

Future research should begin with an evaluation of the musculoskeletal characteristics determined to be modifiable risk factors for lower extremity musculoskeletal injury in athletes who participate in different levels of competition. This will provide insight on the generalizability of the results of the present study. In addition to evaluating these characteristics in athletes who participate in different competition levels, an investigation of these musculoskeletal characteristics in lower extremity dominant sports not included in the present study may be necessary. Sports such as track and cross country, are traditionally considered lower extremity dominant sports, but these sports have a significantly different injury profile than the sports chosen to be represented in the present study. A majority of the lower extremity musculoskeletal injuries suffered in these sport types, track and cross country, are overuse injuries as opposed to the acute injuries demonstrated by the sport types which were examined in the present study. Determining the musculoskeletal characteristics which are modifiable risk factors for lower extremity musculoskeletal injury in sport types other than the types included in the present study may be an important next step. Examining the differences in the musculoskeletal characteristics deemed modifiable risk factors for lower extremity injury in sport types with predominantly acute injuries and sport types with predominantly overuse injuries may provide further insight into the best way to treat athletes who participate in lower extremity dominant sports.

Another important future research direction is the development of injury prevention initiatives based on the findings of the present study. Exercises included in the injury prevention initiatives should be chosen deliberately in order to address the modifiable risk factors for lower extremity musculoskeletal injury identified in the present study. Once the injury prevention initiatives are developed, intervention studies would be necessary to prove the exercises are effective in changing the modifiable risk factors for lower extremity musculoskeletal injury. If the intervention has the ability to change the modifiable risk factors for lower extremity musculoskeletal injury, then it is necessary to determine if, in addition to changing the modifiable risk factors, there is a subsequent reduction in lower extremity musculoskeletal injury, identified through a prospective study.

5.7 CONCLUSIONS

Lower extremity musculoskeletal injury is a significant and prevalent problem in athletes who participate in lower extremity dominant sports.[3-5, 28, 29, 31, 47] The present study was able to identify lower extremity musculoskeletal injury rates in University of Pittsburgh Division I NCAA athletes who participate in the following sports: men's soccer, women's soccer, women's volleyball, football, men's basketball, and women's basketball. Range of motion, flexibility, and strength of the lower extremity were determined to be risk factors for lower extremity musculoskeletal injury in all sport types excluding men’s soccer. Each sport type displayed a different profile of risk factors for lower extremity musculoskeletal injury. Therefore, it is important that clinicians focus on sport type specific modifiable risk factors for lower extremity musculoskeletal injury.

APPENDIX A

NCAA INJURY SURVEILLANCE SYSTEM

A.1 INJURY SURVEILLANCE DATA COLLECTION FORM

Appendix A.

2003-04 Individual INJURY Form—Women's Volleyball

NCAA Injury Surveillance System

INJURY DEFINITION: A reportable injury in the ISS is defined as one that:
1. Occurs as a result of participation in an organized intercollegiate practice or contest;
2. Requires medical attention by a team athletics trainer or physician; and
3. Results in any restriction of the athlete's participation or performance* for one or more days beyond the day of injury.
4. **Any dental injury regardless of time loss.**

* See POINTS OF EMPHASIS.

School Code: ______________________

Select one: Fall season Spring season

1. Year:
(1) FR (2) SO (3) JR (4) SR (5) Fifth

2. Age: ________ years **4. Weight:** __________ pounds

3. Height: _____ inches **5. Date of injury:** __________ (month/day)

6. Injury occurred during:
(1) Preseason (before first regular-season match)
(2) Regular season
(3) Postseason (after final regular-season match)
(99) Other: ______________________

7. Injury occurred in:
(1) Competition—varsity
(3) Practice

8. COMPETITION ONLY—Where did this injury occur?
(1)Home (3) Neutral site
(2)Away (99) Other: ______

9. Injury occurred during:
Competition: (1) Warm-up (2) Game 1 (3) Game 2 (4) Game 3 (5) Game 4 (6) Game 5
Practice: (7) First half (8) Second half
(99) Other: ___

10. This injury is a:
(1) New injury
(2) Recurrence of injury from this season
(3) Recurrence of injury from previous season (this sport)
(4) Complication of previous injury (this sport)
(5) Recurrence of other-sport injury
(6) Recurrence of nonsport injury
(7) Complication of other-sport injury

11. Has student-athlete had unrelated injury recorded this season?
(1) Yes (2) No

12. *Not applicable to this sport; proceed to next question.*

13. How long did this injury keep student-athlete from participating in the sport? (If end of season, give best estimate.)
(1) 1-2 days (4) 10 days or more
(2) 3-6 days (5) Catastrophic, nonfatal
(3) 7-9 days (6) Fatal

14. This injury involved:
(1) Contact with another competitor
(2) Contact with playing surface
(3) Contact with apparatus/ball
(4) Contact with other in environment (e.g., wall, fence, spectators)
(5) No apparent contact (rotation about planted foot)
(6) No apparent contact (other)
(99) Other: ______________________

15. Principal body part injured (for 1-10, complete Head-Injury Information; for 31 or 32, complete Knee-Injury Information):

(1) Head	(23) Spine
(2) Eye(s)	(24) Lower back
(3) Ear(s)	(25) Ribs
(4) Nose	(26) Sternum
(5) Face	(27) Stomach
(6) Chin	(28) Pelvis, hips, groin
(7) Jaw (TMJ)	(29) Buttocks
(8) Mouth	(30) Upper leg
(9) Teeth	(31) Knee
(10) Tongue	(32) Patella
(11) Neck	(33) Lower leg
(12) Shoulder	(34) Ankle
(13) Clavicle	(35) Heel/Achilles' tendon
(14) Scapula	(36) Foot
(15) Upper arm	(37) Toe(s)
(16) Elbow	(38) Spleen
(17) Forearm	(39) Kidney
(18) Wrist	(40) External genitalia
(19) Hand	(41) Coccyx
(20) Thumb	(42) Breast
(21) Finger(s)	(99) Other: __________
(22) Upper back	

HEAD INJURY (answer only if response in question 15 was 1-10)

16. This student-athlete was diagnosed as having:
(1) 1° cerebral concussion. [No loss of consciousness, short post-traumatic amnesia (seconds up to two minutes).]
(2) 2° cerebral concussion. [Loss of consciousness (less than five minutes) and amnesia for up to 30 seconds].
(3) 3° cerebral concussion. [Loss of consciousness (more than five minutes) and extended amnesia.]
(4) No cerebral concussion
(5) Unknown

17. Was a mouthpiece (MP) worn?
(1) MP worn—dentist-fitted (3) MP not worn
(2) MP worn—self-fitted

18. Type eye injury:
(1) Orbital fracture (4) Soft tissue
(2) Cornea (99) Other: __________
(3) Ruptured globe

KNEE INJURY (answer only if response in question 15 was 31 or 32)

19. Circle ALL knee structures injured:
(1) Collateral (5) Patella and/or patella tendon
(2) Anterior cruciate (6) None
(3) Posterior cruciate (99) Other: __________
(4) Torn cartilage (meniscus)

– Please Answer All Questions –

Appendix A (cont).

– Please Answer All Questions –

20. Primary type of injury (circle one):
(1) Abrasion
(2) Contusion
(3) Laceration
(4) Puncture wound
(5) Bursitis
(6) Tendinitis
(7) Ligament sprain (incomplete tear)
(8) Ligament sprain (complete tear)
(9) Muscle-tendon strain (incomplete tear)
(10) Muscle-tendon strain (complete tear)
(11) Torn cartilage
(12) Hyperextension
(13) AC separation
(14) Dislocation (partial)
(15) Dislocation (complete)
(16) Fracture
(17) Stress fracture
(18) Concussion
(19) Heat exhaustion
(20) Heatstroke
(21) Burn
(22) Inflammation
(23) Infection
(24) Hemorrhage
(25) Internal injury (nonhemorrhage)
(26) Nerve injury
(27) Blisters
(28) Boil(s)
(29) Hernia
(30) Foreign object in body orifice
(31) Avulsion (tooth)
(99) Other: ____________

21. Did a laceration or wound that resulted in oozing or bleeding occur as a part of this injury?
(1) Yes (2) No

22. Did this injury require surgery?
(1) Yes, in-season (2) Yes, postseason (3) No

23. Describe the joint surgery:
(1) Arthrotomy
(2) Diagnostic arthroscopy
(3) Operative arthroscopy
(4) No joint surgery
(99) Other: ____________

24. Injury assessment (best assessment procedure):
(1) Clinical exam by athletic trainer
(2) Clinical exam by M.D./D.D.S.
(3) X-ray
(4) MRI
(5) Other imagery technique
(6) Surgery
(7) Blood work/lab test
(99) Other: ____________

25. Injury occurred during:
(1) Offensive play
(2) Defensive play
(3) Neither

26. Type of surface:
(1) Wood
(2) Composition
(99) Other: ____________

Additional comments (optional): ____________

____

____

____

____

____

____

27. Injury was caused by:
(1) Injured player coming down on another player
(2) Another player coming down on injured player
(3) Other contact with another player
(4) Contact with net
(5) Contact with standard
(6) Contact with floor
(7) Contact with ball
(8) Contact with out-of-bounds observers (team, fans, media, cheerleaders)
(9) Contact with out-of-bounds apparatus (tables, bleachers, cameras)
(10) No apparent contact
(99) Other: ____________

28. Injured player's activity:
(1) Serving
(2) Spiking
(3) Setting
(4) Passing
(5) Digging
(6) Blocking
(7) Conditioning
(99) Other: ____________

29. Position played at time of injury (circle one):
(1) Left front
(2) Center front (middle blocker)
(3) Right front
(4) Left back
(5) Center back (defensive specialist)
(6) Right back
(7) Nonpositional/conditioning drill
(99) Other: ____________

30. Assuming the athlete plays for Team A, which number best represents where the injury occured while she was playing the ball?
(1) Area 1 (outside Team A's court)? ☐
(2) Area 2 (on court)? ☐
(3) Area 3 (across center line, outside opponent's court)? ☐

PRACTICE ONLY

31. Injury occurred during:
(1) A triple session day
(2) A double session day
(3) A single session day
(99) Other: ____________

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A.2 EXPOSURE DATA COLLECTION FORM

Appendix B.

2003-04 Weekly EXPOSURE Form—Women's Volleyball

NCAA Injury Surveillance System

EXPOSURE DEFINITION: An athlete exposure, the unit of risk in the ISS, is defined as one student-athlete participating in one practice or competition where he or she is exposed to the possibility of an athletics injury. Please report all weeks that include FORMAL team practices involving the entire team. Do not report optional or "captain's" practices.

Note: Please be as accurate as possible in reporting number of participants. PRACTICE participants must be included in a majority of the drills. GAME participants must have **actual playing time.** In most cases, the number of game participants is *less than* the number of practice participants.

School Code: ________________ **Week of:** ________________
(Sunday to Saturday)

Please answer all questions

PRACTICE

1. **Number of practices this week (Sunday to Saturday):** ________________
2. **This week was part of:**
   (1) Preseason (before first regular-season contest)
   (2) Regular season
   (3) Postseason (after final regular-season contest; includes conference, regional and national tournaments)
3. **Average number of participants per practice** (see instructions): ________
4. **Number of practices on wood surface:** ________
5. **Number of practices on composition (non-wood) surface:** ________

VARSITY CONTEST

6. **Was a varsity contest played?**
   (1) No (stop)
   (2) Yes (go to next question)
7. **Number of varsity contests:** ________
8. **For each varsity contest, provide the following information:**

Contest	Total Number of Participants **With Actual Playing Time** (your team)	Location (check one) Home	Away	Type of Surface (check one) Composition (non-wood)	Wood
No. 1	________	____	____	____	____
No. 2	________	____	____	____	____
No. 3	________	____	____	____	____
No. 4	________	____	____	____	____
No. 5	________	____	____	____	____

NCAA 17430-7/03

APPENDIX B

UNIVERSITY OF PITTSBURGH INJURY PREVENTION INITIATIVE

B.1 INJURY SURVEILLANCE DATA COLLECTION FORM

IRB #:
Title: Injury Risk Factors for Lower Extremity Injury in Collegiate Women's Voellyball Athletes

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Subject ID: ____________ Date of Survey: ____________

☐ **No history of dominant lower extremity injury**

Date of Injury (mm/yyyy): ____________ Injury # ____________

Provide a brief description of how the injury occurred:

Sport	**Time Missed / Restricted Activity**	**Notes**
☐ Soccer	Restricted ______ days / wks / yrs	
☐ Basketball		
☐ Volleyball	Missed ______ days / wks / yrs	
☐ Football	**Injured body region**	
☐ Gymnastics		
☐ Track and Field		
☐ Other: ____________		
When did your injury occur?	**Injury type**	
☐ Practice	☐ Arthritis	
☐ Competition	☐ Avulsion fracture	
☐ Other	☐ Bursitis	
	☐ Capsulitis	
Location of Injury	☐ Dislocation	
☐ Right	☐ Fracture	
☐ Left	☐ Impingement	
Stage	☐ Inflammation	
☐ Acute	☐ Infection	
☐ First Time	☐ Laceration	
☐ Recurrent	☐ Nerve injury	
☐ Chronic (pain > 6 months)	☐ Open wound	
☐ Overuse	☐ Periostitis	
Cause of injury	☐ Rupture (ligamen, Grade 3)	
☐ Direct contact w/player	☐ Sprain (Grade 1, 2)	
☐ Direct contact w/ball	☐ Strain	
☐ Fall/stumble - same level	☐ Stress fracture	
☐ Slip/twist/turn (no fall)	☐ Subluxation	
☐ Running	☐ Tendonitis	
☐ Landing	☐ Other	
☐ Jumping		
☐ Weight Lifting	**Surgery**	
☐ Unknown	☐ No	
☐ Other	☐ Yes	

BIBLIOGRAPHY

1. Agel J, Dick R, Nelson B, Marshall SW, Dompier TP. Descriptive epidemiology of collegiate women's ice hockey injuries: National Collegiate Athletic Association Injury Surveillance System, 2000-2001 through 2003-2004. *J Athl Train.* 2007;42(2):249-254.

2. Agel J, Dompier TP, Dick R, Marshall SW. Descriptive epidemiology of collegiate men's ice hockey injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train.* 2007;42(2):241-248.

3. Agel J, Evans TA, Dick R, Putukian M, Marshall SW. Descriptive epidemiology of collegiate men's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2002-2003. *J Athl Train.* 2007;42(2):270-277.

4. Agel J, Olson DE, Dick R, Arendt EA, Marshall SW, Sikka RS. Descriptive epidemiology of collegiate women's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train.* 2007;42(2):202-210.

5. Agel J, Palmieri-Smith RM, Dick R, Wojtys EM, Marshall SW. Descriptive epidemiology of collegiate women's volleyball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train.* 2007;42(2):295-302.

6. Arnason A, Gudmundsson A, Dahl HA, Johannsson E. Soccer injuries in Iceland. *Scand J Med Sci Sports.* 1996;6(1):40-45.

7. Association NCA. 1981-82-2004-05 NCAA Sports Sponsorship and Participation Rates Report. *National Collegiate Athletic Association*. Indianapolis, IN; 2006.

8. B G, K B, H W, C F. Reliabiilty of common lower extremity musculoskeletal screening tests. *Physical Therapy in Sport.* 2004;5(2):90-97.

9. Backous DD, Friedl KE, Smith NJ, Parr TJ, Carpine WD, Jr. Soccer injuries and their relation to physical maturity. *Am J Dis Child.* 1988;142(8):839-842.

10. Bahr R, Bahr IA. Incidence of acute volleyball injuries: a prospective cohort study of injury mechanisms and risk factors. *Scand J Med Sci Sports.* 1997;7(3):166-171.

11. Bahr R, Lian O, Bahr IA. A twofold reduction in the incidence of acute ankle sprains in volleyball after the introduction of an injury prevention program: a prospective cohort study. *Scand J Med Sci Sports.* 1997;7(3):172-177.

12. Baumhauer JF, Alosa DM, Renstrom AF, Trevino S, Beynnon B. A prospective study of ankle injury risk factors. *Am J Sports Med.* 1995;23(5):564-570.

13. Bell NS, Mangione TW, Hemenway D, Amoroso PJ, Jones BH. High injury rates among female army trainees: a function of gender? *Am J Prev Med.* 2000;18(3 Suppl):141-146.

14. Bennell KL, Talbot RC, Wajswelner H, Techovanich W, Kelly DH, Hall AJ. Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. *Aust J Physiother.* 1998;44(3):175-180.

15. Beynnon BD, Murphy DF, Alosa DM. Predictive Factors for Lateral Ankle Sprains: A Literature Review. *J Athl Train.* 2002;37(4):376-380.

16. Beynnon BD, Renstrom PA, Alosa DM, Baumhauer JF, Vacek PM. Ankle ligament injury risk factors: a prospective study of college athletes. *J Orthop Res.* 2001;19(2):213-220.

17. Bigland-Ritchie B, Woods JJ. Changes in muscle contractile properties and neural control during human muscular fatigue. *Muscle Nerve.* 1984;7(9):691-699.

18. Boden BP, Dean GS, Feagin JA, Jr., Garrett WE, Jr. Mechanisms of anterior cruciate ligament injury. *Orthopedics.* 2000;23(6):573-578.

19. Brown AM, Zifchock RA, Hillstrom HJ. The effects of limb dominance and fatigue on running biomechanics. *Gait Posture.* 2014;39(3):915-919.

20. Brown TN, Palmieri-Smith RM, McLean SG. Sex and limb differences in hip and knee kinematics and kinetics during anticipated and unanticipated jump landings: implications for anterior cruciate ligament injury. *Br J Sports Med.* 2009;43(13):1049-1056.

21. Butler RJ, Lehr ME, Fink ML, Kiesel KB, Plisky PJ. Dynamic balance performance and noncontact lower extremity injury in college football players: an initial study. *Sports Health.* 2013;5(5):417-422.

22. Caleb Johnson MF, Michelle Varnell, Mita Lovalekar, Jennifer Csonka, Karl Salesi, Timothy Sell. A Quantitative Analysis of Musculoskeletal Variables, Comparative to Team Normas, Leading to a First-time, ACL rupture in a Female Soccer Player. 2015.

23. Chappell JD, Herman DC, Knight BS, Kirkendall DT, Garrett WE, Yu B. Effect of fatigue on knee kinetics and kinematics in stop-jump tasks. *Am J Sports Med.* 2005;33(7):1022-1029.

24. Chomiak J, Junge A, Peterson L, Dvorak J. Severe injuries in football players. Influencing factors. *Am J Sports Med.* 2000;28(5 Suppl):S58-68.

25. Corbeil P, Blouin JS, Begin F, Nougier V, Teasdale N. Perturbation of the postural control system induced by muscular fatigue. *Gait Posture.* 2003;18(2):92-100.

26. Cortes N, Quammen D, Lucci S, Greska E, Onate J. A functional agility short-term fatigue protocol changes lower extremity mechanics. *J Sports Sci.* 2012;30(8):797-805.

27. Dick R, Agel J, Marshall SW. National Collegiate Athletic Association Injury Surveillance System commentaries: introduction and methods. *J Athl Train.* 2007;42(2):173-182.

28. Dick R, Ferrara MS, Agel J, et al. Descriptive epidemiology of collegiate men's football injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train.* 2007;42(2):221-233.

29. Dick R, Hertel J, Agel J, Grossman J, Marshall SW. Descriptive epidemiology of collegiate men's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train.* 2007;42(2):194-201.

30. Dick R, Hootman JM, Agel J, Vela L, Marshall SW, Messina R. Descriptive epidemiology of collegiate women's field hockey injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2002-2003. *J Athl Train.* 2007;42(2):211-220.

31. Dick R, Putukian M, Agel J, Evans TA, Marshall SW. Descriptive epidemiology of collegiate women's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2002-2003. *J Athl Train.* 2007;42(2):278-285.

32. Dick R, Romani WA, Agel J, Case JG, Marshall SW. Descriptive epidemiology of collegiate men's lacrosse injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train.* 2007;42(2):255-261.

33. Dietz V. Human neuronal control of automatic functional movements: interaction between central programs and afferent input. *Physiol Rev.* 1992;72(1):33-69.

34. Ekstrand J, Gillquist J. The avoidability of soccer injuries. *Int J Sports Med.* 1983;4(2):124-128.

35. Ekstrand J, Gillquist J. Soccer injuries and their mechanisms: a prospective study. *Med Sci Sports Exerc.* 1983;15(3):267-270.

36. Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc.* 2003;35(10):1745-1750.

37. Freeman MA, Wyke B. Articular reflexes at the ankle joint: an electromyographic study of normal and abnormal influences of ankle-joint mechanoreceptors upon reflex activity in the leg muscles. *Br J Surg.* 1967;54(12):990-1001.

38. Gandevia SC, Enoka RM, McComas AJ, Stuart DG, Thomas CK. Neurobiology of muscle fatigue. Advances and issues. *Adv Exp Med Biol.* 1995;384:515-525.

39. Glick JM, Gordon RB, Nishimoto D. The prevention and treatment of ankle injuries. *Am J Sports Med.* 1976;4(4):136-141.

40. Goldie PA, Bach TM, Evans OM. Force platform measures for evaluating postural control: reliability and validity. *Arch Phys Med Rehabil.* 1989;70(7):510-517.

41. Gomez JE, Ross SK, Calmbach WL, Kimmel RB, Schmidt DR, Dhanda R. Body fatness and increased injury rates in high school football linemen. *Clin J Sport Med.* 1998;8(2):115-120.

42. Gwinn DE, Wilckens JH, McDevitt ER, Ross G, Kao TC. The relative incidence of anterior cruciate ligament injury in men and women at the United States Naval Academy. *Am J Sports Med.* 2000;28(1):98-102.

43. H J, P S. The Neurophysiology of Joints. *Mechanics of Joints: Physiology, Pathophysiology and Treatment.* 1993:243-290.

44. Herrington L, Hatcher J, Hatcher A, McNicholas M. A comparison of Star Excursion Balance Test reach distances between ACL deficient patients and asymptomatic controls. *Knee.* 2009;16(2):149-152.

45. Hertel J, Braham RA, Hale SA, Olmsted-Kramer LC. Simplifying the star excursion balance test: analyses of subjects with and without chronic ankle instability. *J Orthop Sports Phys Ther.* 2006;36(3):131-137.

46. *Daniels and Worthingham's Muscle Testing Techniques of Manual Examination* [computer program]. Version: W.B. Saunders Company; 2002.

47. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train.* 2007;42(2):311-319.

48. Hopper DM, Hopper JL, Elliott BC. Do selected kinanthropometric and performance variables predict injuries in female netball players? *J Sports Sci.* 1995;13(3):213-222.

49. Hosea TM, Carey CC, Harrer MF. The gender issue: epidemiology of ankle injuries in athletes who participate in basketball. *Clin Orthop Relat Res.* 2000(372):45-49.

50. Hsieh CY, Walker JM, Gillis K. Straight-leg-raising test. Comparison of three instruments. *Phys Ther.* 1983;63(9):1429-1433.

51. Hughes G, Watkins J. A risk-factor model for anterior cruciate ligament injury. *Sports Med.* 2006;36(5):411-428.

52. III JR, ME H, PW C, GM L. Effect of Lower Extremity Muscular Fatigue on Motor Control Performance. *Med Sci Sports Exerc.* 1996;30:1703-1707.

53. Ireland ML, Willson JD, Ballantyne BT, Davis IM. Hip strength in females with and without patellofemoral pain. *J Orthop Sports Phys Ther.* 2003;33(11):671-676.

54. Jones BH, Bovee MW, Harris JM, 3rd, Cowan DN. Intrinsic risk factors for exercise-related injuries among male and female army trainees. *Am J Sports Med.* 1993;21(5):705-710.

55. Kaufman KR, Brodine SK, Shaffer RA, Johnson CW, Cullison TR. The effect of foot structure and range of motion on musculoskeletal overuse injuries. *Am J Sports Med.* 1999;27(5):585-593.

56. Kerr ZY, Dompier TP, Snook EM, et al. National collegiate athletic association injury surveillance system: review of methods for 2004-2005 through 2013-2014 data collection. *J Athl Train.* 2014;49(4):552-560.

57. Knapik JJ, Sharp MA, Canham-Chervak M, Hauret K, Patton JF, Jones BH. Risk factors for training-related injuries among men and women in basic combat training. *Med Sci Sports Exerc.* 2001;33(6):946-954.

58. Krivickas LS, Feinberg JH. Lower extremity injuries in college athletes: relation between ligamentous laxity and lower extremity muscle tightness. *Arch Phys Med Rehabil.* 1996;77(11):1139-1143.

59. Leardini A, Stagni R, O'Connor JJ. Mobility of the subtalar joint in the intact ankle complex. *J Biomech.* 2001;34(6):805-809.

60. LL D, EG K. Violence: A Global Public Health Problem. Paper presented at: World Report on Violence and Health, 2002; Switzerland.

61. Macefield G, Hagbarth KE, Gorman R, Gandevia SC, Burke D. Decline in spindle support to alpha-motoneurones during sustained voluntary contractions. *J Physiol.* 1991;440:497-512.

62. Malinzak RA, Colby SM, Kirkendall DT, Yu B, Garrett WE. A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clin Biomech (Bristol, Avon).* 2001;16(5):438-445.

63. Marx RG, Jones EC, Allen AA, et al. Reliability, validity, and responsiveness of four knee outcome scales for athletic patients. *J Bone Joint Surg Am.* 2001;83-A(10):1459-1469.

64. Massion J. Postural control system. *Curr Opin Neurobiol.* 1994;4(6):877-887.

65. MC M. Incidence, Mechanisms, and severity of game-related college football injuries on FieldTurf versus nature grass: a 3-year prospective study. . *Am J Sports Med.* 2010;38:687-697.

66. McGuine TA, Greene JJ, Best T, Leverson G. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med.* 2000;10(4):239-244.

67. McKay GD, Goldie PA, Payne WR, Oakes BW. Ankle injuries in basketball: injury rate and risk factors. *Br J Sports Med.* 2001;35(2):103-108.

68. McLean SG, Fellin RE, Suedekum N, Calabrese G, Passerallo A, Joy S. Impact of fatigue on gender-based high-risk landing strategies. *Med Sci Sports Exerc.* 2007;39(3):502-514.

69. McNabb SJ, Chungong S, Ryan M, et al. Conceptual framework of public health surveillance and action and its application in health sector reform. *BMC Public Health.* 2002;2:2.

70. Messina DF, Farney WC, DeLee JC. The incidence of injury in Texas high school basketball. A prospective study among male and female athletes. *Am J Sports Med.* 1999;27(3):294-299.

71. Milgrom C, Shlamkovitch N, Finestone A, et al. Risk factors for lateral ankle sprain: a prospective study among military recruits. *Foot Ankle.* 1991;12(1):26-30.

72. Murphy DF, Connolly DA, Beynnon BD. Risk factors for lower extremity injury: a review of the literature. *Br J Sports Med.* 2003;37(1):13-29.

73. Myklebust G, Maehlum S, Holm I, Bahr R. A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. *Scand J Med Sci Sports.* 1998;8(3):149-153.

74. Nilstad A, Andersen TE, Bahr R, Holme I, Steffen K. Risk factors for lower extremity injuries in elite female soccer players. *Am J Sports Med.* 2014;42(4):940-948.

75. Orchard J, Seward H, McGivern J, Hood S. Intrinsic and extrinsic risk factors for anterior cruciate ligament injury in Australian footballers. *Am J Sports Med.* 2001;29(2):196-200.

76. Orchard JW. Intrinsic and extrinsic risk factors for muscle strains in Australian football. *Am J Sports Med.* 2001;29(3):300-303.

77. Ostenberg A, Roos H. Injury risk factors in female European football. A prospective study of 123 players during one season. *Scand J Med Sci Sports.* 2000;10(5):279-285.

78. P G. Peripheral Neural Mechanisms in Proprioception. *J Sport Rehabil.* 1994;3:2-17.

79. Pandy MG, Shelburne KB. Dependence of cruciate-ligament loading on muscle forces and external load. *J Biomech.* 1997;30(10):1015-1024.

80. Piva SR, Fitzgerald K, Irrgang JJ, et al. Reliability of measures of impairments associated with patellofemoral pain syndrome. *BMC Musculoskelet Disord.* 2006;7:33.

81. Piva SR, Goodnite EA, Childs JD. Strength around the hip and flexibility of soft tissues in individuals with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther.* 2005;35(12):793-801.

82. PL G. The development of state and local injury surveillance systems. *J Safety Res.* 1987;18:191-198.

83. R G, G L. Hamstring muscle tightness. *Physical Therapy* 1983;63(7):1085.

84. Riddle DL, Pulisic M, Pidcoe P, Johnson RE. Risk factors for Plantar fasciitis: a matched case-control study. *J Bone Joint Surg Am.* 2003;85-A(5):872-877.

85. Riemann BL, Lephart SM. The sensorimotor system, part I: the physiologic basis of functional joint stability. *J Athl Train.* 2002;37(1):71-79.

86. Riemann BL, Lephart SM. The Sensorimotor System, Part II: The Role of Proprioception in Motor Control and Functional Joint Stability. *J Athl Train.* 2002;37(1):80-84.

87. Rotto DM, Kaufman MP. Effect of metabolic products of muscular contraction on discharge of group III and IV afferents. *J Appl Physiol (1985).* 1988;64(6):2306-2313.

88. Schieppati M, Hugon M, Grasso M, Nardone A, Galante M. The limits of equilibrium in young and elderly normal subjects and in parkinsonians. *Electroencephalogr Clin Neurophysiol.* 1994;93(4):286-298.

89. Sefton JM, Hicks-Little CA, Hubbard TJ, et al. Sensorimotor function as a predictor of chronic ankle instability. *Clin Biomech (Bristol, Avon).* 2009;24(5):451-458.

90. Sell TC. An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adults. *Phys Ther Sport.* 2012;13(2):80-86.

91. Sell TC, Abt JP, Crawford K, et al. Warrior Model for Human Performance and Injury Prevention: Eagle Tactical Athlete Program (ETAP) Part I. *J Spec Oper Med.* 2010;10(4):2-21.

92. SM L, BL R, FH F. Introduction to the sensorimotor system *Proprioception and Neuromuscular Control in Joint Stabilty*. Champaign, IL: Human Kinetics; 2000:37-51.

93. Smith AD, Stroud L, McQueen C. Flexibility and anterior knee pain in adolescent elite figure skaters. *J Pediatr Orthop.* 1991;11(1):77-82.

94. Soderman K, Alfredson H, Pietila T, Werner S. Risk factors for leg injuries in female soccer players: a prospective investigation during one out-door season. *Knee Surg Sports Traumatol Arthrosc.* 2001;9(5):313-321.

95. Surve I, Schwellnus MP, Noakes T, Lombard C. A fivefold reduction in the incidence of recurrent ankle sprains in soccer players using the Sport-Stirrup orthosis. *Am J Sports Med.* 1994;22(5):601-606.

96. Tropp H, Ekstrand J, Gillquist J. Factors affecting stabilometry recordings of single limb stance. *Am J Sports Med.* 1984;12(3):185-188.

97. Vicenzino B, Branjerdporn M, Teys P, Jordan K. Initial changes in posterior talar glide and dorsiflexion of the ankle after mobilization with movement in individuals with recurrent ankle sprain. *J Orthop Sports Phys Ther.* 2006;36(7):464-471.

98. Vuillerme N, Nougier V, Prieur JM. Can vision compensate for a lower limbs muscular fatigue for controlling posture in humans? *Neurosci Lett.* 2001;308(2):103-106.

99. Wikstrom EA, Tillman MD, Smith AN, Borsa PA. A new force-plate technology measure of dynamic postural stability: the dynamic postural stability index. *J Athl Train.* 2005;40(4):305-309.

100. Windhorst U, Boorman G. Overview: potential role of segmental motor circuitry in muscle fatigue. *Adv Exp Med Biol.* 1995;384:241-258.

101. Witvrouw E, Bellemans J, Lysens R, Danneels L, Cambier D. Intrinsic risk factors for the development of patellar tendinitis in an athletic population. A two-year prospective study. *Am J Sports Med.* 2001;29(2):190-195.

102. Witvrouw E, Danneels L, Asselman P, D'Have T, Cambier D. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players. A prospective study. *Am J Sports Med.* 2003;31(1):41-46.

103. Zelisko JA, Noble HB, Porter M. A comparison of men's and women's professional basketball injuries. *Am J Sports Med.* 1982;10(5):297-299.