Epidemiology of High School Sports-related Injuries: A descriptive epidemiological study of a single high school during the 2021-2022 academic year

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BS in Athletic Training, The University of Texas, Austin, 2021

Submitted to the Faculty of the

School of Health and Rehabilitation Sciences

of the requirements for the degree of

Master of Science in Sports Medicine

University of Pittsburgh

2023

UNIVERSITY OF PITTSBURGH

SCHOOL OF HEALTH AND REHABILITATION SCIENCES

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March 14, 2023

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Epidemiology of High School Sports Injuries: A descriptive epidemiological analysis of the 2021-2022 school year at a private high school

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University of Pittsburgh, 2023

Millions of high school students participate in school-sanctioned athletic events each year in the United States. Participation in athletics comes with inherent adverse consequences including sports-related injury. Current epidemiological studies aim to describe the pattern of injuries between several demographic groups to enhance clinical knowledge, develop injury risk profiles, and employ prevention strategies. **Purpose:** The purpose of this descriptive epidemiological study was to describe patterns and incidence of anatomic location, injury type, mechanism and onset of injury, injury timing, and sport-specific injury patterns in a group of high school athletes at a private high school. The secondary and tertiary aims of this study were to compare incidence and patterns of injuries between sexes and compare incidence and patterns of injuries between single sport and interscholastic multi-sport athletes. **Methods:** The current study employed a descriptive epidemiological study design. Data from SOAP (subjective, objective, assessment, plan) notes were extracted and analyzed with the goal of establishing relationships between various demographic variables and incidence of sports-related injuries within a population of adolescent female and male athletes at a private high school during a single academic year. **Results:** The key findings of this study included a higher injury incidence for boys than girls, a higher overall incidence of acute injuries compared to chronic injuries, a higher overall incidence of non-contact injuries, and a higher incidence of injuries in football, basketball, and soccer. Furthermore, the most common injury location was the lower extremity, sprains were the most common injury overall, and injuries were sustained most often during practice. The percentage of interscholastic multisport (ISMA) athletes who sustained an injury (39/115 = 33.9%) was lower than the percentage of single-sport athletes who sustained an injury (40/66 = 60.6%). This difference was significant ($p < 0.001$). **Conclusion:** Adolescent participation in athletics is accompanied by inherent, often unmodifiable, risks of injury. Despite the potential negative consequences, participation in athletics provides youth with several physical, cognitive, and social benefits. Preservation of the positive impacts of sports participation may encourage continued engagement and minimize the physical and financial burden associated with sports-related injuries.

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Preface

The following project would not have been possible without the contributions of my academic mentors at The University of Pittsburgh and The University of Texas at Austin. To my thesis advisor, Dr. Mita Lovalekar, thank you for your dedication to this project and encouraging me to believe in myself and my voice. To Dr. Mary Murray, Dr. Katelyn Allison, and Dr. Michelle Varnell, thank you for your feedback, guidance, and commitment to the completion and quality of this paper. To Kelvin Phan, my undergraduate athletic training mentor, thank you for encouraging me to take on the challenge of graduate school and for your frequent over-the-phone mentorship.

To my co-workers at Pine-Richland High School, Leigh Anne Cowger, Mike Rizzo, and Matt Mahood, who have seen this entire project through, thank you for input, for always being there to put a smile on my face, and for creating a space for my academic and clinical growth.

To my classmates in the sports medicine program at The University of Pittsburgh: thank you a million times over. I'm proud to call you all my colleagues and friends. I look forward to seeing all the amazing ways you'll contribute to the field of sports medicine and beyond.

To my family and friends, no allotment of space would be sufficient to express my gratitude for your support. To Emily, my best friend and roommate, thank you for uplifting me, for always being a shoulder to lean on, and for cooking a delicious meal whenever I needed it. To my aunt Dr. Connie O'Regan at The University of Galway, thank you for our Zoom calls, for our emails, and for being a mentor; you inspire me. To Claire, thank you for your love, your support, and belief in me at times when it wavered for myself. To my brother, Satchel, thank you for being you; I have the best brother. To my Mom and Dad, thank you for your unconditional love and for your unwavering belief in me. Thank for inspiring me, for pushing me, and for challenging me to never back down from my dreams, no matter how big they are.

Lastly, to my all my athletes, past, present, and future, you are what makes this all worth it. Because of you, I have the best job in the world.

1.0 Introduction: High School Sports in America

Almost 8 million high school students participate in a school-sanctioned athletic activity each year in the United States (US).[1] High school sports are a cornerstone to many communities and have deep roots in American culture and tradition. Plastered on walls in bedrooms, locker rooms, and classrooms are posters of American greats such as Babe Ruth, Michael Jordan, and Abby Wambach. They are seen as figures of resilience, triumph, and athletic excellence. Emulation of these athletes, their character, and performance habits has vastly changed the landscape of youth sports. Most notably, youth sports have become increasingly competitive and require a tremendous dedication of time and physical commitment. This near obsession with athletic success and the development of youth "super athletes" makes discussing social and physical injury risk a challenge. For researchers and clinicians involved in youth athletics, budging a paradigm is an uphill battle. As youth athletics continue to expand and intensify, however, there is an immediate need for a dialogue about risk, prevention, and safety.

Beyond participation in tradition, youth gain extensive social, cognitive, and physical benefits from organized athletic participation. Social benefits include higher self-esteem, enhanced self-purpose, and exposure to uncomfortable situations with learned methods of resilience. [2,3] Additionally, active participation in athletic activity has been shown to improve mental health and decrease feelings of hopelessness and suicidal ideation.[2,4,5] Cognitively, youth develop complex problem-solving skills, efficiency in task completion, and report greater academic success when compared to youth not participating in organized athletics. [2] The physical benefits are extensive and perhaps most pertinent with respect to combatting the nationally rising rates of childhood obesity. While most 6–17-year-old youth fall short of the CDC's recommendation of 60 or more minutes of aerobic physical activity per day, participation in an organized activity provides an engaging avenue to meet health recommendations. [6] Consistent physical activity promotes the development of motor skills, muscle mass, and improves bone health, cardiovascular fitness, coordination, and balance. [7] [2] [8] High school physical activity participation has also been linked to a decrease in high-risk behaviors such as cigarette smoking and illicit drug use.[9] [10]

Despite the benefits, athletic participation comes with inherent risks. Risks include, but are not limited to, musculoskeletal injuries, social rejection, perfectionism obsession, and sleep disturbances. [11] Physical and cognitive immaturity plays a role in the development of negative consequences. [12] Clinicians, coaches, and parents must be aware of the intersectionality of adolescence and negative risk. [13] More importantly, they must be willing to educate themselves and their respective communities. This thesis will focus on injury risk within the high school athletic population.

1.1 Changes in Sports Participation in a Post-Covid World

According to the National Federation of State High School Associations, the United States has seen a steady, but slow rise in high school sports participation from the years 1991-2019 with a particularly sharp increase for girls in the early 1970s.[1] The sudden increase is due to the 1972 passage of Title IX which prohibits sex discrimination in federally funded education programs. The passage of Title IX, coupled with a rise in national feminism, supported the development of athletic teams and spaces for female youth. [14] While less reported, the academic years beyond 2019 saw a decline in sports participation due to the COVID-19 pandemic. Although post-pandemic youth participation continues to rise, certain activities such as baseball, cheerleading, gymnastics, soccer, and swimming have seen over 15% decreases in participation over the 2019-2020 year.[1] However, sports such as tennis and golf have seen an overwhelming rise in youth participation. This is likely due to socioeconomic status and the ability to participate in both tennis and golf while adhering to the CDC's social distancing requirements. Football and basketball have seen declines in participation over the recent years likely due to increased parental caution as information on concussion and other traumatic brain injuries continues to grow.[1]

Socioeconomic status plays a significant role in access to resources and sports participation for youth. The 2021 State of Play report published by the Aspen Institute reported that 32% of families with a household income of less than $50,000 expressed that they struggle to support their child's athletic endeavors compared to only 16% of families making $50,000 or more.[15] Moreover, a survey conducted by Utah State University and Project Play reported that only 13%-14% of youth in the lower-income bracket returned to a higher level of sports participation following COVID-19.[15] In addition, children of color were disproportionally impacted by the pandemic. Project Play data suggests that 47% of Hispanic youth and 42% of black youth did not return to the same level of sports participation that they were involved in before the pandemic.[15] Only 31% of white youth, however, did not return to a higher level of sports participation.[15] Socioeconomic status may also have implications on healthcare availability; thus, youth of lower socioeconomic status may be omitted from reported statistics.

1.2 Epidemiology of High School Sports-Related Injuries

As high school and youth sports continue to evolve and flourish in popularity, understanding those at risk remains pertinent to modifying current prevention strategies and promoting the safety of student-athletes. High school children, those aged roughly 14-18, are particularly vulnerable to musculoskeletal injury due to physiological maturation patterns and a shifting youth sports culture. [16,17] Youth epidemiological sports injury research is ongoing as defining exposure and injury both are a challenge and inconsistent between studies. [16] Most published studies, however, utilize data from the High School Reporting Online (RIO) database, a national online injury database operated by the Datalys Center for Sports Injury Research and Prevention in Indianapolis, Indiana. The RIO Database, first implemented for the 2005-2006 school year, is an online database that compartmentalizes information on athlete exposures and injuries reported by certified athletic trainers (AT) at various high schools in the US. In addition to athlete exposure and injury details (body part, type, severity), the RIO Database collects specific details related to the injury event such as playing surface, mechanism of injury, and player position. In the High School RIO Database, sports injuries are defined as injuries sustained during an event or practice, required medical attention from a trained healthcare provider, and resulting in the loss of participation allowance for at least 24 hours. [1,16] Athlete exposure is defined as any single athlete participating in a single competition or practice. [16] In the past 17 years, data from the RIO Database has guided our knowledge of sports injury epidemiology in high school athletes and catalyzed discussion of identifying risk and employing prevention strategies.

Despite the shifting rates of youth sports participation and a changing post-pandemic culture, there are close to 8,000,000 children participating in high school sports. This is roughly 57.4% of high schoolers nationally.[1] As of the 2021-2022 academic school year in the US, football is the most popular sport for boys while track and field and indoor volleyball are the most popular sports for girls.[1] With an increase in sports specialization, year-round training, and the development of elite club travel teams, youth injury incidence is on the rise. [18] Due to sex differences in physiological maturity progressions, movement patterns, sport demands, and social culture, adolescent males and females are at risk for diverse types of sports-related injuries. [19]

1.2.1 Epidemiology of Injuries During Football

Over 1,000,000 high school aged boys participate in football every academic year, an estimated 6.24% of all high school students. [1,20] Due to the vast number of participants and contact nature of football, injury rates per exposure are higher in football than other high school sport. [20] RIO Database injury data from school years 2004-2014 reported 5,241,905 football-sustained time-loss injuries. This represents a 4.01 injury rate (IR) per 1,000 athlete-exposures (AE). 53.2% of all time-loss injuries were sustained during practice with 69.3% of injuries occurring during regular season practices. [20] Ligament sprains were the most common injuries sustained with an incidence rate of 3.67, followed by concussions (IR: 2.57) and contusions at a (IR: 1.88). Joints of the lower extremity, including the knee and ankle were the most injured joints at 13.3% and 12.2% during practice and 16.4% and 12.9% during competition respectively. [20] The head and face, however, had the highest IR per exposure of all body parts.[20] Most injuries occurred as a result of contact mechanisms, such as being tackled (23.8%) or delivering a tackle (20.4%) during competitions. [20]

1.2.2 Epidemiology of Injuries During Basketball

Basketball, for both boys and girls, is popular high school sport. According to the National Federation of State High School Associations, 540,769 boys and 399,067 girls participated in high school basketball during the 2018-2019 academic year.[1] The physical demands of the game, such as cutting, jumping, and player to player contact contribute to a heightened injury risk for student-athletes. A pair of 2018 epidemiology studies (during the 2005-2014 academic school years) conducted by Clifton and colleagues of high school basketball injuries found a IRs of 3.43 per 1,000 AEs for boys and a 1.82 per 1,000 AEs for girls. [21] [22] With both sexes, injuries occurred more often during competitions than practices and during the regular season compared to the pre or post season.[21] [22] Overall, the most injured body part was the ankle, followed by the head/face and the knee.[22] For boys, ligament sprains during competitions were most common (IR: 1.07/1,000 AEs) followed by concussions (IR: 0.33), fractures/avulsions (IR: 0.32) and muscle/tendon strains (IR: 0.21). [22] For girls, similar injuries and order of commonality were found with the addition of contusions between concussions and fractures/avulsions.[21] However, the respective IRs were 1.44 IR, 0.74 IR, 0.26 IR, 0.25 IR, and 0.25 IR. The most common mechanism of injury for both boys and girls was contact with another player.[22] For boys, contact with another play composed 44.1% of injuries during practice and 51.9% of injuries during competition.[22] For girls, contact with another player composed 27.9% of injuries during practice and 45.6% of injuries during competition.[21]

1.2.3 Epidemiology of Injuries During Soccer

Soccer is the most popular sport worldwide.[23] While not as popular as football in America, youth soccer is a well-participated sport in the US. According to the National Federation of High School State High School Associations, 459, 077 boys and 394,105 girls participated in high school soccer during the 2018-2019 school year.[1] A Kerr and colleagues' descriptive epidemiological study of high school boys' soccer injuries (between 2005-2014) found a 1.83 IR per 1,000 athlete-exposures. [24] Moreover, a similar DiStefano study of high school girls' soccer injuries (between 2005-2014) found a 2.33 IR per 1,000 athlete-exposures. [25] For both boys and girls, injuries occurred most often during competitions (67.7% for girls and 60.3% for boys).[24 25] Similarly, most injuries across both sexes occurred during the regular season compared to the pre or post season (72.0% for boys and 77.7% for girls).[24,25] For boys, the head/face (0.97 IR) was the most frequent injury site followed by the ankle (0.67 IR), knee (0.51 IR), and hip/thigh/upper leg (0.45).[24] For girls, the head/face was the most frequent injury site followed by the knee, ankle, and hip/thigh/upper leg.[25] Ligament sprains were the most prominent injury for girls at a 1.81 IR, followed by concussions (1.28 IR), contusions (0.70 IR), and muscle/tendon strains (.0.59 IR).[25] Ligament sprains were the most prominent injury for boys at a 0.96 IR, followed by concussions (0.77 IR), contusions (0.69 IR), and fractures/avulsions (0.46 IR). Contact with another person during competition was the most prominent mechanism of injury for both sexes at 52.5% for girls and 60.0% for boys. [24,25]

1.2.4 Epidemiology of Injuries During Baseball

According to the National Federation of State High School Associations, 11% of high school boys participate in baseball each academic year; this equates to over 480,000 student-athletes per year.[1] Unlike other popular US sports, baseball's non-contact nature diminishes the risk of acute injuries. However, the repetitive demands of the upper extremity joints associated with baseball increase the risk of microtrauma overtime and subsequently overuse injury. This issue is a popular discussion with respect to injury prevention and youth baseball pitchers. A Wasserman and colleagues' descriptive epidemiological study of high school baseball injuries (between 2005-2014) found a 0.98 IR per 1,000 athlete-exposures.[26] Of all injuries, 55.3% were recorded during competition with 65.9% of injuries occurring during the regular season.[26] The shoulder/clavicle (18.5%) was injured most frequently followed by the head/face (17.6%), and the hand/wrist (15.4%).[26] The most common injury overall was muscle/tendon strains (25.0% at practice and 19.9% during competition) followed by ligament sprains.[26] Non-contact mechanisms during competition were most the common culprits of injuries at 23.2% of all injuries.[26]

1.2.5 Lower Extremity Injury

The lower extremity is the most common site for adolescent sports-related injury with the knee and ankle being most frequently injured.[27,28] Ankle sprains, specifically lateral ankle sprains, are among the most observed injuries across any high school sport. [27,29] Ankle sprains are most common in football, basketball, soccer, track and field, and indoor volleyball with an increased incidence in team sports played on a court.[30] The knee is also a common injury sight, observed often in football by traumatic cause and cross country by overuse cause.[30] Injuries to the tibiofemoral complex, or knee joint, include sprains of ligaments and damage to non-contractile tissues such as the meniscus and osseocartilaginous regions.[31] A study conducted by Fernandez and colleagues found the thigh/upper leg, foot, and hip to follow the ankle and knee in observed injury prevalence of a cohort of high school athletes.[28] The same study found that of the 4,350 lower extremity injuries sustained over a single year span (from a random sample of 100 high schools), the leading diagnosis were sprains (50%) followed by strains (17%), contusions (12%), and fractures (5%).[28] Soccer was implicated as the highest risk sport for lower extremity injury.[28]

1.2.6 Upper Extremity Injury

Upper extremity injuries occur mainly in upper-extremity dominant sports that require repetitive motion of the shoulder, elbow, or wrist such as baseball and gymnastics.[32] While overall injury is more common in the lower extremity, fractures are more prevalent in the upper extremity.[33] Swenson and colleagues reported that 32.1% of all fractures reported over a three-year high school athlete observation period were to the fingers and hand.[33] They also found the incidence of fractures reduces linearly with increase in age and participation level (e.g. junior varsity to varsity).[33] This is likely due to maturation and development of the musculoskeletal system with puberty progression. Moreover, fractures are most prevalent in contact sports such as football and both girls' and boys' soccer. Boys, however, sustain more fractures than girls on average.[32,33] In addition to fractures, strains and sprains of the upper extremity are common. The shoulder is a prevalent upper extremity injury location in adolescents being home to four joints, one of which, the glenohumeral joint, being the most unstable joint in the body.[34] The unstable nature of the glenohumeral joint creates a reliance on surrounding contractile tissues for functional stability. Those contractile tissues, then, are at risk for overuse trauma. Adolescent shoulder injuries often result from repetitive overuse, poor biomechanics, and limited rest, such as with youth baseball pitchers.[34,35] Common overuse injuries include tendinopathies of the rotator cuff and several types of labral tears.[33,36] Although less common, acute injuries to the shoulder are seen with dislocations and humeral head fractures.[33]

1.2.7 Sex Differences in Injury Occurrence

Sex differences in injury patterns, occurrence, and severity is prevalent among high school aged children. Injury incidence differs partly because there are larger percentages of either sex in specific sports. Additionally, each activity has its own unique movement demands. However, the physiological differences between males and females are thought to play a significant role in the relationship between sex and injury.[37] Literature suggests that females sustain more injuries than their male counterparts, especially with respect to overuse injuries.[19,37,38] An array of intrinsic and extrinsic factors contributes to this fact. From a physiological lens, males (on average) have protective advantages against injury such as greater muscle mass and bone density.[37] In children undergoing puberty, strength deficits, lack of flexibility, an immature skeleton, and overall rapid periods of growth are both culprits and risk factors for injuries.[19] The anatomical differences between males and females, such as the structure and shape of the femur puts females, on average, at greater risk for traumatic injuries to the lower extremity.[39] The lateral femoral notch, seen as a risk factor for ACL injury, is more common in females than males.[40] Compensatory biomechanics, poor neuromuscular control, and dynamic knee valgus are also strong culprits of injuries in females.[41-43] In contrast, males are at a greater risk for injury to the upper extremity, likely due to a greater percentage of males in upper extremity dominant sports such as baseball and football.[19]

1.2.8 Overuse vs Acute Injury

According to the CDC almost half of youth sport-related injuries are preventable.[44] Acute injuries, those that result from an immediate bout of trauma, are not usually considered preventable. Overuse injuries, however, are considered preventable and account for about half of all high school athletics injuries.[44] Caused by repetitive microtrauma over time, overuse injuries often result from an array of modifiable factors. Overuse injuries are more common in female high school athletes than male high school athletes.[45] This exact reason for this is unknown, but it is speculated that biomechanics and help-seeking behaviors of females play a role.[45,46] While intrinsic, unmodifiable factors, such as prior injury, skeletal immaturity, anatomical abnormalities, hormonal factors, and fatigue may encourage overuse injury, addressing extrinsic factors such as inappropriately prescribed training, poor biomechanics, and ill-suited equipment can almost completely offset the risk of injury.[47-49]

1.3 Pathophysiology of Injury

Pediatric athletes, particularly those undergoing puberty, are at risk of injury due to physiological immaturity.

1.3.1 Skeletal Injury

Bony growth centers are present in both the physis and epiphysis in adolescent bones.[50] These regions are particularly susceptible to injury due to immature bony geometry of the growth cartilage.[51] Furthermore, growth regions are less mineralized than their boney shaft counterparts making them less resistant to withstanding force.[50] Injury to growth plate regions is commonly seen during periods of rapid growth whereby structural changes are occurring while the regions are exposed to repetitive or forceful trauma. [52] While immature bones are more prone to damage than bone with mature, fused growth centers, adolescent bones contain more elastin and heal faster than mature bone.[53]

Bone development and puberty differs between sexes. While girls undergo puberty earlier than boys, they have a smaller window of bone development. Adolescent boys and girls can share similar bone densities until peak, but since boys have a larger skeleton, they retain a biomechanical advantage and can withstand stronger forces, on average, than girls.[54] There remains evidence, however, that both girls and boys benefit positively from resistance training observed through an increase in bone density and subsequent strength.[55]

Apophyseal injuries, those that occur at osteotendinous junctions, are among the most common injuries sustained by adolescent athletes.[51] This is due to the imbalanced relationship between the immature bony site and the fast-strengthening tendon whereby the boney attachment site is too weak to withstand repetitive forceful contraction from the muscle. Repetitive microtrauma to apophyseal regions results in a common pediatric condition known as apophysitis. Apophysitis most commonly occurs at the tibial tubercle (insertion site of the quadriceps tendon), the medial epicondyle (the insertion site of the forearm pronators and extensors), and the calcaneal tuberosity (the insertion site of the Achilles tendon). The conditions are known as Osgood-Schlatter disease, Little Leaguers Elbow, and Sever’s disease, respectively. Apophysitis can also be observed at various regions on the pelvis including the anterior superior inferior iliac spine, the insertion site of the sartorious muscle, and the ischial tuberosity, the insertion site of the common hamstring tendon.

1.4 Risk Factors

Injury risk, particularly within the adolescent population, should be understood employing a multifactorial model. Through milestones of physical and physiological maturation, adolescents experience changes in movement patterns and musculoskeletal tissue composition.[56] The culmination of changes coupled with the intersection of intrinsic and extrinsic injury risk factors encourages injury development.

1.4.1 Intrinsic Factors

Intrinsic, unmodifiable, factors pose a significant risk to adolescent injury. Intrinsic factors include those that are genetic, pathological, and physiological to an individual. Literature includes a variety of intrinsic factors that may serve a critical function in understanding pediatric injury etiology. The following section will discuss prior injury, anatomical factors, hormonal factors, and the role of fatigue in injury risk.

1.4.1.1 Prior Injury

Among the most prevalent intrinsic risk factors is prior injury. Repetitive overuse injuries often result from a failure to identify or modify a previous injury-inducing risk factor.[51] This failure of intervention or inadequacy of rehabilitation, then, becomes cyclic whereby one injury remains noxiously present causing pain and compensatory movement patterns enhancing the risk for additional injury by secondary association. Moreover, research suggests that previous injury serves as an important predictive factor to continued injury risk.[57,58]

An example of this arrangement is with female adolescents and anterior cruciate ligament injury.[43] Research conducted by Wiggins and colleagues found that roughly 1 in 4 adolescent female athletes who sustain an ACL tear will sustain another ACL tear after full resumption of athletic participation.[43] This puts, as they reported, athletes with a history of ACL tears about 30 to 40 times more likely to sustain a re-injury.[43,59] This risk and re-injury model is observed readily with ankle sprains as well.[60] A study conducted by Sugimoto and colleagues sought to observe risk factors associated with chronic ankle sprains, finding a pattern between ankle sprains and an individual's joint range of motion.[60] Excessive joint range of motion, particularly with dorsiflexion and plantarflexion in the sagittal plane and at the talocrural joint, are indicators of ankle instability. Instability, then, promotes greater joint laxity and poses a risk for the development of chronic ankle instability (CAI). Research has extensively associated CIA with chronic sprains and various other ankle dysfunctions.[61,62]

1.4.1.2 Anatomic Factors

Anatomical factors refer to unmodifiable genetic body position. With respect to adolescent injury, anatomic factors are usually referring to unfavorable bony alignments. Pes planus, pes cavus, patellar maltracking, and increased q-angle of the femur are common bony alignment patterns that are implicated in the development of injuries.[63-65] Additional non-bony anatomical factors that may reduce the risk of injury include excessive ligament laxity and hypermobile joints.[61] Anatomic factors can increase both the risk of overuse and traumatic injury, but are specifically associated with overuse injury, especially in the adolescent population and with respect to the lower extremity.[50]

Patellofemoral pain, one of the most common overuse injuries in adolescents and has etiological roots in patellar orientation and maltracking. Fick et al. reported up to 29% of all adolescent athletes experience patellofemoral pain at some point.[66] Anatomic factors such as unfavorable patella tracking and orientation poses risk to the development of altered and potentially injury-inducing biomechanical faults. While risky movement patterns are seen most readily as lower extremity causing injury factors, poor biomechanics have strong roots in upper extremity injuries as well. A youth baseball pitcher is a fundamental example of this arrangement. Excessive overhead motion in both youth and adults has been found to cause a glenohumeral internal rotation deficit, commonly known as GIRD.[67,68] Greenberg et al. found that athletes with 13 degrees or more of an internal rotation deficit are 6 times more likely to sustain an injury to the shoulder complex than their counterparts with no range of motion deficit.[67] Poor biomechanics can either be intrinsic meaning they are caused by a unmodifiable anatomic factor or extrinsic meaning they are a result of consciously faulty patterns of movement. Extrinsic biomechanical faults are often caused by a lack of proper coaching and/or education.

1.4.1.3 Hormonal Factors

Hormones are thought to play a role in the development of injury in adolescents, especially for females. Female knee kinematics, specifically valgus knee collapse, is thought to have an association with female sex hormones.[69] Valgus knee collapse during functional maneuvers, as readily presented in research, is a risk factor for injury to the anterior cruciate ligament.[70,71] Although more complex than this, an excess of female sex hormones is theorized to alter tendon and ligament properties.[69] Thus, during periods of mensuration, research questions whether there is a heightened risk of tissue failure.

As an adolescent transitions through high school, consideration needs to be given to holistic evaluation of social and cognitive factors that enhance the risk of injury. Social and cognitive challenges and burnout increases the risk of a common hormonal complications associated with a condition known as the "female athletic triad." [72] The female athletic triad, most common in athletes participating in "lean physique" activities such as cross country and ballet, is comprised of three components: low energy availably, menstrual dysfunction, and disordered eating.[72,73] If not identified early, an athlete suffering from the female athlete triad is at an increased risk of stress fractures and long-term menstrual dysfunction.[74]

1.4.1.4 Fatigue

The physiology of fatigue and neuromuscular control in injury development and risk is a complex topic beyond the scope of this thesis. However, it is important to note that excess fatigue and diminished neuromuscular control play a key role in decreasing functional joint stability.[75] Various factors enhance the risk of mental and physical fatigue in adolescent athletes. Examples include overtraining with limited recovery, stress, and sleep deprivation.[76,77]

A study conducted by Mair and colleagues on the role of fatigue in acute muscle strain injury found that fatigued muscles are less cable of absorbing energy making them more susceptible to injury compared to non-fatigued muscles during functional movement.[78] Similarly, Huygaerts and colleagues suggested that central fatigue (voluntary activation of muscle) and peripheral fatigue (alteration in muscle contraction capacity) can result in faulty biomechanical alterations and ultimately increase the risk of injury.[79]

1.4.2 Extrinsic Factors

Extrinsic injury risk factors are those that can be modified. They are most often environmentally related and play an equally significant role in injury development as intrinsic factors. The extrinsic factors that will be discussed in the following section are training, equipment, and biomechanics.

1.4.2.1 Overtraining

Intense physical training has become increasingly more prevalent in youth sports with the goal of early performance enhancement and skill development. Particularly resistance and aerobic training can provide vast health benefits to adolescents including lowering the risk of chronic diseases and offsetting the rise of childhood obesity.[80-82] Resistance training has been shown to increase bone density, enhance neuromuscular control, and promote overall physiological and psychological wellness in both children and adolescents.[82] Literature suggests that the most prominent advantage of resistance training for children is neural adaptations with the absence of muscle hypertrophy. Reported neural adaptations of children include an increased efficiency of the stretch shortening cycle, increased motor unit activation, recruitment efficiency, and enhanced muscle firing rates. Muscle hypertrophy is more common with advanced stages of musculoskeletal maturity, thus seen mostly in adolescence.[82,83] Drenowatz and colleagues suggest that the inability to achieve hypertrophy during child training correlates with specific hormonal unavailability. Other studies have reported that testosterone, specifically with respect to adolescent males, supports enlargement of cross-sectional muscle area and subsequentially, hypertrophy.[84]

If improperly prescribed or performed, however, training can be physically harmful and reduce the efficacy of the benefits. Ideally, a training program is crafted with the intention of meeting specific individual-oriented goals. With adolescents, a comprehensive understanding of RTSC (resistance training skill competency) and training age is fundamental to creating and progressing an individual through an effective and safe training program.[80] The term “training age” refers to the amount of time an individual has been exposed to organized training while RTSC describes a more in-depth profile of appropriate resistance range, exercise selection, and level of psychological maturity.[80] As more children are participating in competitive sports at younger ages, the failure of coaches, parents, and additional training personnel to incorporate RTSC and training age into program development is supporting the rise in adolescent sport-related injury.

Inadequate rest between strenuous bouts of training is a crucial culprit of injury in youth, particularly with respect to overuse injury. Periods of sufficient physical and psychological rest are said to enhance physiological recovery and have implications for injury prevention.[85] However, with the increasing numbers of youth dual-participating in both high school and travel team athletics, rest periods have diminished. The National Athletic Training Association’s 2011 position statement on overuse injuries in adolescents recommends that adolescents participate in no more than 16-20 hours of organized physical activity per week.[86] When competing on multiple teams during one season, however, many adolescent athletes exceed this mark. In addition to the allotted practice or game times, adolescent athletes often invest a considerable amount of time traveling from one place to the next, so their sport-investment hours may be much more than reported. Their plentiful time investment in athletics may cause their other responsibilities, such as academic-related tasks, to be crammed into the few free hours they have every week and day, enhancing stress and causing sleep deprivation.

1.4.2.2 Equipment

Depending on the activity, athlete, and sport league regulations equipment is either recommended or required. Most athletic equipment is designed to prevent injury and enhance performance. If ill-fitted or improperly worn, however, equipment can increase the risk of injury.

A well-studied example of this is with footwear. As an adolescent transitions through stages of growth their footwear needs vary rapidly, and frequent shoe changes are recommended. However, adolescent footwear is often worn beyond its functional life enhancing injury risk. Depending on the anatomy of an athlete's foot, the biomechanics of their gait, and the demands of the activity, a specific type of shoe is recommended. For example, research suggests an athlete with pes planus, a term for an overpronated, flat, arch during weightbearing, benefits from a shoe with a firm heel counter, a deep toe box, and medial longitudinal arch support.[87] If not addressed, pes planus can alter the biomechanics of the joints proximal to those of the foot and ankle including the tibiofemoral and acetabular femoral joints.[88] An alteration of biomechanics of the proximal joints of the kinetic chain may enhance injury risk. For example, Jumper's knee, a common term for pediatric patella tendinopathy, has been widely associated with excessive femoral internal rotation, a potential resultant of pes planus.[89] Moreover, femoral internal rotation has also been implicated to increase patellofemoral contact area resulting in cartilage damage.[90] While appropriate footwear cannot completely correct poor biomechanics, it can enhance awareness of movement patterns and be an effective complement to corrective physical therapy.

As research continues to address questions of concussions in youth athletics, the youth football helmet has been in the spotlight. The youth brain is far more susceptible to brain damage than the adult brain in the presence of impact.[91] While there is a tremendous amount of development that occurs through childhood and into adolescence, an infant brain already contains over 100 billion neurons, about the amount that an adult brain is composed of.[91] The difference, however, between and child's brain and an adult's brain, is the orientation, myelination, and overall maturity of the neurons. Immature neurons are far less resilient under traumatic stresses and the damaging of such neurons may leave lasting impacts on cognitive function through development.[91] While no research suggests a football helmet can completely remove the risk of head injury as there is an inherent risk of injury at any level of participation, current literature aims to seek a relationship between a helmet and the reduced risk of head acceleration during impact.

Among many types of equipment used by youth, footwear and helmets are often worn beyond their functional lives. While accredited boards such as NOCSAE (the National Operating Committee on Standard for Equipment) require refurbishment of helmets and other sports equipment, helmets are often worn damaged due to high price of replacement and the underreporting or unawareness of helmet damage. Similar to damaged helmets, excessively worn footwear no longer performs its intended function and may lead to increased injury risk.

1.4.3 Biomechanics

Biomechanics is a term used to describe the objective observation of human movement. Proper biomechanics are essential to safe participation in any athletic activity. Poor biomechanics pose the risk of injury by faulty movement patterns and excessive unfavorable forces during dynamic activity. It is important to have a fundamental understanding of both kinetic chains and exercise type. Most sports require what is known as open kinetic chain activity. Known for being more prone to injury, open kinetic chain motions are those that a limb is not fixed to a surface through a range of motion. Examples of open kinetic chain activities include throwing a projectile or kicking a ball. Conversely, closed kinetic chain motions are those for which all limbs are fixed to a surface through a range of motion. An example of this would be with a squat or push-up.

While open kinetic chain activities are more common in athletics, they pose a substantial risk for injury due to their reliance on often single or smaller muscle groups through given degrees in a range of motion. For example, during a throwing motion, the actions of the rotator cuff muscle vary through the phases of throwing. While the supraspinatus, infraspinatus, and trees minor are most active during the early and late cocking phase to initiate shoulder external rotation, the subscapularis is most active during the acceleration phase to initiate shoulder internal rotation.[92] Any weakness in a muscle of the rotator cuff may cause unfavorable motion, excessive forces, or accessory motion at other joints. All factors may play a significant role in injury development. Poor throwing mechanics are seen often with youth athletes who are subject to excessive training, limited rest, and inadequately informed coaches.

Observation of joint angles through dynamic ranges of motion is also used as an indicator of adequate biomechanics. Perhaps the most well-known example of a movement pattern that is associated with injury risk is dynamic knee valgus. Seen mostly in females, dynamic knee valgus is excessive adduction of the knee during functional movement. This is usually observed during the landing phase of a cutting or jumping maneuver. Research suggests that this movement pattern is a risk factor for ligamentous knee injuries, most notably ACL injuries.[93] Research also suggests that excessive elbow valgus during overhead throwing is associated with various elbow injuries as is limited dorsiflexion associated with various injuries to the ankle.[92]

1.5 Sports Specialization

Sports specialization is becoming increasingly more common for youth in the US. While a concrete definition remains unclear, sports specialization can be understood as the succession of various athletic activities to focus or specialize in one sport. This sport, then, is central to an adolescent's life. They spend year-round physical and social battery participating in one specific sport. Coaches, parents, and athletes alike believe that a young athlete focusing on one sport will enrich their skill set and enhance their chances to compete at an elite level. Ultimately, they believe specialization will develop to mastery and eventually excellence over an adolescent's peers in a single activity.

Current research, however, suggests otherwise. There is limited research to report that specialization in one activity translates to mastery. It is well reported that participation in a variety of activities help develop what is known as physical literacy. Physical literacy is comprised of basic, but fundamental movement patterns such as agility, balance, and coordination.[94] Developing proficiency in fundamental movement patterns enhances motor skills and ultimately has implications for injury risk and performance.[95] In addition, participation diversification exposes an athlete to various social settings and new complex problems within various contexts. Moreover, sports specialization is a vehicle commonly driven by parents and coaches who believe they are encouraging athletic success. In the process, however, the "fun" part of sports often dissolves, and resentment develops.

Central to this paper's conversation, sports specialization, particularly early sports specializations, enhances the risk of injury. Overuse injuries are the most common type of injury sustained by specialized athletes with prevalence in single limb-dominated sports such as baseball and tennis.[96] Specialization and overuse injury is more prevalent in females than male athletes with significantly high injury rates in individual sports such as dance, gymnastics, and tennis.[96] With respect to both sexes, however, individual skill-specific sports report both earlier specialization ages and a 1.67 times greater risk of overuse injury rate when compared to team sports.[96] Overuse injury risk is intimately associated with excessive and inappropriately prescribed training volume. Moreover, sport specialization is often a culprit of overtraining. If the suggested 2:1 organized to free play ratio is exceeded, injuries are often observed. An altered ratio enhances physiological burnout risk and subsequent injury risk with roots in neuromuscular fatigue.

A universal definition of sports specialization has not yet been proposed in literature; thus, clinicians are faced with the challenge of effectively and universally determining if an adolescent is specializing. The 3-point Jayanthi sports specialization scale, proposed by Neeru A. Jayanthi (a renown sports medicine physician), is one of the few developed ranking systems.[96] It is a questionnaire comprised of three yes or no questions. An answer of "yes" receives a 1 while an answer of "no" receives a 0. Thus, after completion of the questionnaire, the participant is left with a score of 0-3. The scores, then, are correlated with a classification of specialization degree. 0-1 points are associated with low specialization, 2 points are associated with moderate specialization, and 3 points are associated with high specialization. The three questions inquire about if the athlete discontinued participation in all other sports, if the athlete views the specialization sport as more important than other activities, and if the chosen activity is participated in consecutively for more than 8 months out of the calendar year. The Jayanthi scale allows a clinician to determine the specialization status of an adolescent and can assist them in determining the most appropriate next steps of care.

Sports specialization can be broken into early, before puberty or the age of 12, and late, after puberty specialization. Although early sports specialization is associated with a higher risk of negative physical and psychological outcomes when compared to late specialization, both are discouraged by current evidence.[94] It is recommended that children withhold specialization until the age of 15 or 16.[18,94,97] This age is considered late adolescence whereby most individuals have developed adequate motor, cognitive, and social skills to benefit from intense training while safely withstanding physical demands.[98] Prior to specialization, it is recommended that children and adolescents participate in a diverse array of physical activities. Activity diversification is thought to promote the development of neuromuscular and motor skills and consequently reduce the risk of injury.[18] Moreover, the National Athletic Trainers Association recommends that pediatric athletes take 2-3 months off a single sport per year to give time for substantial recovery.[96] During the recovery period, it is further recommended that youth do not participate in sports with similar physical demands. For example, during a recovery period for a baseball pitcher it is recommended that the athlete does not participate in another overhead throwing activity. Often, however, these recommendations are inadequately presented to parents and coaches or are disregarded all together.

1.6 Burnout

Burnout is becoming increasingly more common in the adolescent population.[99] Up until recently, however, research has focused on burnout in adult athlete populations.[99] Also known as overtraining syndrome, burnout represents a variety of physiological and psychological responses to high-level training with limited rest.[99,100] For adolescents, it is usually seen with highly specialized athletes.[96] In general, however, athletes are a population at high-risk for burnout due to their increased level of commitment and willingness to sacrifice mental and physical health for performance success. Common manifestations of the syndrome include anxiety, depression, chronic joint pain, and decreased athletic performance.[99]

In 2001, Radeake & Smith crafted one of the first and most widely used definitions of burnout. They understood burnout as multidimensional and proposed three categories by which burnout consequences can be observed. The first category is emotional and physical exhaustion, the second is withdrawal and detachment from activity, and the third is disinterest in skill and sport development.[101] From these three categories, they developed a questionnaire known as the Athlete Burnout Questionnaire (ABQ). The ABQ is comprised of 15 parts, split under 3 main dimensions of burnout: physical/emotional exhaustion, sport devaluation, and reduced sense of accomplishment. [102] Under each domain is 5 subsections which are scored on a 5-point scale with 5 being “almost always” and 1 being “almost never.” The usefulness and applicability of the ABQ has been challenged. Gustafson and colleagues argue that the ABQ is crafted on an inconclusive definition of burnout and the selection of the three dimensions lacks rational.[103] Gerber conducted a prospective study that validated the internal consistency of the questionnaire.[102] However, they also stated that psychometric measurements continue to pose concerns.[102]

Athletes will always experience performance stressors that come with the fear of disappointing their coaches, parents, and teammates.[104] It is not possible to mitigate all psychological consequences of athletics, but it is important that vulnerable populations are determined and monitored to decrease the risk of burnout development and its residual consequences.

1.7 Public Health Model

The Public Health Model is a data-driven systematic approach to addressing public health obstacles, including injuries. The model functions by identifying population-wide health risks, employing prevention strategies, and assessing the efficacy of interventions. Its purpose is to promote wellness and education while reducing wide-spread population burdens of a disease or illness. The Public Health Model employs a four-step process to achieve this goal. The first step of the Public Health Model is to describe the burden of the disease. The second step is to identify risk and protective factors. The third and fourth steps are to develop and test prevention strategies and ensure widespread adoption, respectively.

This thesis will attempt to address the first step by understanding the epidemiological patterns and burden of adolescent sports-related injuries within a high school athletic population. Completing the first step of the model is essential before risk factors can be identified and injury prevention interventions can be tested. Holistically understanding injury incidence provides insight to addressing further steps in the Public Health Model.

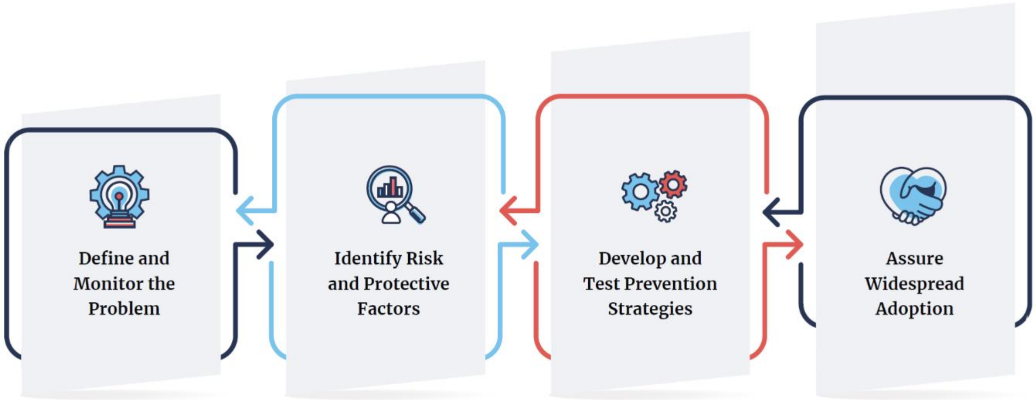

Figure 1. Public Health Model

1.8 Methodological Considerations

This study employed a descriptive epidemiological study design with the goal of understanding the epidemiology of sports-related injuries of a cohort of high school athletes during the 2021-2022 academic year. This study design was chosen due to its feasibility and cost-effectiveness.

1.9 Problem Statement

Youth sports have become a fundamental part of American society with over 8,000,000 children participating in high school sports alone.[1] Current research aims to understand risk factors associated with injury, but there remains uncertainty. The need for establishing injury risk profiles is pertinent and may address the rising number of injuries, especially within high school athletics. There is a particular need for information on the relationship between characteristics such as multi-sport participation, time of injury, and sport type (contact/noncontact) on pediatric injury sustained during high school sanctioned events. Thus, further research is warranted to observe how these variables interact with one another and the risk of injury.

1.10 Study Purpose

The purpose of this descriptive epidemiological study was to describe patterns and incidence of anatomic location, injury type, mechanism and onset of injury, injury timing, and sport-specific injury patterns in a group of high school athletes at a private high school. Secondary and tertiary aims of this study were to compare incidence and patterns of injuries between sexes and compare incidence and patterns of injuries between single sport and multi-sport athletes.

1.11 Specific Aims/Hypothesis

- Aim 1: Describe incidence and patterns of injuries in high school athletes.
    - Aim 1A: Describe anatomic location and injury types.
    - Aim1B: Describe mechanism and onset of injuries (contact vs non-contact).
    - Aim 1C: Describe when injuries occur (practice vs competition).
    - Aim 1D: Describe upper and lower extremity injuries.
    - Aim 1E: Describe injuries within specific sports.
    - Aim 1F: Describe incidence.

- Aim 2: To compare incidence and patterns of injuries between sexes.
    - The incidence and patterns of injuries will be different between sexes.
- Aim 3: To compare incidence and patterns of injuries between interscholastic multisport athletes and interscholastic single sport athletes.
    - The incidence and patterns of injuries will be different between interscholastic multi-sport and single sport athletes.

1.12 Study Significance

An understanding of the epidemiology of injuries within a population of high school athletes can assist sports medicine personnel in identifying at-risk populations, guide the implementation of preventative measures, and enhance our current knowledge of evidence-based practice. This study provides researchers with a better understanding of present epidemiology within this population, and thus achieves the goals listed above.

2.0 Experimental Design

The current study employed a descriptive epidemiological study design. Data from SOAP (subjective, objective, assessment, plan) notes were extracted and analyzed with the goal of establishing relationships between various demographic variables and incidence of sports-related injuries within a population of adolescent female and male athletes at a private high school during a single academic year.

The high school enrollment is 333 students; 181 participated on a school-sponsored athletic team during the 2021-2022 school year. Students were eligible to participate in multiple sports throughout the school year and, in some cases, multiple sports in a single season. The school had a single athletic trainer (AT) who was responsible for all care and documentation of the high school students. The AT was present at all practices, home regular season competitions, and playoff competitions.

2.1 Independent Variables

Demographic variables of interest:

- Sex
- Multi-sport or single sport athlete

Sport-specific variables of interest:

- Contact or non-contact sport
- Sustained during practice or competition

- Sport

2.2 Dependent Variables

Injury-specific variables of interest:

- Injury type
- Injury onset
- Anatomic location
- Injury mechanism (contact vs non-contact)
- Injury timing (practice vs competition)

2.3 Subjects

The subjects that are included in this study were all private high school students that attended the same private high school of interest in Pittsburgh, PA. The school has a student body of 333 with 181 enrolled in school-sponsored athletics. Both males and females are enrolled, with 55% female enrollment and 45% male enrollment. They were all students currently enrolled at the high school that participate in a school-sanctioned athletic event. Prior to their respective athletic seasons, they completed an approved pre-participation physical packet for clearance to participate. The subjects who sustained injuries in either football, girls' soccer, boys' soccer, girls' basketball, boys' basketball, girls' volleyball, and boys' volleyball were included in the analysis.

The school of interest was a private high school for which there were multiple levels of interscholastic participation. For example, boys' basketball had four levels of participation: 9^{th} grade, freshman, junior varsity, and varsity. Thus, the sports with multiple levels of participation had the largest number of participants on average. Conversely, cross country and track (for both boys' and girls') only had a single level/team, which was varsity. Moreover, each sport had a different length season depending on success in post-season play. For example, the boys' basketball team won regional and state championships, so their season was longer, and thus more injuries were recorded for those respective athletes.

As with many private high schools, there is a tremendously competitive culture around sports participation; This school of interest is no exception. In many cases, parents opt to send their children to a private school simply for the ability to partake in high-level athletics. Therefore, the population of athletes participating in athletics at the present high school were highly skilled and competitive. The athletics-driven culture was a staple of the identity at the school.

2.4 Recruitment

The present study obtained data from a review of the PI's subjective, objective, assessment, and plan (SOAP) notes. No subjects were contacted/recruited for the sole purpose of participating in the study.

2.5 Inclusion Criteria

Subject Inclusion:

- Enrolled as a full-time student at the high school
- All pre-participation clearance requirements are fulfilled to participate
- Included on official high school team roster

Data Inclusion:

- Injury reported to AT
- Injury onset or exacerbation during a school-sanctioned athletic event
- Injury required removal of athlete for at least one practice or game

2.6 Exclusion Criteria

Subject Exclusion:

Data Exclusion:

- Injury required no intervention or time-loss
- Injury was reported to a different healthcare provider or parent/coach.

2.7 Power Analysis

This was a descriptive epidemiology study designed to describe injuries among athletes at a high school. All injuries for which care was sought from the AT employed by the high school were included in this analysis.

2.8 Procedures

The PI was an AT employed at the high school of interest. The SOAP notes included were a routine part of the AT's job. Following an injury at a home practice, game, or playoff competition, an injury report (in the form of a SOAP note) was written. Each SOAP note contained demographic information and a subjective, objective, assessment, and plan section for which specific information was collected. The subjective section complied information relating to patient-reported details such as recall of the event, history, and pain description. The objective section included information on the AT's physical exam findings such as range of motion measurements and vital signs. The assessment section included the AT's final diagnosis based on the information collected in the previous two sections and lastly, the plan section included information on the following steps of care.

At the end of the academic year, a year-long excel injury log was created. The injury log compiled data on sex, sport, anatomical location, injury type, injury occurrence time, injury mechanism, and whether the athlete was a single sport or multi-sport athlete. Following completion of the log, information was transferred into SPSS for data analysis and observation of patterns and incidence among the target population of high school athletes.

2.9 Operational Definitions

An injury was defined as a musculoskeletal complaint reported to the AT that occurred as a result of participating in a school-sponsored event. All injuries included were present in evaluation notes written by AT. To be included, the injury required removal from participation from at least one practice or game and/or therapeutic intervention from the AT.

An interscholastic multisport athlete (IMSA) was defined as an athlete who competed for more than one athletic team during the 2021-2022 academic school year. Information regarding athletic participation status outside of the academic institution was not collected, as this was not permitted by the IRB. The definition of an IMSA included athletes who also participated in multiple sports during a single season. However, the limit of number of sports participated in during a single season was 2. Athletes who participated in multiple sports during a single season only did so during the fall season. No single athlete participated in more than 4 sports for the entire academic year.

2.10 Data Reduction

All data was collected by a single AT employed through the private high school. Data was collected in the form of post-injury evaluation SOAP (subjective, objective, assessment, plan) notes and specific information was extracted. Demographic information such as grade, sex, sport, and multi-sport participation status along with injury-specific information such as injury type (acute/chronic), injury location (body part, side) was extracted.

INJURY EVALUATION NOTE – SOAP NOTE

Name: ______________ **Grade:** ___
Date: ______________ **Sport:** ____________
Event: practice/game
Sex: M/F

Location: _____________
Side: R/L or N/A
Type: acute/chronic
Mechanism: contact/non-contact

Chief Complaint: ____________________________

History/Subjective:____
____
____
____

Objective:____
____

Assessment:____
____
____

Plan:____
____
____

Signature: _______________________ ATC

Figure 2. Sample SOAP/Evaluation Note

2.11 Data Analysis

2.11.1 Estimation of Injury Incidence and Frequency

Injury incidence was expressed as the number of injured athletes per 100 athletes per academic year. As shown in formula 1.

$$Injury\ Incidence = \frac{Number\ of\ athletes\ who\ sustained\ an\ injury\ during\ the\ academic\ year}{Total\ number\ of\ athletes\ on\ the\ roster\ during\ the\ same\ academic\ year}\ x\ 100$$

Injury Incidence. Formula 1.

Injury frequency was expressed as the number of injuries per 100 athletes per academic year. As shown in formula 2.

$$Injury\ Frequency = \frac{Number\ of\ injuries\ sustained\ by\ athletes\ during\ the\ academic\ year}{Total\ number\ of\ athletes\ on\ the\ roster\ during\ the\ same\ academic\ year}$$

Injury Frequency. Formula 2.

2.11.2 Statistical Analysis

Descriptive statistics were calculated for all variables (mean, standard deviation, median, interquartile range, or proportion, as appropriate). Various injury attributes (location, mechanism, etc.) were described using absolute and relative (percent) frequencies. Injury incidence was compared between groups using Fisher's Exact Tests.

Statistical analysis was conducted using SPSS Statistics (Version 28; IBM Corp., Armonk, NY). Statistical significance will be set a priori at alpha = 0.05, two-sided.

3.0 Results

3.1 Demographics – subjects and school

Table 1 depicts the demographics for the high school athletic population during the 2021-2022 academic year. The student-athlete population included 181 students; 100 were boys and 81 were girls. Of the 181 athletes, 41 (22.7%) were in 9th grade, 32 (17.7%) were in 10th grade, 62 (34.3%) were in 11th grade, and 46 (25.4%) were in 12th grade during the 2021-2022 academic year. Almost all athletes were identified as multi-sport athletes (115/181 – 63.5%). The remaining 66 (66/191 – 36.5%) athletes were identified as single-sport athletes.

Table 1. **Sex, grade level, multi-sport/single-sport status demographics of all high school athletes**

Demographic	Frequency	Percent
Sex		
Female	81	44.8%
Male	100	55.2%
Grade		
9	41	22.7%
10	32	17.7%
11	62	34.2%
12	46	25.4%
Multi-sport/Single-sport		
Multi-sport	115	63.5%
Single-sport	66	36.5%

Of all subjects, 78/181 (43.0%) sustained an injury. Most athletes only sustained a single injury (65/93 = 69.9%).

Figure 3 depicts the number of athletes included on each athletic program roster for which data was collected. The term program clarifies that data was collected from all participation levels within any specific sport (freshman, junior varsity, varsity).

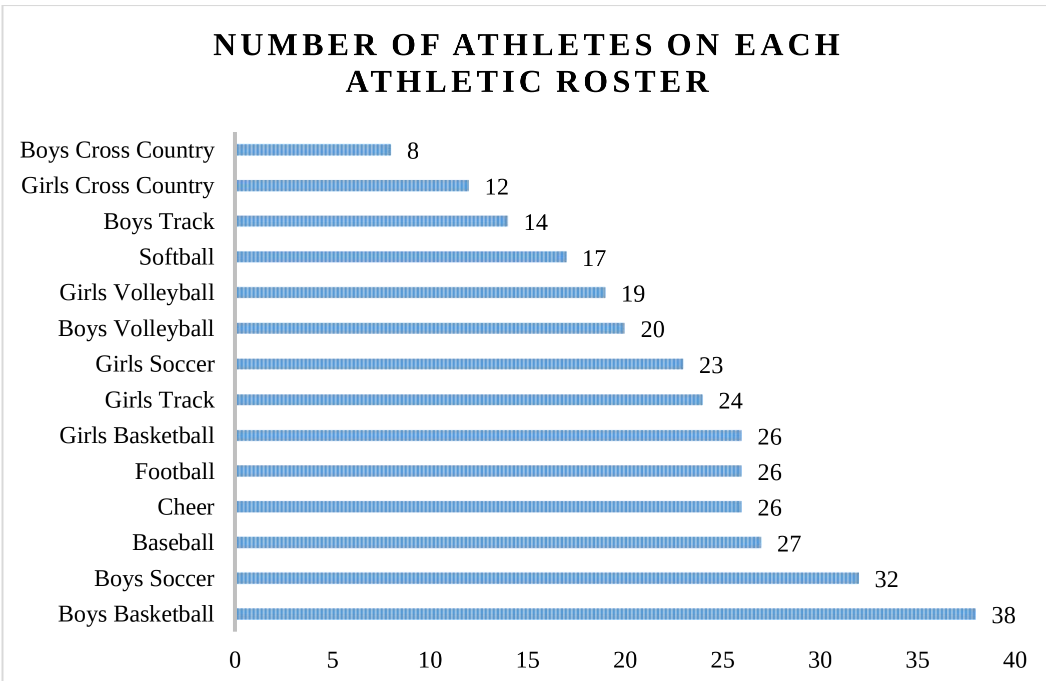

Figure 3. Number of athletes on each athletic program roster

***The number of athletes does not add up to 181 as some athletes played >1 sport**

Boys' basketball contained the largest number of program participants at 38, followed by boys' soccer at 32, and baseball at 27. Girls' basketball, football, and cheer were tied for the fourth largest programs at 26 participants each. Boys' and girls' cross country contained the smallest number of program participants at 8 and 12 respectively.

3.2 Interscholastic Multi-Sport/Single-Sport Athlete Status – Association with Sex and Injury Risk

A total of 115 of the 181 athletes (64%) were identified as multi-sport athletes. The percentage of girls who were multi-sport athletes (48/81 = 59.3%) was lower than the percentage of boys who were multi-sport athletes (67/100 = 67.0%) although this difference was not statistically significant ($p = 0.352$). The percentage of interscholastic multisport athletes who sustained an injury (39/115 = 33.9%) was lower than the percentage of single-sport athletes who sustained an injury (40/66 = 60.6%). This difference was significant ($p < 0.001$).

3.3 Injuries by Anatomic Location

Figure 4 depicts injuries stratified by anatomic location. Figure 5 depicts the anatomic location of injuries stratified by sex of the athlete.

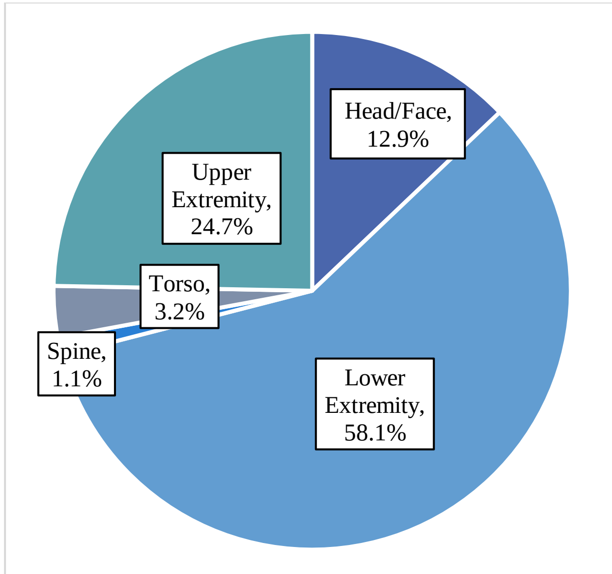

Figure 4. Anatomic location of injuries sustained by high school athletes

Girls

Boys

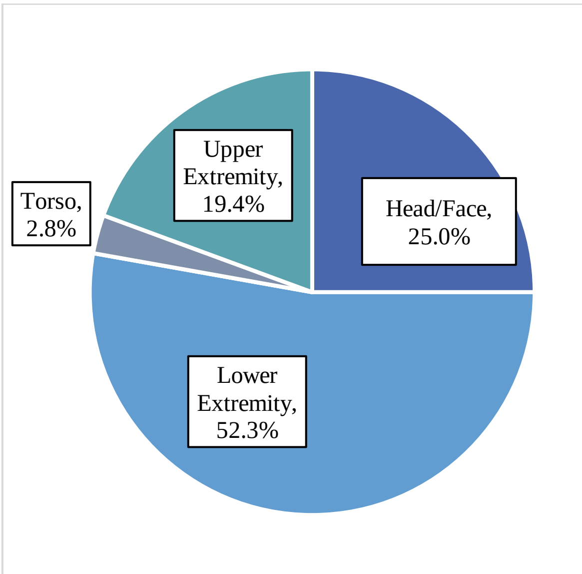

Figure 5. Anatomic location of injuries sustained by high school girls

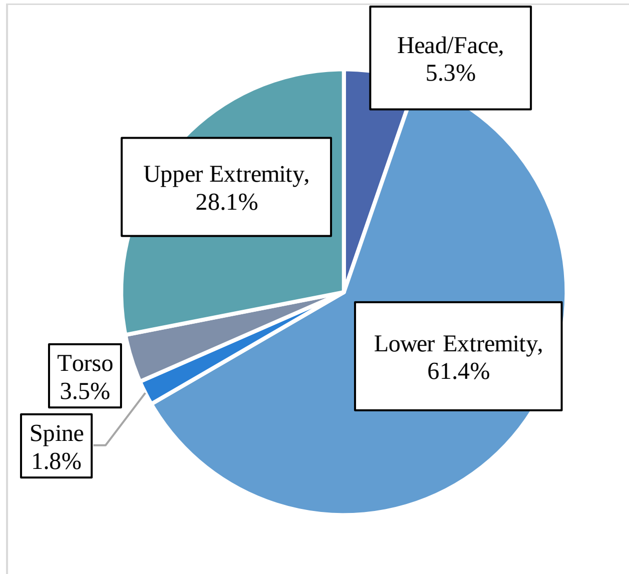

Figure 6. Anatomic location of injuries sustained by high school boys

Overall, 58.1% of injuries occurred to the LE, followed by the UE (24.7%), the H/F (12.9%), the torso (3.2%), and the spine (1.1%). For girls, 52.3% of injuries occurred to the LE, followed by the H/F (25.0%), the UE (19.4%), the torso (2.8%), and the spine (0.0%). For boys, 61.4% of injuries occurred to the LE, followed by the UE (28.1%), the H/F (5.3%), the torso (3.5%), and spine (1.8%).

3.4 Anatomic Sublocation of Injuries

Table 2. Anatomic location and anatomic sublocation of injuries sustained by high school athletes [count(percent)]

Anatomic Location	Anatomic Sublocation	All Athletes	Girls	Boys
Head/Face	Head/Face	12 (12.9)	9 (25.0)	3 (5.3)
Lower Extremity	Foot and Toes	6 (6.5)	3 (8.3)	3 (5.3)
	Ankle	22 (23.7)	7 (19.4)	15 (26.3)
	Lower Leg	5 (5.4)	3 (8.3)	2 (3.5)
	Knee	6 (6.5)	1 (2.8)	5 (8.8)
	Hip	7 (7.5)	3 (8.3)	4 (7.0)
	Thigh	9 (9.7)	2 (5.6)	7 (12.3)
Spine	Lumbo-pelvic	3 (3.2)	1 (2.8)	2 (3.5)
Torso	Thoracic	1 (1.1)	0 (0.0)	1 (1.8)
Upper Extremity	Hand and Fingers	7 (7.5)	5 (13.9)	2 (3.5)
	Wrist	3 (3.2)	1 (2.8)	2 (3.5)
	Elbow	1 (1.1)	1 (2.8)	0 (0.0)
	Shoulder	11 (11.8)	0 (0.0)	11 (19.3)
Total		93	36	57

The most common injury anatomic sublocation overall was the ankle (23.7%) followed by the head (12.9%), shoulder (11.8%), and thigh (9.7%). After stratification by sex, the data revealed the head (25.0%), ankle (19.4%), hand/fingers (13.95%), and lower leg (8.3%)/hip (8.3%) were the most prevalent anatomical sublocations injured by girls. Girls injured the shoulder (0.0%), thoracic spine (0.0%), and wrist/elbow (2.8%) the least. In contrast, in boys, the ankle (26.3%), shoulder (19.3%), thigh (12.3%), and knee (8.8%) as the most common injured sublocations. Boys injured the elbow (0.0%), thoracic spine (1.8%), and lumbo-pelvic spinal region (3.5%)/lower leg (3.5%)/hand/fingers (3.5%) the least.

3.5 Injury Anatomic Location after Stratification by Sport

Tables 3, 4, 5, and 6 demonstrate the number of injuries sustained to a particular anatomic location and sublocation for each sport. Data for girls are included in tables 3 and 4, and data for boys are included in tables 5 and 6.

Table 3. Location of injuries sustained by female high school basketball, cheer, soccer, and softball athletes [count(percent)]

Anatomic Location	Anatomic Sublocation	Basketball	Cheer	Soccer	Softball
Head/Face	Head and Face	6 (54.5)	0 (0.0)	3 (23.1)	0 (0.0)
Lower Extremity	Foot and Toes	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
	Ankle	2 (18.2)	0 (0.0)	3 (23.1)	0 (0.0)
	Lower Leg	0 (0.0)	0 (0.0)	3 (23.1)	0 (0.0)
	Knee	0 (0.0)	0 (0.0)	0 (0.0)	1 (33.3)
	Hip	0 (0.0)	0 (0.0)	1 (7.7)	0 (0.0)
	Thigh	0 (0.0)	0 (0.0)	2 (15.4)	0 (0.0)
Spine	Lumbo-pelvic	0 (0.0)	0 (0.0)	1 (7.7)	0 (0.0)
Upper Extremity	Hand and Fingers	2 (18.2)	1 (50.0)	0 (0.0)	1 (33.3)
	Wrist	0 (0.0)	1 (50.0)	0 (0.0)	0 (0.0)
	Elbow	0 (0.0)	0 (0.0)	0 (0.0)	1 (3.33)
Total		11	2	13	3

Table 4. Location of injuries sustained by female high school track, cross country, and volleyball athletes [count(percent)]

Anatomic Location	Anatomic Sublocation	Track	Cross Country	Volleyball
Head/Face	Head and Face	0 (0.0)	0 (0.0)	0 (0.0)
Lower Extremity	Foot and Toes	1 (100.0)	1 (50.0)	0 (0.0)
	Ankle	0 (0.0)	0 (0.0)	2 (50.0)
	Hip	0 (0.0)	1 (50.0)	1 (25.0)
Upper Extremity	Hand and Fingers	0 (0.0)	0 (0.0)	1 (25.0)
Total		1	2	4

Basketball and track resulted in 69% of all injuries for girls. Of the 13 injuries recorded for girls' soccer, 3 (23.1%) were to the head/face, 3 (23.1%) were to the ankle, 3 (23.1%) were to the lower leg, 2 (15.4%) were to the thigh, 1 (7.7%) was to the hip, and 1 (7.7%) was to the lumbo-pelvic region. Of the 11 injuries recorded for girls' basketball, 6 (54.5%) were to the head/face, 2 (18.2%) were to the ankle, 2 (18.2%) were to the hand/fingers, and 1 (9.1%) was to the foot/toes. Of the 4 injuries recorded for girls' volleyball, 2 (50%) were to the ankle, 1 (25%) was to the hip, and 1 (25%) was to the thigh. Softball produced 3 injuries; 1 (33.3%) was to the knee, 1 (33.3%) was to the hand/fingers, and 1 (33.3%) was to the elbow. 2 injuries were recorded for both girls' cross country and cheer. Of the 2 injuries recorded for cheer, 1 (50%) was to the hand/fingers and 1 (50%) was to the wrist. Of the 2 injuries recorded for cross country, 1 (50%) was to the foot/toes, and 1 (50%) was to the hip. One injury was recorded for girls' track; It was to the foot/toes.

Table 5. Location of injuries sustained by male high school baseball, basketball, football, and soccer athletes [count(percent)]

Anatomic Location	Anatomic Sublocation	Baseball	Basketball	Football	Soccer
Head/Face	Head and Face	0 (0.0)	1 (7.1)	2 (9.5)	0 (0.0)
Lower Extremity	Foot and Toes	0 (0.0)	2 (14.3)	0 (0.0)	1 (16.7)
	Ankle	0 (0.0)	6 (42.9)	5 (23.8)	1 (16.7)
	Lower Leg	2 (40.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Knee	0 (0.0)	1 (7.1)	3 (14.3)	0 (0.0)
	Hip	0 (0.0)	1 (7.1)	1 (4.8)	2 (33.3)
	Thigh	0 (0.0)	1 (7.1)	4 (19.0)	1 (16.7)
Spine	Lumbo-pelvic	0 (0.0)	0 (0.0)	1 (4.8)	0 (0.0)
Upper Extremity	Hand and Fingers	1 (20.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Wrist	0 (0.0)	2 (14.3)	0 (0.0)	0 (0.0)
	Shoulder	2 (40.0)	0 (0.0)	5 (23.8)	1 (16.7)
Total		5	14	21	6

Table 6. Location of injuries sustained by male high school volleyball and cross-country athletes [count(percent)]

Anatomic Location	Anatomic Sublocation	Volleyball	Cross Country
Lower Extremity	Ankle	2 (22.2)	1 (50.0)
	Lower Leg	0 (0.0)	0 (0.0)
	Knee	1 (11.1)	0 (0.0)
	Thigh	0 (0.0)	1 (50.0)
Spine	Lumbo-pelvic	1 (11.1)	0 (0.0)
Torso	Thoracic	1 (11.1)	0 (0.0)
Upper Extremity	Hand and Fingers	1 (11.1)	0 (0.0)
	Shoulder	3 (33.3)	0 (0.0)
Total		9	2

Football and basketball produced the greatest number of injuries for boys. Together, they comprised 61.4% of all injuries for boys. Of the 21 injuries recorded for football, 5 (23.8%) were to the ankle, 5 (23.8%) were to the shoulder, 4 (19.0%) were to the thigh, 3 (14.3%) were to the knee, 2 (9.5%) were to the head/face, 1 (4.8%) was to the hip, and 1 (4.8%) was to the lumbo-pelvic region. Of the 14 injuries recorded for boys' basketball, 6 (42.9%) were to the ankle, 2 (14.3%) were to the foot/toes, 2 (14.3%) were to the wrist, and 1(7.1%) was to the hip, thigh, knee, and head/face. Of the 9 injuries recorded for boys' volleyball, 3 (33.3%) were to the shoulder, 2 (22.2%) were to the ankle, and 1 (11.1%) was to the knee, hand/fingers, and thoracic and lumbo-pelvic regions. Of the 6 injuries sustained in boys' soccer, 2 (33.3%) were to the hip, and 1 (16.7%) was to the foot/toes, ankle, thigh, and shoulder. Of the 5 injuries sustained in baseball, 2 (40%) were to the lower leg, 1 (20%) was to the hand/fingers, and 2 (40%) was to the shoulder. Of the 2 injuries recorded for boys' cross country, 1 (50%) was to the ankle, and 1 (50%) was to the thigh.

The category for shoulder injuries and thoracic spine injuries were removed from Table 3 as there were no injuries recorded to these regions for girls' basketball, cheer, soccer, and softball. The categories for lower leg, knee, thigh, lumbo-pelvic region, thoracic region, wrist, elbow, and shoulder were omitted from Table 4 as no injuries occurred to these regions for girls participating in track, cross country, and volleyball. The elbow and thoracic region categories were removed from Table 5 as no injuries to these locations occurred in boys' baseball, basketball, football, and soccer. Categories for the head and face, foot and toes, lower leg, hip, wrist, and elbow were removed from Table 6 as no boys participating in volleyball or cross-country sustained injuries to those regions.

3.6 Injury Type

Table 7. Injury types sustained by all high school athletes [count(percent)]

Injury Type	Girls' injuries	Boys' Injuries	All injuries
Apophysitis	1 (2.8)	0 (0.0)	1 (1.1)
Bursitis	0 (0.0)	2 (3.5)	2 (2.2)
Chondral degeneration	1 (2.8)	0 (0.0)	1 (1.1)
Compartment Syndrome	1 (2.8)	0 (0.0)	1 (1.1)
Concussion	8 (22.2)	3 (5.3)	11 (11.8)
Contusion	0 (0.0)	1 (1.8)	1 (1.1)
Disc pathology	0 (0.0)	1 (1.8)	1 (1.1)
Fracture	1 (2.8)	3 (5.3)	4 (4.3)
Impingement	0 (0.0)	4 (7.0)	4 (4.3)
Lateral luxation	1 (2.8)	0 (0.0)	1 (1.1)
Medial Tibial Stress Syndrome	1 (2.8)	0 (0.0)	1 (1.1)

Sprain	11 (30.6)	20 (35.1)	31 (33.3)
Strain	6 (16.7)	13 (22.8)	19 (20.4)
Stress fracture	2 (5.6)	0 (0.0)	2 (2.2)
Subluxation	1 (2.8)	2 (3.5)	3 (3.2)
Tendinopathy	2 (5.6)	7 (12.3)	9 (9.7)
Tendon Tear	0 (0.0)	1 (1.8)	1 (1.1)

Sprains (33.3%), strains (20.4%), and concussions (11.8%) accounted for over 65% of all injuries recorded. Tendinopathy (9.7%), fractures (4.3%), and impingement syndromes (4.3%) accounted for most of the remaining injuries. Both boys and girls were evaluated for sprains more than any other injury (35.1% for boys, 30.6% for girls), followed by strains for boys (22.8%) and concussions (22.2%) for girls. The percentage of girls who sustained a concussion (8/81 = 9.9%) was higher than the percentage of boys (3/100 = 3.0%) who sustained a concussion although this was not statistically significant ($p = 0.066$). Conversely, tendinopathy accounted for 12.3% of injuries for boys and only 5.6% for girls. Boys sustained a greater number of fractures (5.3%) than girls (2.8%), however, both boys and girls sustained the same number of stress fractures (2 each). Boys sustained four cases of impingement, amounting to 4.3% of all injuries, while girls sustained 0.

Overall, lateral ankle sprains were the most common injury (16/93 – 17.2%) and the most common injury of athletes with multiple injuries (7/16 – 43.7%).

3.7 Acute vs Chronic Injuries

Table 8 and Figure 7 depict the percent of acute and chronic injuries sustained by the athletes.

Table 8. Percent of acute/chronic injuries sustained by boys and girls [count(percent)]

	All	**Girls**	**Boys**
Acute	68 (73.1)	26 (72.2)	42 (73.7)
Chronic	25 (26.9)	10 (27.8)	15 (26.3)

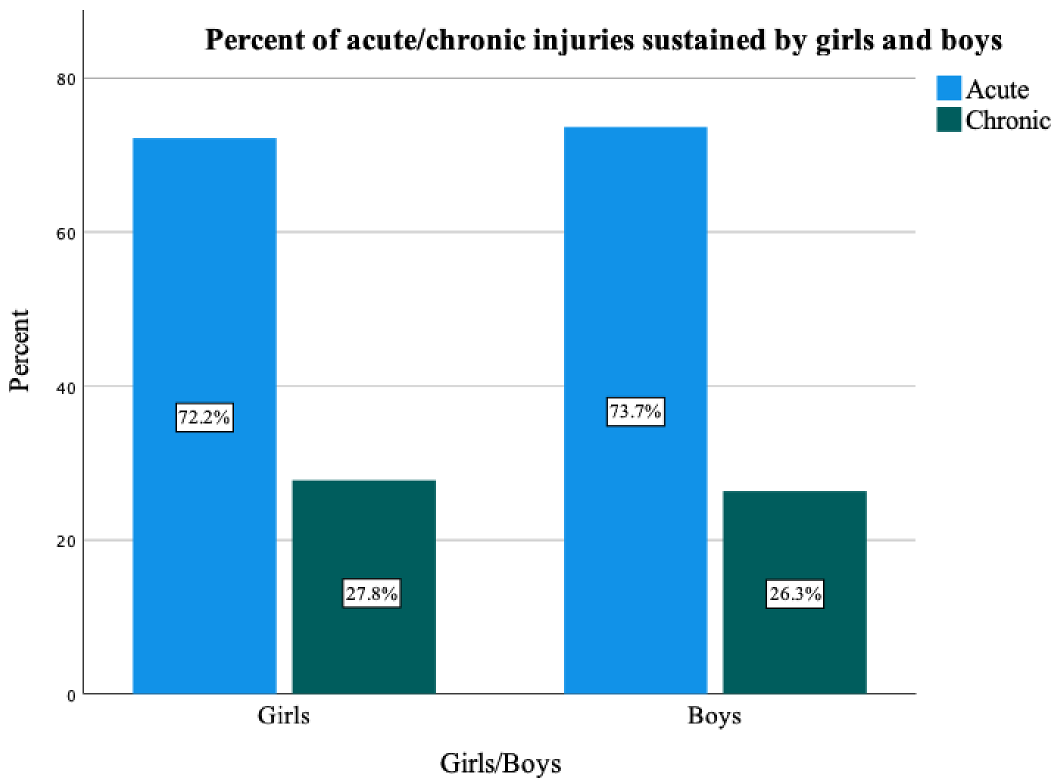

Figure 7. Percent of acute/chronic injuries sustained by girls and boys

Most injuries recorded (73.1%) were acute in nature. 26.9% were identified as chronic. Once stratified by sex, boys and girls showed a similar distribution of acute and chronic injuries. For girls, 72.2% were acute and 27.8% were chronic. For boys, 73.7% were acute and 26.3% were chronic.

3.8 Contact vs Non-contact Injuries

Figure 8 and table 9 depict the percent of contact and non-contact injuries sustained by girls and boys.

Table 9. Contact vs non-contact injuries sustained between girls and boys (count[percent])

	All	**Girls**	**Boys**
Contact	40 (42.0)	20 (55.6)	20 (35.1)
Non-contact	53 (57.0)	16 (44.4)	37 (64.9)

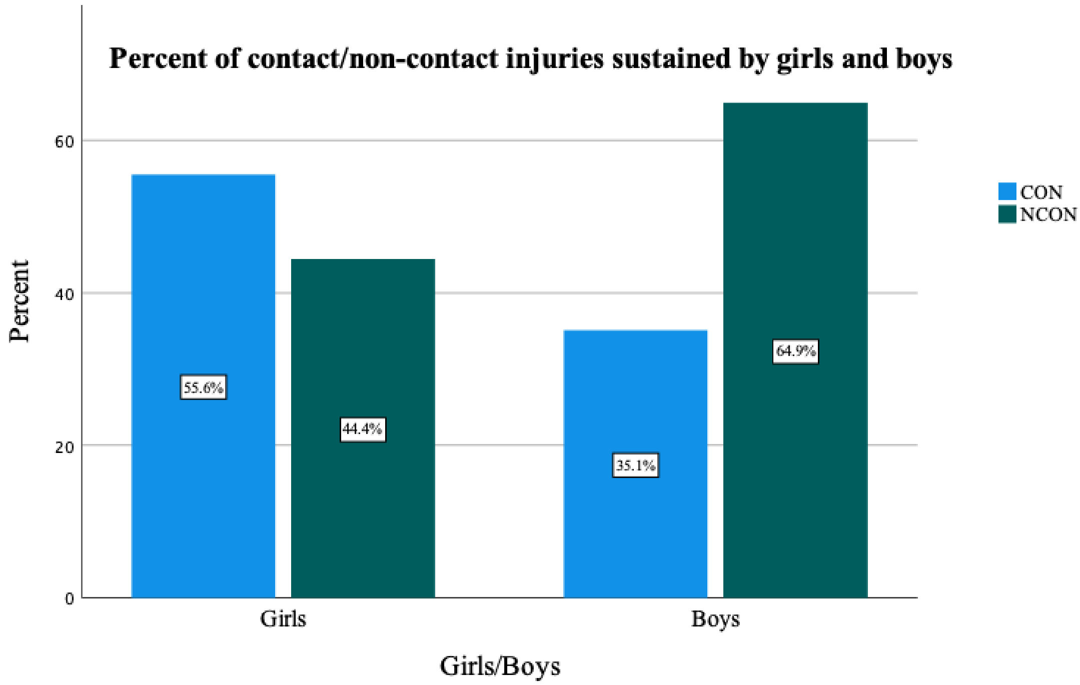

Figure 8. Percent of contact/non-contact injuries sustained by boys and girls

Overall, most injuries recorded occurred from a non-contact mechanism. 57% of all injuries occurred from non-contact mechanisms while only 42.0% occurred from contact mechanisms. The percentage of girls with at least one non-contact injury (16/81 = 19.8%) was lower than the percentage of boys with at least one non-contact injury (33/100 = 33.0%) although this was not statistically significant ($p = 0.064$).

Table 10. depicts the total number of practice injuries and total number of competition injuries sustained during the academic year. Figure 9. depicts the percentage of contact and non-contact injuries that were sustained during practice and competition.

Table 10. Number of injuries sustained in practice and competition (count[percent])

Practice	Competition
47 (50.7%)	46 (49.3%)

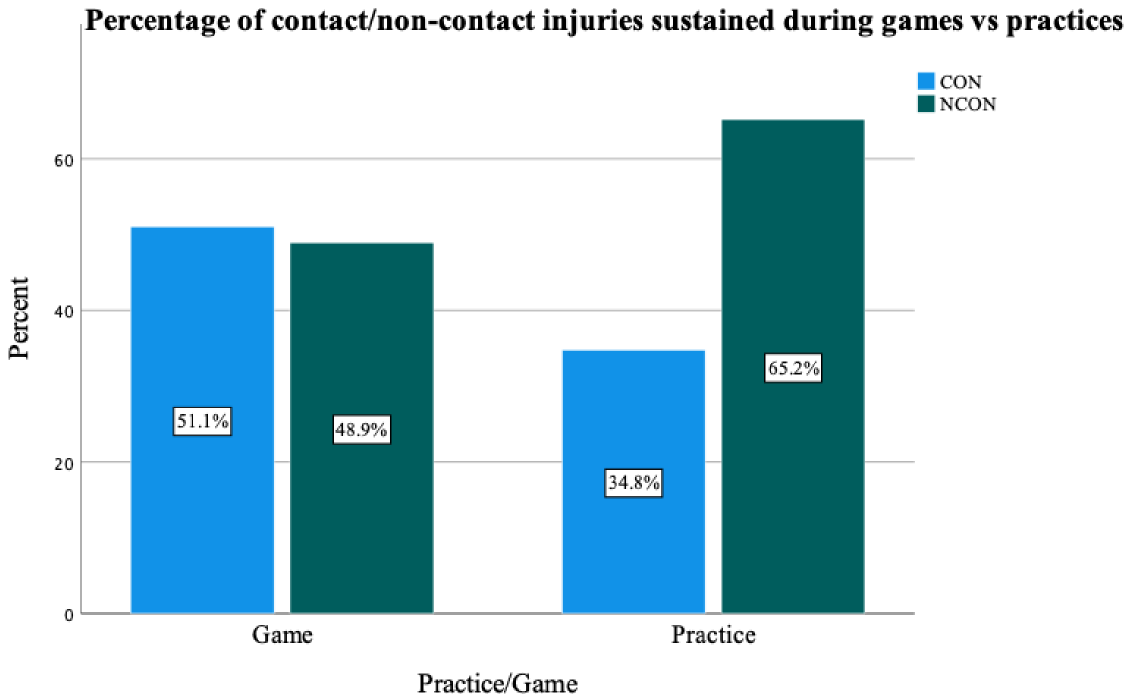

Figure 9. Percentage of contact/non-contact injuries sustained during games vs practices

More injuries were sustained during practice than competition. Most injuries resulting from game play were caused by a contact mechanism (51.1%) while most injuries from practice participation were caused by a non-contact mechanism (65.2%).

3.9 Injury Risk Associated with Sex

Table 11. shows the injury frequency and incidence of injury between boys and girls.

Table 11. Injury Frequency and Incidence per the academic year

	Injury Frequency	Injury Incidence
Girls	(36/81) – 44.4%	(32/81) – 39.5%
Boys	(57/100) – 57.0%	(46/100) – 46.0%

Boys had a greater injury frequency at 57.0% compared to girls at 44.4%. Multiple injuries within the same athlete were more common among boys (21 of 57 injuries = 36.8%) compared to girls (7 of 36 injuries = 19.4%). The percentage of girls with at least one injury (32/81 = 39.5%) was lower than the percentage of boys with at least one injury (46/100 = 46.0%) although this was not statistically significant (p = 451).

3.10 Injury Frequency and Incidence Associated with Sport

Tables 11 and 12 describe injury occurrence by specific sport.

Table 12. Injury frequency and incidence for boys' sports

	Injury Frequency	Injury Incidence
Baseball	(5/27) – 18.5%	(5/27) – 18.5%
Boys Basketball	(14/38) – 36.8%	(12/38) – 31.5%
Boys Volleyball	(9/20) – 45.0%	(9/20) – 45.0%
Football	(21/26) – 80.8%	(13/26) – 50.0%
Soccer	(6/32) – 18.8%	(6/32) – 18.8%
Cross Country	(2/8) – 25.0%	(2/8) – 25.0%

Table 13. Injury frequency and incidence for girls' sports

	Injury Frequency	Injury Incidence
Cheer	(2/26) – 7.7%	(2/26) – 7.7%
Girls Basketball	(11/26) – 42.3%	(9/26) – 34.6%
Girls Volleyball	(4/19) – 21.0%	(4/19) – 21.0%
Track	(1/24) – 4.5%	(1/24) – 4.5%
Soccer	(12/23) – 52.2%	(12/23) – 52.2%
Cross Country	(2/12) – 16.7%	(2/12) – 16.7%
Softball	(2/17) – 11.8%	(2/17) – 11.8%

Football had the largest injury frequency at 81.0%, followed by girls' soccer at 52.2%, boys' volleyball at 45%, and girls' basketball at 42.3%. Girls' soccer recorded the largest injury incidence at 52.2% followed by football at 50.0%, boys' volleyball at 45% and girls' basketball at 34.6%.

4.0 Discussion

The present study was a descriptive epidemiological study that investigated the trends, incidence, and frequency of injuries among a sample of high school athletes during a single academic year. The key findings of this research included a higher injury incidence for boys than girls although this was not statistically significant. Acute injuries were more common compared to chronic injuries. Non-contact injuries were more common compared to contact injuries. There was a higher incidence of injuries in football, basketball, soccer, and boys' volleyball compared to other sports. The most common injury location was the lower extremity, sprains were the most common injury overall, and injuries were sustained most often during practice. Single-sport athletes sustained more injuries than interscholastic multi-sport athletes. Lastly, multiple injuries within the same athlete were most common in football.

4.1 Differences in Injuries Between Sexes

Prior to data collection, it was hypothesized that there would be a difference in incidence and patterns of injuries among sexes. It was found that a difference in incidence and patterns of injuries exists between sexes.

4.2 Injury Incidence and Frequency Associated with Sex

The present study found boys to have a higher incidence and frequency of injuries compared to girls although this was not statistically significant. However, trends in adolescent literature suggests that females, on average, sustain more injuries than males.[19,37,38] Boys in this study participated in more contact sports than girls, so exposure and activity type may have contributed to this result. Additionally, various intrinsic and extrinsic factors, such as musculoskeletal immaturity, anatomic abnormalities, and training status, as discussed earlier, are theorized to play a significant role in the injury frequency differences.

4.3 Acute and Chronic Injuries

Most injuries were considered acute in nature, and this was true even after stratification by sex. The relationship between adolescent sports participation and chronic/acute injuries is well studied. Literature suggests girls are more likely to sustain chronic injuries while boys are more likely to sustain acute injuries.[45] A six yearlong surveillance study on high school athletes conducted by Schroeder and colleagues found that rates of overuse injuries were higher in girls compared to boys across all sports.[105] Similarly, a study conducted by Cuff and colleagues utilizing self-reported surveys found girls to report more overuse injuries than boys.[106] However, acute injuries reveal a different pattern in literature. Boys are more likely to sustain acute injuries, especially with respect to fractures.[33]

Aligned with current literature and this present study, the lower extremity is the most common site for both acute and overuse injuries.[45] Acute injuries are often sustained during competition whereas chronic injuries are aggravated during training sessions. The adolescent population is particularly vulnerable to both overuse and acute injuries as per the variety of intrinsic and extrinsic factors relating to adolescents that were discussed in Chapter 1.

4.4 Mechanisms of Injury Across Sexes and Sports

Mechanisms of injury, including contact and non-contact mechanism status, were collected to understand injury etiology between sexes and sports. The present study revealed that non-contact injuries comprised most injuries for the academic year. Yang and colleagues found contact to be the most prevalent mechanism of injury within a cohort of young recreational athletes.[107] The percentage of girls with at least one non-contact injury (16/81 = 19.8%) was lower than the percentage of boys with at least one non-contact injury (33/100 = 33.0%) although this was not statistically significant ($p = 0.064$). This finding may be due, in part, to the large percentage of ankle sprain injuries for boys, by which are usually caused by acute non-contact mechanisms. Additionally, boys suffered a large percentage of tendinopathy injuries for which also are usually by repetitive non-contact mechanisms. The unique physical demands of each sport alter the risk of injury by specific mechanism. For example, activities for which are not considered contact, usually yield less contact-related injuries. In this sample specifically, cross country and track, two non-contact activities, produced no contact injuries.

4.5 Injury Location

The lower extremity was found to be the most common injury site across all athletes, with the ankle being the most frequent injury location. This presentation is commonly reflected in literature for the adolescent population.[27] An injury surveillance study of high school athletes conducted by Nelson et al. found a 5.23 ankle IR per 10,000 athlete exposures with the majority of ankle injuries being ankle sprains.[108] Similar to Nelson and colleagues' paper, this present study found ankle sprains to comprise almost a quarter of all injuries sustained, making ankle sprains the most common injury in this sample overall.

The upper extremity followed the lower extremity in injury frequency location for boys. All shoulder injuries recorded were sustained by boys. The musculoskeletal complexity of the shoulder girdle and the unstable nature of the glenohumeral joint plays a significant role in adolescent upper extremity injuries, particularly for boys.[37] [35] A paper published by Matzkin addressing common sex sports-related injuries discussed the higher incidence of shoulder injuries in boys, citing that despite the girls (on average) having greater ranges of shoulder motion and increased laxity, boys are more likely to suffer from prolonged shoulder instability.[37] This, they theorize, is likely due to the higher rates of shoulder dislocations in boys than in girls.[37] The higher rates of male dislocations greatly increase the risk of subsequent instability. Furthermore, skeletal immaturity, poor overhead biomechanics, and scapular dyskinesis, all of which are prevalent in adolescent boys, are common culprits of shoulder injuries and may have contributed to the finding of multiple shoulder injuries in boys.[35] According to Moyer and colleagues, the most common reasons for adolescent shoulder pain are little leaguer's shoulder (widening of the humeral growth plate), glenohumeral instability, and rotator cuff injuries, all of which were found to be causes of shoulder pain in this study.[35]

Following the ankle, the second most common injury location for girls was the head and face region; This was due to the large number of concussions sustained by girls. A Marar et al. epidemiological study of concussions within a high school population found football and boys' hockey to have the overall highest concussion IR per athlete exposure, but within gender-comparable sports (such as soccer), girls sustained more concussions than boys.[109] The increased risk of concussion for girls is popular topic in adolescent sports medicine research. Current literature suggests that biomechanical differences relating to the head and neck and help-seeking behaviors might explain this sex trend.[110] Concussions in female athletes will be discussed in more detail in an upcoming section.

4.6 Location of Injuries in football, basketball, and soccer

Football presented with the largest number of injuries followed by boys' basketball and girls' soccer. All contact sports by nature, football, basketball, and soccer are well-cited as injury prone activities.[111] Within football, most injuries were recorded to the ankle, thigh, and shoulder. This finding is similar those of a multi-year high school football injury surveillance study conducted by Kerr and colleagues which found the lower extremity, particularly the ankle to be a site with a high frequency of injury.[20] Most injuries occurred to the ankle in boys' basketball while most injuries occurred to the head/face in girls' basketball. These trends are consistent with Clifton and colleagues' surveillance studies of high school basketball injuries which found the ankle and head/face as common locations for injures across sexes.[21,22] Particularly within the sport of basketball, ankle sprains are highly prevalent.[21,22] Other than the demands of the sport, it is theorized that the playing surface serves as an important predictive factor for injury risk. A study conducted by Doherty and colleagues found female sex, age, and participation in a court-based activity are all significant predictors of an ankle sprain.[112]

Following football and basketball, this study found soccer to have a high injury frequency, particularly for girls. DiStefano and colleagues conducted an injury surveillance study over an eight-year period of high school girls' soccer injuries and found most injuries to be sustained to the lower extremity, particularly the knee and ankle.[25] The same study recorded a high frequency of injuries to the head/face, specifically concussions. DeStefano's study's findings are similar to those of this present study, whereby almost a fourth of all injuries recorded for female soccer athletes were concussions. DiStefano theorizes that their high frequency of concussion findings may be a result of advancements in detection methods and patterns of reporting between sexes and sports. This rationale is likely also a reason for this study's results. Interestingly, there were no injuries to the head/face recorded for boys' soccer. This is consistent with the results of a surveillance study conducted by Kerr and colleagues which found head/face injuries to comprise only a small percentage of total injuries for high school male soccer players.[24]

4.7 High Occurrence of Sprains and Strains

Sprains comprised most of the injuries in this sample followed by strains and concussions. These findings are similar to those of a study conducted by Fernandez and colleagues of 100 high schools found the leading injury diagnoses to be sprains followed by strains.[28] Sprains, specifically ankle sprains, often follow a cyclic pattern whereby a single sprain increases the likelihood of an additional one. Furthermore, recurrent ankle sprains may lead to an orthopedic condition known as chronic ankle instability (CAI) which is also a predictor of future sprains.[113] This relationship may explain why ankle sprains are the most common injury overall. Although not as documented as sprains, strains often follow a similar cyclic pattern.[114] In youth, however, strains are very prevalent likely due to faulty biomechanics and excessive fatigue associated with overtraining.[115] A study conducted by Opar and colleagues discussed the relationship between initial hamstring strain and injury reoccurrence. They implicated neural adaptations after muscle trauma and the inability to reach peak muscle torque, particularly within eccentric demands, to be significant predictive factor of subsequent injury.[114]

Research has suggested that sprains to the lower extremity, specifically the knee and ankle, are highly associated with age and competition level. In a pair of studies conducted by Clifton et al. that compared ankle and knee sprains across youth, high school, and collegiate levels of athletic participation, collegiate football was implicated as the activity that produced the most sprains.[116,117] Clifton suggested that a reason for the trends of sprains in relation to age could be that simply those competing at a higher level of athletics are exposed to their activity for a longer period and potentially have less rest periods.[116] Furthermore, they theorized that competitiveness associated with higher-level athletics may also play a role in injury risk.

Strains can be caused by an acute overstretch of a muscle or by micro-tearing overtime. Often, the mechanical stress placed on an adolescent's muscle through organized athletic activity far exceeds its functional capability and thus injury occurs. The present study found strains to comprise almost a fifth of all injuries. Strains were relatively more common in boys compared to girls. Strains were found to be more common in boys than girls in a study conducted by Cross and colleagues comparing male and female soccer athletes.[118] Joint stiffness and abnormal movement patterns (common characteristics of a growing adolescent) have been identified as risk factors of strains.[119] Furthermore, excessive fatigue with inadequate bouts rest may explain a high frequency of strains in this sample.

4.8 Sprains across Sexes

Boys sustained more sprains across all sports than did girls. Literature is inconclusive on the exact relationship between sprains and sex, as an array of cofounding, intrinsic variables, cloud the ability to make any conclusive statements, specifically with respect to ankle sprains. It is theorized, however, that specific factors such as poor balance, age, and playing surface may serve as risk factors for lateral ankle sprains in youth.[120] Shoulder and knee sprains, specifically in this sample, were more common in boys. The higher frequency of shoulder sprains in boys likely has to do with more boys participating in upper-extremity dominant activities than girls in this population. More boys sustaining knee sprains, however, is an interesting result of this study. A Fernandez study of lower extremity injuries in high school athletes found the frequency of knee sprains to be similar between boys and girls, but girls to have a much higher rate of knee sprains requiring surgery.[28] Other studies have found that there is no sex difference in knee sprains between boys and girls, but girls are much more likely to sustain ACL sprains specifically.[121]

4.9 Concussions Across Sports

Concussions, across all sports and sexes, made up almost a tenth of all injuries. Concussions were diagnosed more readily in this study, particularly for girls, than what has commonly been seen in adolescent sports-related injury epidemiology. This may be due to the large female enrollment in contact activities compared to female enrollment in non-contact activities and the documented sex difference in sports-related concussions. Regardless, contact sports such as football, soccer, and basketball are often culprits of sports-related concussions.[122] This present study supports this trend as the most head injuries were recorded in girls' soccer, girls' basketball, and football.

Among interested trends in injury types, the study found that girls sustained almost three times the number of concussions as boys. Literature has well documented sex differences in concussion rates and severity. On average, adolescent girls sustain more concussions than adolescent boys and the subsequent recovery time for girls is usually longer.[123] Boys are more likely to encounter a concussive impact from contact with another player while girls are more likely to sustain a concussion by contact with playing equipment.[123] However, research has suggested that higher concussion rates in girls likely cannot be completely attributed to activity type and exposure.[124] Symptom reporting and general concussion understanding is suggested to play a key role.[125] A 2016 study conducted by Miyashita and colleagues found girls to be more likely to report concussion-symptoms, more likely to report multiple concussions and more likely to understand the severity and consequences of a poorly managed concussion.[125] Comfort to address feelings is another suggested reason for higher concussion reporting rates in girls as compared to boys.[126]

4.10 Interscholastic multi-sport vs Interscholastic single-sport Athletes and Injury Risk

Sports specialization and multi-sport vs single-sport athlete status has become a focal point of conversation in the adolescent sports medicine community. As the landscape of adolescent athletics is evolving, with more competitive and time intensive participation at every level, more youth are opting to specialize in a single sport. The injury risk consequence of this arrangement is becoming more known; sports specialization likely increases the risk of injury.[96] Aligned with current research, the present study found single sport athletes to have a higher rate of injury as compared to multi-sport athletes; this association was found to be statistically significant. In this study's sample, most specialized athletes were boys. Although the association between multi-sport status and sex was not found to be significant, literature suggests that boys are more likely to specialize than girls.[127] In this sample, 33 boys and 33 girls were identified as single-sport (specialized athletes); because of this, the higher injury incidence in boys compared to girls might not be directly attributed to sport specialization status, but to larger exposure rates due to higher numbers of participants in boys sports. Overall, understanding the relationship between sport specialization status and injury risk is pertinent to modifying current recommendations enhancing the safe participation for adolescent athletes.

4.11 Multiple Injuries in Athletes

Previous injury has been identified as a predictive factor for subsequent injury.[128] Sprains, specifically ankle sprains, often present as reoccurring injuries.[57] Other studies suggest that there is a relationship between concussion and subsequent musculoskeletal injury by way of neurocognitive deficits.[129] This study found that the most common injury of athletes with multiple injuries were ankle sprains. This may suggest a relationship between ankle sprains and subsequent injury. However, more investigation is necessary to suggest a significant relationship between ankle sprains specifically and subsequent injury. Athletes with multiple injuries were most commonly boys and participants in football. Football had the highest percentage of recurrent injuries, likely due to the contact nature and physical demands of the sport.

4.12 Time of injury

An understanding of injury time provides valuable insight into injury patterns and potentially vulnerable populations. This study collected data on injury timing; An injury was identified as either sustained during practice or competition. It was found that more injuries were sustained during practice than competition, which is inconsistent with previous studies[111]. However, it was a one injury difference between practice and competition injuries. More injuries may have been evaluated and recorded at practice because the AT was present for all practices. The AT did not partake in traveling to away games during the regular season, thus all available injuries may not have been collected.

Football and basketball produced the most competition injuries, likely due to the contact nature of the activities and increased competitiveness during game play as opposed to practice. Furthermore, the present study found game injuries to be caused by more contact mechanisms as opposed to non-contact mechanisms. In contrast, practice injuries were found to be caused by more non-contact mechanisms than contact mechanisms. Similar to the rational for injury patterns during games versus competitions, these findings may suggest that players exhibit more aggressive behaviors during game settings.[111]

5.0 Limitations

This study had several limitations. Firstly the sample size was small and only included student-athletes at a single high school. Because of this, results of this study may not be generalizable to a broader high school athletic population. Most epidemiology studies similar to this one employed a multi-year surveillance-type study design whereby thousands of student-athletes and hundreds of high schools are included. In addition to sample-specific limitations, the present study did not collect athlete-exposure data which would have allowed the statistical analysis to include a description of injury risk per athlete-exposure (incidence rate; IR). Incidence rate is commonly collected in adolescent sports-related injury epidemiology studies and is an accurate way of distinguishing if injury risk is altered by athlete exposure to participation. Specifically, it allows researchers to identify what capacity injury and exposure are related. However, collecting athlete-exposure information is challenging and exposures are often hard to define. Moreover, the operational definition of an injury, for which time-loss was defined as the injury-related removal of an athlete from one practice or game, caused an exclusion of data that may have altered the results of the study. In addition, the characterization of multi-sport athlete status was limited to interscholastic athletic participation. An interscholastic multisport athlete (IMSA) was defined as an athlete who competed for more than one athletic team during the 2021-2022 academic school year. Information regarding athletic participation status outside of the academic institution was not collected, as this was not permitted by the IRB. The definition of an IMSA included athletes who also participated in multiple sports during a single season. However, the limit of number of sports participated in during a single season was 2. Athletes who participated in multiple sports during a single season only did so during the fall season. No single athlete participated in more than 4 sports for the entire academic year. Lastly, the PI of this investigation was a single AT for which all injury evaluations were completed by. Although this promoted consistency, repeated human error may have existed. Multiple ATs completing evaluations may have harnessed a broader scope of knowledge and thus more accurate evaluations and diagnoses.

5.1 Further Investigation

The results of this study prompt further investigation within the field of adolescent sports-related injury epidemiology. First, the present study only briefly examined the relationship between injury risk and multi-sport/single-sport athlete status. With the rising number of adolescent athletes specializing in sports, further investigation should be done into sport-specific injuries and the long-term physical and cognitive impacts of cessation of all activities to focus entirely on one. Furthermore, the present study characterized mechanisms into contact or non-contact. These definitions are broad and do not entirely represent a full description of an injury-causing event(s). Other studies define injury mechanisms as multiple different types of contact such as “contact with another player,” “contact with the playing surface”, and “contact with equipment.” These definitions better describe an injury-causing event in detail and with specificity. Further research is warranted to study common injury-causing mechanisms. A deeper understanding of injury mechanisms will provide the basis for injury prevention strategies.

6.0 Conclusion

There is no way to completely alleviate the possibility of injury. However, the field of adolescent sports-related injury epidemiology has greatly broadened available knowledge regarding risk of injury between activities and among specific populations. In addition to the advancement of knowledge, current research has provided the basis for policy changes which have positively impacted safe participation in youth athletics. In the case of changes to concussion legislation, alterations in rules to lower the risk of catastrophic spinal cord injuries, and amendments to sudden cardiac arrest management, research has had potentially life-saving impacts on adolescents.

This study adds to current knowledge relating to high school sports-related injury epidemiology. The significance is relevant for ATs and other clinicians working with active adolescent populations, specifically at high school level. An understanding of injury patterns and population risk may increase the preparedness of clinicians and cultivate the development of injury prevention strategies.

Adolescent participation in athletics is accompanied by inherent, often unmodifiable, risks of injury. Despite the potential negative consequences, participation in athletics provides youth with several physical, cognitive, and social benefits. A preservation of the positive impacts of sports participation may encourage continued engagement and minimize the physical and financial burden associated with sports-related injuries.

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