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Sport-Related Concussion and Lower Extremity Musculoskeletal Injuries in High School Athletes

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Walden University
2018

Abstract

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Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

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Abstract

Sport-related injuries (SRI) can be foreseen and averted when mechanisms and risk factors are completely understood. An appreciation of the relationship between sport-related concussion (SRC) and lower extremity musculoskeletal injuries (LEMI) is emerging amid professional and collegiate athletes. However, findings of such a relationship in adults may not be generalizable to younger populations, and the literature has not addressed this relationship in adolescents. The purpose of this cross-sectional quantitative study was to examine the relationship between SRC and LEMI in high school athletes. The dynamic model of etiology in sport injury provided the study's conceptual framework. A de-identified secondary dataset of high school athletic injuries was obtained from the Athletic Training Practice Based Rehab Network and analyzed with descriptive and inferential statistics. Concussions, knee sprains, and ankle sprains represented about 12%, 17%, and 70%, respectively, of the 1,613 cases in the dataset. Chi-square tests revealed that SRCs, and the number of SRCs, were associated with knee sprains [($p < .001$), Cramer's $V = .148$] and ankle sprains [($p < .001$), Cramer's $V = .545$]. This study may promote positive social change by prompting further retrospective and prospective studies to clarify whether a relationship exists between SRC and LEMI in high school athletes, and if so, whether this relationship is causal in nature. New knowledge may be used to guide practices and policies to reduce sports injuries in high school athletes, which may lead to fewer SRIs among adolescents, fewer school absences, more physical activity, and better health and well-being throughout the lifespan, thereby promoting a more active, productive, and healthy society.

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Table of Contents

List of Tables……………………………………………………………………………vi

List of Figures vii

Chapter 1: Introduction to the Study.. 1

Introduction... 1

Background of the Study 2

Long-Term Consequences of SRC and LEMI.. 4

Mechanisms of Injury 6

SRC and LEMI Risk Factors 7

Problem Statement 12

Purpose of the Study 14

Research Questions and Hypotheses 15

Conceptual Framework 17

Nature of the Study 19

Variable Definitions 22

Assumptions.. 23

Scope and Delimitations 23

Limitations 24

Significance of the Study 25

Summary 26

Chapter 2: Literature Review 28

Introduction... 28

Literature Search Strategy... 29

Conceptual Model 30

Pathophysiology of Concussions 32

Return to Play 34

Neurocognition and Motor Dysfunction 35

Neurocognition and Musculoskeletal Injury 38

Motor Control and Postural Stability 39

Concussion and Lower Extremity Injury 40

Strengths and Limitations of Existing Studies 44

Summary and Transition 46

Chapter 3: Methods 48

Introduction 48

Research Design and Rationale 48

Methodology 49

Study Population 49

Sampling and Sampling Procedures 49

Sample Size 51

Data Extraction 52

Data Analysis Plan 52

Dependent Variable 53

Independent Variable 54

Covariates 54

Statistical Analysis Approach 55

Threats to Validity 59

Construct Validity 59

Internal Validity 60

Statistical Conclusion Validity 60

External Validity 61

Ethical Procedures 61

Summary 62

Chapter 4: Results 63

Introduction 63

Data Collection 64

Data Collection Process 64

Data Reduction Process 64

Data Transformation 69

Data Aggregation 72

Modifications in Data Collection 74

Descriptive and Demographic Characteristics of the Sample 77

Sample 81

Results 81

Assumptions 82

Data Analysis Approach 83

Research Question 1 83

Research Questions 1a and 1b 88

Research Question 2 103

Research Question 3 105

Research Question 4 107

Summary and Transition.. 112

Chapter 5: Discussion, Conclusions, and Recommendations.. 122

Introduction.. 122

Interpretation of the Findings... 123

Consequences of Incomplete Information 124

Interpretation of the Goodness-of-Fit Test 126

Justification for Additional Research.. 127

Findings in the Context of the Theoretical Model 129

Limitations of the Study.. 131

Recommendations... 133

Implications.. 133

Conclusion 134

References... 135

Appendix A: Permissions……………………………………………………………...158

List of Tables

Table 1. Data Inclusion and Exclusion 66

Table 2. Variations in Data Collection 75

Table 3. Characteristics of the Sample 78

Table 4. Chi-Square Analysis With Concussion Ever and Lower Extremity Musculoskeletal Injury Ever Variables 84

Table 5. Chi-Square Analysis With Age and Lower Extremity Musculoskeletal Injury Ever Variables 85

Table 6. Chi-Square Analysis With Age Group and Lower Extremity Musculoskeletal Injury Ever Variables 86

Table 7. Chi-Square Analysis With Gender and Lower Extremity Musculoskeletal Injury Ever Variables 86

Table 8. Chi-Square Analysis With Sport Type and Lower Extremity Musculoskeletal Injury Ever Variables 87

Table 9. Chi-Square Analysis With Concussion Ever and Knee Sprain Ever Variables . 90

Table 10. Chi-Square Analysis With Age and Knee Sprain Ever Variables 91

Table 11. Chi-Square Analysis With Age Group and Knee Sprain Ever Variables 92

Table 12. Chi-Square Analysis With Gender and Knee Sprain Ever Variables 92

Table 13. Chi-Square Analysis With Sport Type and Knee Sprain Ever Variables 93

Table 14. Binomial Logistic Regression Analysis of the Concussion Ever and Knee Variables 96

Table 15. Cross Tabulation With Concussion Ever and Ankle Sprain Ever Variables 97

Table 16. Cross Tabulation With the Age and Ankle Sprain Ever Variables.................. 98

Table 17. Cross Tabulation With Age Group and Ankle Sprain Ever Variables 99

Table 18. Cross Tabulation With Gender and Ankle Sprain Ever Variables 99

Table 19. Cross Tabulation With the Sport Type and Ankle Sprain Ever Variables 100

Table 20. Binomial Logistic Regression Analysis of Concussion Ever and Ankle Sprain Variables 103

Table 21. Cross Tabulation With Number of Concussions and Lower Extremity Musculoskeletal Injury Ever Variables.. 104

Table 22. Cross Tabulation With Number of Concussions and Knee Sprain Ever Variables 106

Table 23. Cross Tabulation With Number of Concussions and Ankle Sprain Ever Variables 109

Table 24. Binomial Logistic Regression Analysis of the Number of Sport-Related Concussions and Ankle Sprain Ever Variables 112

List of Figures

Figure 1. A dynamic, recursive model of etiology in sport injury.…………….…..……….18

Figure 2. Athletic training practice-based clinical practice sites.……..…………………81

Chapter 1: Introduction to the Study

Introduction

Physical activity promotes health, but sport-related injuries can limit mobility and encumber biopsychosocial health immediately after injury and throughout the lifespan (Bruhmann & Schneider, 2011; Emery, Hagel, & Morrongiello, 2006). Injury prevention, especially among youth, is a pressing public health issue due to the afflictions that result from the initial injury, sequelae, subsequent inactivity, and associated health care costs (Caine, 2010; Ozturk & Kilik, 2013). Therefore, it is important to determine the factors that may contribute to sport-related injuries to inform injury prevention approaches, safeguard young athletes from the negative effects of sports injuries, and allow the benefits of athletic activities to transcend the risks (Bahr & Holme, 2003; Bruhmann & Schneider, 2011; Meeuwisse, Tyreman, Hagel, & Emery, 2007; Ozturk & Kilik, 2013).

Exploration of the literature revealed that the association between sport-related concussion (SRC) and lower extremity musculoskeletal injuries (LEMI) has not been established among high school athletes. This study may facilitate positive social change by increasing awareness of the gap in the literature regarding the relationship between SRC and LEMI in this population. This may inspire researchers to conduct retrospective studies to clarify if a relationship exists and prospective studies to determine if the relationship is causal. This could contribute practical knowledge to guide practices and policies to reduce sports-related injuries (SRI) among high school athletes. Fewer SRIs among adolescent athletes could lead to fewer school absences, and this could lead to higher levels of physical activity, improved fitness, health, well-being, and quality of life throughout these individuals' lifespans. This may translate into more active, productive, and healthy societies locally and nationally.

The background of the study, problem statement, and purpose of the study are introduced in this chapter. The research questions, hypotheses, conceptual model, and nature of the study are also presented. The definitions, assumptions, limitations, scope of the study, delimitations, and significance of the study are discussed as well. This chapter concludes with a summary and transition to the next chapter.

Background of the Study

In the United States, over 7.8 million athletes participate in high school sports, in which athletes endure between 1.4 and 2 million injuries each year (Comstock et al., n.d.; Gottschalk & Andrish, 2011; National Federation of State High School Associations [NFSHA], 2016; Powell & Barber-Foss, 1999; Yard, Collins, & Comstock, 2009). High school athletic injuries account for about 500,000 physician encounters and 30,000 hospitalizations annually (U.S. Bone & Joint Initiative [USBJI], 2015). About 6% of high school athletic injuries require surgery (Comstock, Curry, & Pierpoint, n.d.). The economic burden of youth sports injuries in the United States is about 2 billion per year, and in North Carolina, the economic burden of high school sport-related injuries amounts to approximately $10 million, $45 million, and $145 million in healthcare, human capital, and comprehensive expenses, respectively (Adirim & Cheng, 2008; Knowles et al., 2007). MacAuley (2003) found that 58.6% of SRIs in secondary school students resulted in missed school days, and 88% of SRIs resulted in lost playing time. Additionally, almost 33% of parents lost work time while taking injured students to medical appointments (MacAuley, 2003).

Fifteen- to 17-year-olds account for the highest rate of sport-related emergency department visits among children (Youth Sports Safety Alliance [YSSA], 2014). Nearly 8,000 emergency department visits per day are due to sports injuries, and almost 70% of the team sport injuries evaluated in U.S. emergency rooms are musculoskeletal injuries (USBJI, 2015; YSSA, 2014). Lamentably, between 2008 and 2013, there were 273 youth-sport-related deaths in the United States (YSSA, 2014).

The National Sports-Related Injury Surveillance Study revealed that during the 2015-2016 school year, 47% of high school athletic injuries involved the lower extremities, 27% involved the head/face, 18% involved the upper extremities, 4% involved the trunk, 2% involved the neck, and 2% involved other body parts (Comstock et al., n.d.). This study also found that the most common diagnoses in high school athletes included head/face concussions (24.6%), ankle sprains (15.7%), and knee sprains (8.1%; Comstock et al., n.d.). Sprains account for the majority of team and individual SRIs in adolescents, and the two most common lower extremity injuries (LEI) in high school sports are ankle and knee sprains (Comstock et al., n.d.; Fernandez, Yard, & Comstock, 2007; Ingram, Fields, Yard, & Comstock, 2008; Nelson, Collins, Yard, Fields, & Comstock, 2007; USBJI, 2015). Collectively, head/face/concussion and lower extremity injuries account for nearly 75% of new and recurrent injuries in high school sports (Comstock et al., n.d.).

A *concussion* is a brain injury caused by a biomechanical force (Ellis, Leddy, & Willer, 2015; McCrory et al., 2013). *Sprains* occur when ligaments are stretched, separated, or torn (Prentice, 2014; Swenson, Yard, Fields, & Comstock, 2009). *Ligaments*, bands of collagenous connective tissue that connect adjacent bones and provide feedback regarding joint position, are the most commonly injured joint structures (Burns & Lowery, 2010; Hauser et al., 2013). In high school athletes, 36.0% of knee injuries affect the medial collateral ligament (MCL), 19.9% affect the anterior cruciate ligament (ACL), 4.8% affect the lateral collateral ligament (LCL), and 1.8% affect the posterior cruciate ligament (PCL; Comstock et al., n.d.). Nearly 80% of ankle sprains among high school athletes affect the anterior talofibular ligament (Comstock et al., n.d.).

The ligaments and joint capsules provide static joint stability, while muscles provide dynamic joint stability as they respond to information from peripheral and central sources (Konradsen, Voight, & Hojsgaard, 1997). Injuries to ligaments may lead to mechanical instability (joint motion beyond structural constraints) due to disruption of the ligaments and capsule, as well as functional (dynamic) instability (joint motion that exceeds volitional control but does not exceed normal structural limits; Caulfield, 2000; Risberg, Lewek, & Snyder-Mackler, 2004; Tropp, Odenrick, & Gillquist, 1985). Functional joint instability may vary due to changes in motor programs controlled by the central nervous system (CNS; Caulfield, 2000; Tropp, et al., 1985). I discuss the connections between the CNS (brain and spinal cord), the neuromuscular system (nerves, muscles, and joints), SRC, and LEMI in more detail throughout this study.

Long-Term Consequences of SRC and LEMI

Athletes who experience one or more sport-related injuries during youth have more occasions throughout their lives to play, sustain additional injuries, and experience accruing effects from prior injuries than adult athletes do (Guskiewicz & Valovich-McLeod, 2011). Long-term repercussions of concussions include chronic traumatic encephalopathy (CTE), depression, and lingering cognitive, motor, neurologic, vestibulo-ocular, sensory, autoregulatory, emotional, speech, and gait dysfunction (Ellis et al., 2015; Guskiewicz et al., 2007; Konrad et al., 2010; Leddy, Kozlowski, Fung, Pendergast, & Willer, 2007; Schatz & Moser, 2011; Stern et al., 2011). Long-term repercussions of musculoskeletal injuries include impaired growth, lingering pain, chronic joint instability, osteoarthritis, decreased levels of physical activity, comorbidities associated with inactivity, and prolonged disability (Maffulli, Longo, Gougoulias, Loppini, & Denaro, 2010; USBJI, 2015). More than one quarter of U.S. adults are expected to be diagnosed with arthritis by 2030, and this condition often limits mobility and leads to costly joint replacements (USBJI, 2016).

Ultimately, the long-term consequences of concussions and musculoskeletal injuries may lead to reduced quality of life, decreased independence, decreased mobility, progressive deterioration of health, lost wages, increased health care costs, and economic burdens for individuals and society (USBJI, 2016; Valovich-McLeod et al., 2009). Therefore, it is important to (a) determine the magnitude of SRIs; (b) identify associations, risk factors, and causes of injuries; and (c) enhance efforts to decrease the incidence and severity of initial and recurrent sport-related injuries (Guskiewicz & Valovich-McLeod, 2011; Joseph et al., 2013; Meeuwisse et al., 2007; Shrey, Griesbach, & Giza, 2011; Zernickle et al., 2009). Although SRC and LEMI are common in high school sports, the association between these injuries has not been examined in high school athletes, so there is a need to understand this relationship between concussions and musculoskeletal injuries in this population.

Mechanisms of Injury

Awareness of sports injury mechanisms and risk factors is essential for injury prevention (Meeuwisse et al., 2007). The mechanisms for concussion include direct impact to the head or an indirect transfer of force to the head (McCrory et al., 2013). Mechanisms for ankle sprains include inversion, eversion, combined inversion-plantar flexion, or combined eversion-dorsiflexion (Prentice, 2014). The most common type of ankle injury occurs when the foot is inverted and plantar flexed and one or more of the lateral ankle ligamentous structures are partially or completely torn (Adirim & Cheng, 2003; Burns & Lowery, 2010; Gottschalk & Andrish, 2011, Nelson et al., 2007). Sport-related ankle sprains occur most often due to contact with another individual, but they may also occur by contact with a playing surface or by noncontact mechanisms such as running and jumping, rapidly changing directions, and jumping near other athletes (Nelson et al., 2007; Swenson et al., 2013b).

The collateral and cruciate ligaments contribute to knee stability when they are intact. MCL injuries in knees result from valgus forces, with or without external tibial rotation, while LCL injuries in knees result from varus forces, with or without internal tibial rotation (Prentice, 2014). ACL injuries frequently result from noncontact mechanisms including deceleration, pivoting, jumping, unplanned sidestepping, and landing (Anderson, Browning, Urband, Kluczynski, & Bisson, 2016; Boden, Dean, Feagin, & Garrett, 2000; Michaelidis & Koumantakis, 2014). Although numerous articles have been published pertaining to ACL injuries, the mechanism of ACL sprains is not completely understood (Zernickle et al., 2009). It is unclear if healthy ACLs fail when they are overloaded, or if a normal load causes a weakened ligament to fail

(Zernickle et al., 2009). The mechanism for a posterior cruciate ligament (PCL) injury involves posterior translation of the tibia while the knee is flexed 90 degrees (Prentice, 2014). Ingram et al. (2008) found that 52% of knee injuries among high school athletes involved contact with another individual, 15.4% involved contact with the playing surface, 2.9% involved contact with equipment, and 25.4% did not involve contact.

SRC and LEMI Risk Factors

Risk factors are influences that may increase the possibility of injury (Meeuwisse, 1991). Possible risk factors for sports-related injuries include age, gender, prior injury, body structure and composition, level of health, fitness, and skill (Bahr & Holme, 2003; Meeuwisse et al., 2007). The best prognosticator of a future sports injury is a history of the same type of injury (Guskiewicz & Valovich-McLeod, 2011).

Gessel, Fields, Collins, Dick, & Comstock (2007) found that more SRCs occur during competitive events than during practice; they posited that this may be due to play that is more intensive during competition versus practice. Abrahams, McFie, Patricios, Posthumus, and September (2014) conducted a systematic review to examine risk factors for SRC and determined, with a “high level of certainty,” that competition and previous concussion(s) are associated with increased risk of future concussion (p. 91). A history of one concussion increases the risk of incurring another concussion (Guskiewicz et al., 2003). Furthermore, a history of three or more concussions increases the risk of developing postconcussion syndrome (PCS; disrupted sleep, emotional dysfunction, physical symptoms, and/or cognitive symptoms), and the effects of repeated concussions may be summative (Collins et al., 2002; Guskiewicz et al., 2003; Guskiewicz, Weaver, Padua, & Garrett, 2000; Iverson, Brooks, Lovell, & Collins, 2006; Iverson, Gaetz, Lovell,

& Collins, 2004). In high school athletes, most concussions occur in full and partial contact sports (Gessel et al., 2007). The risk factor that accounts for the greatest number of concussions in high school athletes is contact with another player (Gessel et al., 2007). Female gender and youth are associated with increased risk of concussion (Gessel et al., 2007; Guskiewicz & Valovich-McLeod, 2011).

Gessel et al. (2007) determined that female high school and college athletes have higher concussion rates than male high school and college athletes who play the same sports (Gessel et al., 2007). This may be due to lower rates of concussion reporting by boys, as well as differences in playing techniques, anatomy, and biomechanics (Gessel et al., 2007; Mansell, Tierney, Sitler, Swanik, & Stearne, 2005; McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004; Miyashita, Diakogeorgiou, & VanderVegt, 2016; Tierney et al., 2005). Tierney et al. (2005) found differences in head-neck segment acceleration between physically active males and females, and they posited that this may be due to females having less cervical strength, circumference, and head mass than males. Mansell et al. (2005) also found that female collegiate soccer players had less isometric neck strength, neck circumference, head-neck mass, and length of head-neck segments than males. Following an 8-week neck strength training program, female athletes demonstrated increased cervical strength and circumference, but these gains did not translate into significant improvements in dynamic stabilization of their head-neck segments (Mansell et al., 2005).

Concussion pathophysiology and recovery processes differ between youth, who have immature brains, and adults, who have mature brains (Choe, Babikian, Difion, Hovada, & Giza, 2012; Giza & Hovda, 2001; Shrey et al., 2011; Williams, Puetz, Giza,

& Broglio, 2015). I explain the reasons for these differences in the next chapter. Guskiewicz et al. (2000) determined that the incidence of SRC was greater in high school football players than in college football players and suggested that this may be due to differences in skill levels. Gessel et al. (2007) found that concussions accounted for a higher proportion of SRIs in high school versus college athletes, but college athletes had higher concussion rates than high school athletes during athletic events and practice sessions. They posited that this might be due to high school athletes playing with less skill and intensity than college athletes (Gessel et al., 2007).

Concussed adolescents experience more symptoms and take more time to recover than concussed adults do, but the reasons for these differences are not clearly understood (Field, Collins, Lovell, & Maroon, 2003; Moser, Schatz, & Jordan, 2005). The World Health Organization (WHO; 2017) identified adolescents as those aged 10–19 years who are going through the rapid stage of development that occurs between childhood and adulthood. Williams et al. (2015) conducted a systematic review with meta-analysis and found that concussion symptoms resolved more slowly in high school athletes than collegiate athletes, but neurocognitive recovery times were similar. This may be due to differences in neuroplasticity between immature and mature brains (Shrey et al., 2011). Williams et al. (2015) posited that, in addition to physiologic differences between mature and immature brains, high school athletes might be more likely than collegiate athletes to report, and connect their symptoms with, concussions. Preconcussion risk factors such as prior concussion, young age, female gender, and neuropsychiatric disorders may also contribute to differences in recovery times following concussive injury (Collins, Kontos, Reynolds, Murawski, & Fu, 2013; Elbin et al., 2013; Schatz, Moser, Covassin, & Karpf, 2011). Most individuals who sustain concussions recover within 1-2 weeks, but nearly 20% experience PCS, which may persist for several weeks, months, or years postinjury (Cobb & Battin, 2004; Collins, Lovell, Iverson, Ide, & Maroon, 2006; Ellis et al., 2015; Reddy, Collins, & Gioia, 2008; Vidal, Goodman, Colin, Leddy, & Grady, 2012). Athletes who sustain another concussion while they are recuperating from a prior concussion are at increased risk for second-impact syndrome, which may cause sudden death (Bey & Ostick, 2009; Cobb & Battin, 2004; Schatz & Moser, 2011).

Sport-related LEIs occur more often during competition than during practice in high school and collegiate athletes (Comstock et al., n.d.; Hootman, Dick, & Agel, 2007; Murphy, Connolly, & Beynnon, 2003). In high school athletes, knee injury rates, severe knee injury rates, and ankle injury rates are also higher during competition than during practice (Ingram et al., 2008; Nelson et al., 2007; Swenson et al., 2013a; Swenson et al., 2013b). Ingram et al. (2008) determined that illegal play is also a risk factor for LEI in high school athletes. High school girls have higher rates of knee and ankle injuries than boys do in same-sport comparisons (Swenson et al., 2013a; Swenson et al. 2013b).

Female gender, genetic risk factors (family tendency), neurocognitive deficits, prior ACL injury, and prior ankle injury have been shown to increase the risk of ACL injuries (Kramer, Denegar, Buckley, & Hertel, 2007; Smith et al., 2012). Combinations of these risk factors may also increase the risk of ACL injuries (Smith et al., 2012). Ingram et al. (2008) determined that high school girls are twice as likely to endure major knee injuries as their male counterparts, while Zernickle et al. (2009) found that ACL injury rates for adolescent females are 2 to 5 times higher than those for males. ACL injury rates for collegiate females are also higher than for collegiate males when the same sports are compared (Arendt, Agel, & Dick, 1999). Excessive knee valgus motions and moments during the impact phase of jump landings have been associated with an increased risk for ACL injuries in female athletes (Hewett et al., 2005). Girls may be more susceptible to ACL injuries than boys due to (a) anatomic risk factors such as smaller ligament size, increased tibial plateau slope, smaller femoral intercondylar notch size, and lower extremity malalignment; (b) hormonal risk factors; (c) neuromuscular risk factors, including altered movement and muscle activation patterns; and (d) environmental risk factors such as lack of strength and conditioning, sport position, playing surface conditions, interface between footwear and playing surfaces, and illegal play (Adirim & Cheng, 2003; Anderson et al., 2016; Ingram et al., 2008; Kramer et al., 2007; Smith et al., 2012; White, Lee, Cutuk, Hargens, & Pedowitz, 2003; Zernickle et al., 2009).

Swenson et al. (2013b) found that among high school athletes, girls had higher rates of ankle sprains than boys did. Burns and Lowery (2011) reported that malalignment of foot, ankle, and leg structures can increase momentum through the lateral ankle and increase susceptibility to inversion ankle sprains (Burns & Lowery, 2011). Wang, Chen, Shiang, Jan, and Lin (2006), in a study controlling for prior ankle injury, lower extremity malalignment, gender, shoes, ankle supports, and playing surfaces, determined that abnormal postural sway was associated with increased risk for lateral ankle sprains.

The risk of knee injuries may be reduced by improving lower extremity neuromuscular control and avoiding excessive knee valgus while decelerating, pivoting, and landing from jumps (Hewett et al., 2005; Paszkewicz, Webb, Walters, McCarty, &

Van Lunen, 2012). Murphy et al. (2003) conducted a broad review of the literature to clarify risk factors for lower extremity injuries and found that ankle bracing or taping reduces ankle injury incidence. Engstrom and Renstrom (1998) posited that this might be due to improving kinesthetic awareness and reducing rear-foot inversion motion. The risk of ankle injuries many also be reduced by re-establishing normal neuromuscular control through balance training (Wilkstrom, Naik, Lodha, & Cauraugh, 2009).

Concussions and musculoskeletal injuries are common among high school athletes, and the long-term consequences of these SRIs can be devastating. Although the associations between concussion and many biopsychosocial conditions have been established, little is known about the relationship between concussion and musculoskeletal injury in adolescents (Ellis et al., 2015; Guskiewicz et al., 2007). Because SRIs may be foreseen and averted when the problem is thoroughly understood, there is a need to more thoroughly understand the relationship between SRC and LEMI in high school athletes (Emery, 2003; Meeuwisse, 1991).

Problem Statement

Concussions have been shown to alter metabolic, physiologic, and cognitive functions (Broglio, Ferrara, Macciocchi, Baumgartner, & Elliott, 2007; Guskiewicz & Valovich-McLeod, 2011; Leddy et al., 2010; Leddy et al., 2007; Maugans, Farley, Altaye, Leach, & Cecil, 2012). Hutchinson, Comper, Mainwaring, and Richards (2011) discovered that athletes who sustained concussions or musculoskeletal injuries exhibited impaired cognition, whereas noninjured controls did not. This unexpected finding shed light on the possible connections between musculoskeletal injury and concussion.

Nordstrom, Nordstrom, and Ekstrand (2014) were among the first to reveal a progressively higher risk of consequent injuries one year postconcussion in a large cohort of professional European soccer players. They also found that the concussed players were at higher risk of acute injuries, but they acknowledged that they could not verify concussion diagnoses and that there may have been variations in concussion diagnostic criteria among venues (Nordstrom et al., 2014). Pietrosimone, Golightly, Mihalik & Guskiewicz (2015a) found an association between self-reported concussion and musculoskeletal injury histories throughout the professional football careers of retired National Football League (NFL) players. They also found that as the frequency of self-reported concussions increased, the odds of players reporting an LEI increased (Pietrosimone et al., 2015a). However, they relied on self-reported data and could not validate the responses with medical records, so recall bias may have influenced their results (Pietrosimone et al., 2015a). Gilbert, Burdett, Joyner, Llewellyn, & Buckley (2016) surveyed 355 intercollegiate athletes who played 13 sports at 17 colleges or junior colleges and found reported concussions and unreported concussions, were associated with knee injuries while unrecognized concussions were associated with ankle sprains and muscle strains. They also found that concussions were associated with ankle sprains, knee sprains, and muscle strains. Although they studied a more diverse population of adult athletes, they depended on self-reported data and did not account for the influence of other conditions. Lynall, Mauntel, Padua, and Mihalik (2015) found that concussed athletes at one university were more likely than nonconcussed athletes to have sustained a musculoskeletal injury of a lower limb 1 year postconcussion. They addressed the limitation of recall bias by accessing and analyzing data from the athletes' electronic medical records, but their small sample size limited the generalizability of their findings (Lynall et al., 2015).

These studies revealed that an association exists between SRC and LEMI in specific populations of adult professional male athletes and in collegiate athletes, but the problem is that the findings from these studies may not be generalizable to younger male and female high school athletes, who have less mature brains as well as neuromuscular and musculoskeletal systems. Furthermore, little is known about the association between concussion and musculoskeletal injuries among adolescent athletes. Therefore, a study to elucidate the relationship between SRC and LEMI among a large sample of male and female high school athletes was warranted to fill this gap in the literature.

Purpose of the Study

The purpose of this cross-sectional quantitative study was to examine the association between SRC and LEMI among high school athletes. By increasing awareness of the relationship between SRC and LEMI in this population, this study could inspire researchers to conduct prospective studies to determine if the relationship is causal. Findings from these studies could lead to a greater appreciation of the physical and functional transformations in the brain and the lower extremities that might mutually pertain to SRCs and LEMIs, and this could generate new knowledge that could guide practices and policies to reduce sports injuries among high school athletes. This could lead to fewer SRIs among adolescent athletes, which could lead to fewer school absences, higher levels of physical activity and fitness, and better health, well-being, and quality of life throughout individuals’ lifespans. This could translate into more active, productive, and healthy societies locally and nationally.

In this study, the dependent (outcome) variable was LEMI; the independent (predictive) variable was SRC, and the covariates were age, gender, and sport. Because I defined the dependent variable (LEMI) as a knee sprain or an ankle sprain, I also examined the association between SRCs and knee sprains, as well as the association between SRCs and ankle sprains, to more thoroughly understand the relationships between these common sports injuries. Additionally, I examined the association between the number of SRCs and LEMIs more completely by independently investigating the association between the number of SRCs and knee sprains, as well as the association between the number of SRCs and ankle sprains.

Research Questions and Hypotheses

The research questions for this study follow.

1. Is there an association between SRC and LEMI among high school athletes?

    H_{01}: There is not an association between SRC and LEMI among high school athletes while controlling for gender, age, and sport.

    H_{A1}: There is an association between SRC and LEMI among high school athletes while controlling for gender, age, and sport.

    1a. Is there an association between SRC and knee sprains among high school athletes?

    H_{01a}: There is not an association between SRC and knee sprains among high school athletes while controlling for gender, age, and sport.

    H_{A1a}: There is an association between SRC and knee sprains among high school athletes while controlling for gender, age, and sport.

1b. Is there an association between SRC and ankle sprains among high school athletes?

H_{01b}: There is not an association between SRC and ankle sprains among high school athletes while controlling for gender, age, and sport.

H_{A1b}: There is an association between SRC and ankle sprains among high school athletes while controlling for gender, age, and sport.

2. Is the number of SRCs associated with LEMI among high school athletes?

H_{02}: The number of SRCs is not associated with LEMI among high school athletes while controlling for gender, age, and sport.

H_{A2}: The number of SRCs is associated with LEMI among high school athletes while controlling for gender, age, and sport.

3. Is the number of SRCs associated with knee injuries among high school athletes?

H_{03}: The number of SRCs is not associated with knee injuries among high school athletes while controlling for gender, age, and sport.

H_{A3}: The number of SRCs is associated with knee injuries among high school athletes while controlling for gender, age, and sport.

4. Is the number of SRCs associated with ankle injuries among high school athletes?

H_{04}: The number of SRCs is not associated with ankle injuries among high school athletes while controlling for gender, age, and sport.

H_{A4}: The number of SRCs is associated with ankle injuries among high school athletes while controlling for gender, age, and sport.

Conceptual Framework

The dynamic model of etiology in sport injury (Figure 1) provided the conceptual framework to test the hypotheses in this study (Meeuwisse et al., 2007). Meeuwisse et al. (2007) posited that intrinsic (biopsychosocial) risk factors may increase or decrease an athlete's predisposition to injury when that individual is exposed to extrinsic risk factors (forces outside the body) such as playing time, equipment, and so forth, which in turn may increase or decrease an athlete's susceptibility to injury. When an event occurs that can produce an injury, the athlete may or may not be injured (Meeuwisse et al., 2007). If an athlete is injured and does not completely recover, the athlete will not return to play. However, if an athlete sustains an injury, recovers from the injury, and returns to play, that individual's intrinsic and extrinsic risk factors may change (Meeuwisse et al., 2007). The risk factors may also change when an injury does not occur (Meeuwisse et. al., 2007). This dynamic model allows athletes to enter and re-enter the cycle at any of the following phases—the predisposed athlete phase, the susceptible athlete phase, the injury phase, or the no-injury phase—and participate with modified injury risk factors (Meeuwisse et al., 2007).

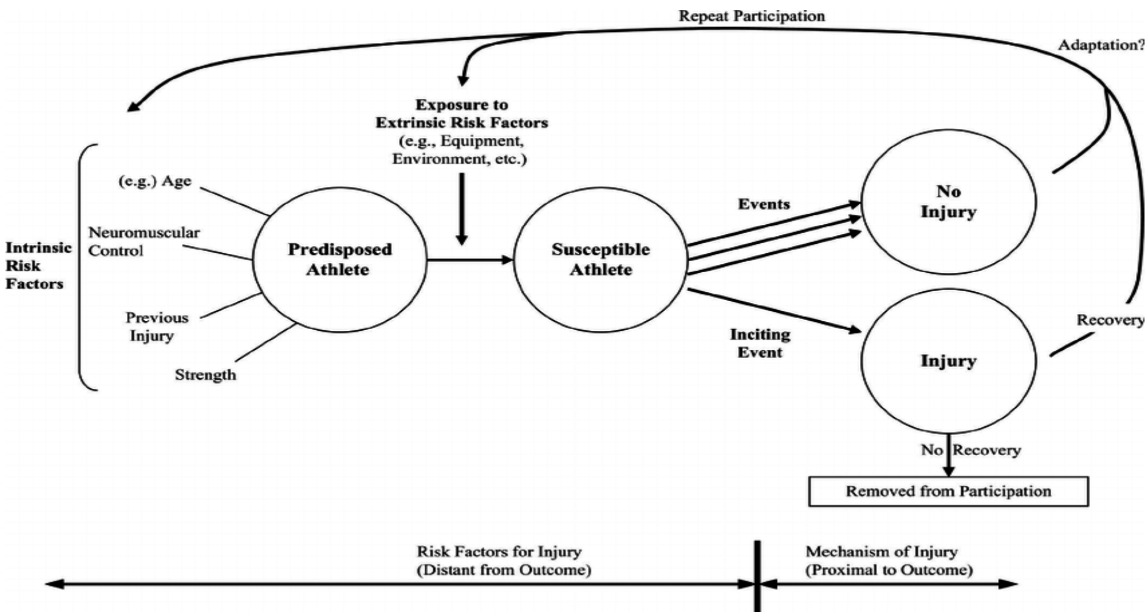

Figure 1. A dynamic, recursive model of etiology in sport injury. From "A Dynamic Model of Etiology in Sport Injury: The Recursive Nature of Risk and Causation," by W. H. Meeuwisse, H. Tyreman, B. Hagel, and C. Emery, 2007, *Clinical Journal of Sport Medicine*, *17*(3), p. 217 Copyright 2007 by Wolters Kluwer Health, Inc. Reprinted with permission.

The key elements of this conceptual framework are connected to the key elements of this study, as the model considers the dynamic nature of intrinsic and extrinsic risk factors for sports injuries, as well as corollaries of recurrent sport participation regardless of the presence or absence of injuries. The framework also relates to the study approach and key research questions by accounting for the fluctuating nature of the determinants of sports injuries. For example, if an athlete sustains a concussion, the interactions between the CNS (brain and spinal cord) and the neuromuscular system (nerves, muscles, and joints) may be altered, and the athlete's predisposition for a sport-related injury may increase (Herman, Zaremski, Vincent, & Vincent, 2015; Hewett, Paterno, & Myer, 2002; Meeuwisse et al., 2007). When the athlete recovers from the injury and returns to play with a modified internal risk factor (prior history of concussion), the interactions between the athlete's current intrinsic and extrinsic risk factors may be altered. For example, if the athlete pivots on a wet playing surface with a planted foot, the athlete may be more susceptible to a knee or ankle sprain due to changes in the playing conditions or changes in lower extremity neuromuscular control following the concussion. When an event occurs that could produce an injury, such as player-to-player contact as the athlete is landing from a jump, the athlete may or may not endure a sport-related injury. If the athlete sustains an injury, recovers, and is able to return to play, the intrinsic and extrinsic risk factors may change again, such that the athlete's predisposition and susceptibility to injury could also change. A more detailed explanation of how SRCs relate to LEMIs within this conceptual framework is presented in Chapter 2.

Nature of the Study

I analyzed an existing numeric data set to test my hypotheses in order to determine the association between an independent variable (SRC) and a dependent variable (LEMI) in high school athletes in a defined period in time while controlling for gender, age, and sport. Therefore, a retrospective, quantitative, cross sectional design was appropriate for answering the research questions (Carlson & Morrison, 2009; Creswell, 2014). A de-identified secondary data set from A. T. Still University's (ATSU) Athletic Training Practice-Based Research Network (AT-PBRN) was analyzed with descriptive statistics, Pearson's chi-square analyses, and binomial logistic regression analyses while controlling for gender, age, and sport.

The AT-PBRN uses the web-based Clinical Outcomes Research Education for Athletic Trainers (CORE-AT) System to capture high school athletic injury surveillance data and electronic medical record (EMR) data from more than 25 high schools throughout the United States (ATSU, n.d.). The EMR includes a concussion-specific evaluation form and region-specific injury evaluation forms (ATSU, n.d.). The CORE-AT system captures injuries that "1) result from participation in interscholastic practices or competitions and 2) require medical attention by a certified athletic trainer or physician and 3) result in restricted participation or performance for 1 or more days beyond the day of injury" (ATSU, n.d., p. 44). AT-PBRN athletic trainers participate in a two hour training session before becoming members of the AT-PBRN to uphold data quality (Valovich-McLeod, Lam, Bay, & Sauers, 2012). Although athlete exposures can be captured in the surveillance portion of the CORE-AT system, the athletic trainers are not required to document exposures, so a common denominator was not available to determine risk or rates of injury in this study.

The key constructs from the data have been described, analyzed, validated, and disseminated in peer-reviewed journals. Sauers, Valovich-McLeod, and Bay (2012) showed how PBRNs can produce data in multiple locations to generate large, diverse samples; surmount the limitations of single-venue studies; connect scholars with practitioners; and transform research results into practice. They also explained the process for establishing PBRN frameworks, safeguarding participants, and complying with government regulations (Sauers et al., 2012). Valovich McLeod et al. (2012) collected and analyzed de-identified data from 22 certified athletic trainers at 22 high school athletic training sites in 7 states within the AT-PBRN to ascertain the value of PBRN data. They found that (a) lower extremity sprains/strains and concussions accounted for most SRIs, and (b) relevant patient care data and athletic training practice pattern data can be obtained from EMRs in PBRNs (Valovich McLeod et al., 2012). In another AT-PBRN study, Lam, Snyder Valier, and Valovich McLeod (2015) analyzed de-identified injury and treatment data obtained by athletic trainers between October 1, 2009, and October 31, 2013, from 62 high schools in 14 states to examine injury and treatment characteristics. They determined that athletic trainers identified and managed similar injuries (mostly lower extremity sprains/strains and concussions) and provided similar services irrespective of sport (Lam et al., 2015). The injury patterns and athletic training practice patterns in this study were also comparable to those reported in earlier studies (Ingram et al., 2008, Marar, Mcllvain, Fields, & Comstock, 2012, Nelson et al., 2007; Swenson et al., 2013; Valovich McLeod, 2012; Yard, Schroeder, Fields, Collins, & Comstock, 2008). Lam, Snyder Valier, Anderson, and Valovich McLeod (2016) analyzed AT-PBRN high school athlete encounter data from EMRs from December 1, 2009, through July 1, 2015, to examine the characteristics of athletic training practice among high school athletic trainers. This study clarified the role that high school athletic trainers play in evaluation, prevention, and management of injuries in high school settings (Lam et al., 2016). These AT-PBRN studies demonstrated that athletic trainers can provide services and capture injury and care data in EMRs in multiple sites throughout the country to provide a valid source of data for large national studies (Lam et al., 2016; Lam et al., 2015; Sauers et al., 2012; Valovich McLeod et al., 2012). These studies also built upon earlier research by Yard, Collins, and Comstock (2009) that demonstrated the utility of athletic trainers being the principal data recorders in large-scale studies.

Variable Definitions

The dependent (outcome) variable (LEMI) and the independent (predictor) variable (SRC) were the sport-related injuries analyzed in this study. Covariates included gender, age, and sport. The definitions of these variables and covariates follow:

Lower extremity musculoskeletal injury (LEMI): (a) A knee sprain delineated by one of the following International Classification of Diseases, ninth revision (ICD-9) codes: 844.0, 844.1, 844.2, or 844.9, or (b) an ankle sprain delineated by one of the following ICD-9 codes: 845.00, 845.01, or 845.03 (ATSU, n.d.; Centers for Medicare and Medicaid Services (CMS; n.d.; Merrick, 2002; Williams, 1971).

Sport-related concussion (SRC): A brain injury caused by a sport-related biomechanical force, delineated by one of the following ICD-9 codes in the EMR: 850.0, 850.5 or 850.9 (CMS, n.d.; Ellis et al., 2015, McCrory et al., 2013).

Gender: The high school athlete’s sex.

Age: The high school athlete’s age at the time of injury.

Age group: The high school athlete’s age range (11-13 years, 14-17 years, and 18-19 years) at the time of injury.

Sport: May refer to *team sports* (e.g., baseball, basketball, cheerleading, field hockey, football, hockey, lacrosse, soccer, softball, or volleyball), which require team members to work together at the same time to achieve the team’s goal or outcome (e.g., defeating an opponent), or *individual sports* (e.g., badminton, cross country, gymnastics, swimming, tennis, track, or wrestling), which require all athletes to be responsible for achieving their own goals or outcomes (e.g., such as setting a personal record, qualifying for an event, or winning an event).

Assumptions

The secondary dataset for this study was obtained from a nationally representative sample of high school athletic injury data that was extracted from electronic medical records within the AT-PBRN. Several assumptions for this study pertained to the quality of these data. I assumed that (a) the original data were collected in an ethical manner, (b) the data were correctly entered into the CORE-AT system, (c) the data from each EMR were independent (i.e., did not influence another athlete's EMR), and (d) the original dataset was reliable and valid (ATSU, n.d.). I assumed that the athletic trainers who contributed data to the AT-PBRN diagnosed concussions and musculoskeletal injuries correctly and coded the injuries accurately. Additionally, I assumed that the secondary dataset was de-identified to prevent direct or indirect disclosure of the athletes' identities. These assumptions were essential in my study because my findings relied upon the integrity of the secondary dataset that I examined, and flaws in the initial data collection process could not be overcome during secondary analysis.

The AT-PBRN athletic trainers received structured EMR training to facilitate consistency in coding and data entry across clinical sites (Lam et al., 2015). Additionally, all clinical sites used the same EMR system and ICD-9 codes so that injury definitions and coding options were clearly and consistently defined throughout the data collection sites (ATSU, n.d.).

Scope and Delimitations

This quantitative cross-sectional study focused on LEMI outcomes, particularly knee and ankle sprains in high school athletes. I selected ankle sprains and knee sprains as the outcomes because they are the two most common LEIs in high school sports, and evidence suggests that impaired neurocognitive function may cause changes in motor responses that increase LEI risk (Herman et al., 2015). Although the AT-PBRN database captures musculoskeletal injury management data and other sports injury data, those outcomes were beyond the scope of this study. This study was delimited to U.S. high school athletes. The results of this study may be generalizable to U.S. high school athletes in the states and regions where the data were generated but not to other populations or geographic areas.

Limitations

The main limitation of this study was my inability to attain meaningful measures of association between the independent and dependent variables, as incomplete information led to lack of convergence and small sample sizes reduced the power of the Hosmer-Lemeshow tests to determine how well the models fit the data during the logistic regression analyses. I explain the reasons I could not attain results for meaningful inference in more detail throughout the fourth and fifth chapters. Moreover, the dataset did not reflect athlete exposures to training, practices, and competitions, so I was not able to determine risk or rates of injury in this study. Additionally, the dataset did not include prior concussion and LEMI histories, so I was not able to determine the directions of the associations.

This cross-sectional study could not establish a causal effect, so the relationships identified in this study could have been influenced by untested variables such as the playing surfaces or athletes' levels of skill (Abrahams et al., 2014). In that quantitative cross-sectional studies examine exposure and outcome concurrently, temporal relationships were not discovered. There was also potential for bias toward including more athletes without concussion or without musculoskeletal injuries if athletes who sustained either one of these injuries were unable to return to play.

Because this study examined the relationship between SRC and LEMI among U.S. high school athletes, generalization of the findings to other athletic or nonathletic populations may not be possible. Therefore, external validity (generalizability of the study's results) could be threatened. I addressed this limitation by not generalizing the results of this study beyond the population represented by this sample. Although the design of this study was aligned with the research questions and methods and my interpretations did not exceed the data, findings, or scope of this study, the threats to internal validity (strength of inferences) and limitations described above could not be overcome in this study. However, many of the limitations in this study could be addressed if this study serves as a springboard for future large-scale prospective studies.

Significance of the Study

The literature is sparse regarding the relationship between SRC and LEMI among adult athletes, and to my knowledge, this relationship has not been examined in adolescent high school athletes. This study may facilitate positive social change by increasing awareness of the gap in the literature regarding the relationship between SCR and LEMI in high school athletes, which may prompt others to contribute to this area of literature. For example, this study could inspire researchers to conduct retrospective studies to determine if a relationship exists, as well as prospective studies to determine if the relationship is causal in young athletes. These findings could lead to a greater appreciation of the pathophysiologic regions in the brain and the lower extremities, which might mutually pertain to SRCs and LEMIs. This could lead to new practical knowledge to guide practices and policies to reduce sports injuries among high school athletes. New knowledge could lead to fewer SRCs and LEMIs among adolescent athletes, which could lead to fewer school absences and higher levels of physical activity and fitness as well as better health, well-being, and quality of life throughout individuals' lifespans. This could translate into more active, productive, and healthy societies locally and nationally.

Summary

Concussions and LEMIs may lead to reduced quality of life, decreased independence, decreased mobility, progressive deterioration of health, lost wages, increased health care costs, and economic burdens for individuals and society (USBJI, 2016; Valovich McLeod et al, 2009). Understanding the factors that contribute to these injuries may inform injury prevention and treatment strategies, reduce initial and recurrent injuries, and ultimately reduce the physical and economic burden of sport-related injuries (Guskiewicz & Valovich McLeod, 2011; Meeuwisse, et al., 2007; USBJI, 2016). The associations between SRC and LEMI among collegiate athletes and male professional athletes have been reported, but the findings from these studies may not be generalizable to younger high school athletes, who have less mature brains and musculoskeletal systems. Therefore, a study to uncover the relationship between SRC and LEMI among a large national sample of male and female high school athletes is warranted to fill a void in the literature.

The background of the study, problem statement, and purpose of the study were delineated in this chapter. The research questions, hypotheses, conceptual model, and nature of the study were also presented. The definitions, assumptions, limitations, delimitations, and significance of the study were clarified, and a summary was provided at the end of this chapter. The next chapter focuses on a review of the literature to support this research.

Chapter 2: Literature Review

Introduction

Sport-related injuries can be foreseen and averted when the problem is thoroughly understood, but evidence pertaining to the relationship between SRC and LEMI is limited (Emery, 2003; Meeuwisse, 1991). Nordstrom et al. (2014) determined that SRC was linked with a progressively higher risk of ensuing injuries 1 year postconcussion. In the same large cohort study, they found that concussed male European soccer players were also at higher risk of acute injuries than nonconcussed players (Nordstrom et al., 2014). In a large cross-sectional study by Pietrosimone et al. (2015a), a positive association between self-reported concussion history and self-reported musculoskeletal injury history was found throughout the NFL careers of retired players. Pietrosimone et al. (2015a) also determined that the odds of players reporting a lower extremity injury increased as the frequency of self-reported concussions increased. Lynall et al. (2015) reported that concussed collegiate athletes at one university were more likely than nonconcussed athletes to have sustained a lower limb musculoskeletal injury 1 year postconcussion. Gilbert et al. (2016) found that histories of reported concussions, unreported concussions, and any concussions were associated with knee injuries, while possibly unrecognized concussions were associated with ankle sprains and muscle strains in college and junior college athletes. They also found that any concussions were associated with ankle sprains, knee sprains, and muscle strains. The problem is that the findings from these studies of adult professional and collegiate athletes may not be generalizable to younger male and female high school athletes, who have less mature brains and musculoskeletal systems. Little is known about the association between concussion and musculoskeletal injuries among adolescent athletes. Therefore, a study to elucidate the relationship between SRC and LEMI among a large national sample of male and female high school athletes is warranted to fill this gap in the literature. The purpose of this cross-sectional quantitative study was to examine the association between SRC and LEMI among high school athletes. This study provides early information to facilitate a more complete understanding of SRCs and LEIs in young athletes to begin to fill a void in the literature.

This chapter includes the literature search strategy, the conceptual model that grounded this study, and the evidence that pertains to adolescent SRCs and LEMIs. This chapter concludes with a summary and transition to the third chapter.

Literature Search Strategy

I conducted an electronic search of health sciences and psychology databases to obtain articles for this literature review. The databases included: Academic Search Complete, Cumulative Index to Nursing and Allied Health Literature (CINAL), Cochrane Database of Systematic Reviews, Google Scholar, Health Source: Nursing/Academic Edition, Medline, Ovid, PsycInfo, PubMed, Sage, Science Direct, and Sport Discus.

The search was limited to full-text articles and abstracts written in the English language. Each database was searched from its beginning date through July 31, 2017. Key search terms included *concussion*, *adolescent and concussion*, *secondary school athletes and concussion*, *concussion and musculoskeletal injury*, and *concussion and sports injury*. Reference lists of pertinent articles and websites provided information on additional sources. Peer-reviewed articles that provided seminal information or the most current evidence pertaining to concussion, sport-related concussion, LEMI, epidemiology, pathophysiology, long-term consequences of these injuries, risk factors, burden of SRC or LEMIs, return to play progression, neurocognition, motor dysfunction, motor control, and postural stability were included in this literature review. Articles that did not meet these criteria for inclusion and did not provide relevant information to contribute to the understanding of SRC and LEMI in high school athletes were excluded from this literature review. An extensive review of the literature was completed to establish the framework for this study.

Conceptual Model

Effective prevention and management of SRIs requires a clear understanding of the causes and pathologies of the injuries (Williams, 1971). Williams (1971) broadly classified all sports related injuries as either (a) *consequential* (caused by sport participation or training) or (b) *nonconsequential* (non-sport-related injuries that adversely affect sport participation or training). Williams (1971) also subclassified consequential injuries into *primary consequential injuries*, which are unequivocally due to sports, and *secondary consequential injuries*, which are caused by untreated or inadequately treated injuries. Subcategories of primary consequential injuries include intrinsic and extrinsic injuries (Williams, 1971). *Extrinsic injuries* may be caused by a direct force from factors outside the athlete's body, whereas *intrinsic injuries* are often caused by a traumatic event (sprain, strain), acute overuse (tenosynovitis), or chronic overuse (tendinosis) due to factors within the athlete's body (Williams, 1971).

The dynamic model of etiology in sports injury provides the conceptual framework for examining the relationship between SRC and LEMI in this study (Meeuwisse et. al., 2007). The model describes how preinjury risk factors change during each sports encounter in the presence or absence of an injury and accounts for how repeated injury exposures may lead to adjustments, maladjustments, injury, full recovery, or partial recovery from injury (Meeuwisse et al., 2007). The dynamic model of etiology in sports injury has been applied in other research to examine sports-related injury risk factors and inform injury prevention strategies. Benson et al. (2013) recognized the dynamic nature of concussion risk factors and referred to this model in their review of SRC risk factors in order to explain how susceptibility to injury varies as interactions among risk factors vary. Hupperets, Verhagen, and van Mechelen (2009) also applied this model to explain how changes in intrinsic risk factors following ankle injuries increase susceptibility to recurrent ankle injuries after an initial injury.

An example of how the dynamic model of etiology in sports injury may be applied to SRC and LEMI follows. With respect to intrinsic risk factors, a young female athlete with a history of one or more concussive injuries, weak neck muscles, small neck circumference, poor health, low level of fitness, and low level of skill who engages in illegal play may increase her predisposition to LEMI due to maladaptive interactions between the CNS (brain and spinal cord) and neuromuscular system (nerves, muscles, and joints); Collins, et al., 2002; Gessel et al., 2007; Guskiewicz et al., 2003; Guskiewicz et al., 2000; Herman et al., 2015; Hewett et al., 2002; Iverson et al., 2006; Iverson ,et al., 2004; Tierney et al., 2005). Conversely, a more mature male athlete without a prior concussion history who has strong neck muscles, a large neck circumference, excellent health, a high level of fitness, and a high level of skill and who engages in legal play may decrease his predisposition to LEMI by developing adaptive (protective) interactions between the nervous system and neuromuscular system. When these athletes are exposed to extrinsic risk factors such as more or less playing time, inadequate or adequate equipment, contact versus noncontact, full contact versus partial contact versus no contact, and so on, the female athlete's susceptibility to injury may be increased while the male athlete's susceptibility may be decreased, or vice versa, depending upon the interactions of the internal and external risk factors. One or both of these athletes may be injured when an inciting event occurs, but many events may occur during the course of training, practice, and competition that will not result in injuries. An injury may be serious enough to preclude a return to sports. However, an athlete may sustain an injury, recover from the injury, and resume play, with different intrinsic risk factors (cognition, reaction time, postural stability, neuromuscular control, etc.), and different extrinsic risk factors (playing time, equipment, etc.). These risk factors may change and continue to change in the presence or absence of new injuries.

In summary, the dynamic model of etiology in sports injury accounts for fluidity of sports injury risk factors, the impact of repeated exposures, and the ways in which each exposure may lead to (a) adaptation (decreased risk) or maladaptation (increased risk), (b) injury or no injury, and (3) full recovery or no recovery. The following sections of this study build upon this foundation.

Pathophysiology of Concussions

Concussions account for most traumatic brain injuries (Cubon, Putukian, Boyer, & Deltwiler, 2010; Ellis et al., 2013). Concussions have been shown to alter cerebral metabolism, ionic equilibrium, mitochondrial function, and cerebral blood flow (Giza & Hovda, 2001; Maugans et al., 2011). Giza and Hovda (2001) reviewed more than 100 studies and surmised that after a concussive injury, a "cascade of ionic, metabolic, and physiologic events" leads to changes in neuronal function that may present clinically as "impaired coordination, attention, memory, and cognition" (p. 233).

Shrey et al. (2011) conducted an extensive review of experimental and human studies that supported Giza and Hovda's (2001) findings and shed light on the pathophysiology of concussions in children, adolescents, and young adults with developing brains. Beginning immediately after a concussion, normal neurometabolic processes can be disrupted for 4 weeks after the injury in humans (Shrey et al. 2011). Even temporary interference with normal neurochemical processes in the developing brain may adversely affect brain plasticity and negatively affect cognitive potential (Choe et al., 2012; Giza & Hovada, 2001; Shrey et al., 2011). These changes increase susceptibility to a second concussion and second impact syndrome (Shrey et al., 2011; Signoretti, Lazzarino, Tavazzi, & Vagnozzi, 2011). A second impact injury before complete recovery from a previous concussive injury can trigger changes in autoregulation of blood vessel constriction and dilation and lead to cerebral autoregulatory failure (Wetjen, Pichelmann, & Atkinson, 2010). Inability to autoregulate cerebral blood flow in conjunction with a catecholamine surge and rapid elevation of blood pressure may lead to rapid, diffuse brain swelling and death (Wetjen et al., 2010).

During the subacute phase of recovery, changes in brain activation patterns and neuroplasticity occur that may delay neurodevelopment and contribute to neurocognitive deficits that may not be recognized for some time (Shrey et al., 2011). Recurrent concussions, or excessive activity, following a concussion contribute to prolonged and more severe postconcussion symptoms and neurocognitive dysfunction (Covassin, Moran, & Wilhelm, 2013; Shrey et al., 2011). Aggregate effects of concussive injuries include aberrant protein deposits and progressive neurodegeneration (Shrey et al., 2011).

Return to Play

Determining when it is safe for high school athletes to return to play (RTP) following concussions and musculoskeletal injuries can be arduous (Echemendia, Giza, & Kutcher, 2015; Guskiewicz & Valovich-McLeod, 2011). Current evidence-based concussion management guidelines include cognitive and physical rest immediately after the injury, followed by gradual return to academic activities, social activities, and physical exertion (Echmendia et al., 2015; Master, Gioia, Leddy, & Crawley, 2012; May, Marshall, Burns, Popoli, & Polikandriotis, 2014; McCrory et al., 2013). Neuropsychological tests are commonly used to assess cognitive function, while balance and postural stability tests are used to assess motor function and guide RTP progression following concussions (Guskiewicz & Teel, 2015; McCrory et al., 2013; Wilkstrom et al., 2009). However, Nelson et al. (2016) found that computerized neurocognitive tests may assist in the recognition of clinical cognitive impairment within the first 24 hours following a concussion or for a brief period after postconcussion symptoms resolve. However, during the later phases of recovery, computerized assessments do not offer more value than concussion symptom scores, so pre- and postconcussion neuropsychological test scores may not be as helpful as initially believed for guiding RTP decisions. McCrea et al. (2012) determined that 10% of high school and college athletes demonstrated postconcussion symptoms that lingered more than 7 days postinjury, and almost 25% of those athletes reported persistent symptoms 6-12 weeks postconcussion. When symptoms lasted 45-90 days postconcussion, significant deficits were not evident in cognitive and postural stability assessments (McCrea et al., 2012). Because postconcussion symptoms and functional impairments vary among athletes, Collins et al. (2013) proposed a model that includes specific clinical trajectories (vestibular, ocular-motor, cognitive/fatigue, posttraumatic migraine, cervical, and anxiety/mood) to inform examinations, treatments, and RTP progressions in order to address each athlete's unique needs. RTP decisions following musculoskeletal injuries are based upon assessments of range of motion, strength, neuromuscular control, proprioception, sport-specific function, and psychological preparedness (Clanton, Matheny, Jarvis, & Jaronimus, 2012).

Neurocognition and Motor Dysfunction

Herman et al. (2015) explained the relationships among neurocognitive performance, motor learning, and neuromuscular control. Neurocognitive performance involves "visual attention, self-monitoring, agility/fine motor performance, processing, and speed/reaction time" (Herman et al., 2015, p. 195). Motor learning entails utilization of tasks and feedback to incorporate sensory information into movements (Boyd & Winstein, 2003). Neuromuscular control involves proprioception (awareness of joint position) and interaction between sensory and motor pathways (Hewett et al., 2002; Swanik, Lephart, Giannantonio, & Fu, 1997). Proprioceptive information is provided to the visual and vestibular systems as well as the peripheral mechanorecptors (Hewett et. al., 2002). The mechanoreceptors "provide position sense and conscious awareness by initiating reflexes to stabilize joints and avoid injury" (Hewett et al., 2002, p. 78). After the mechanoreceptors receive information from the external environment, the information is sent to the CNS, where it is processed, initially at the spinal level (a rapid reflexive response), then by the lower brain (an intermediate speed response), and finally by the cerebrum (the slowest response; Hewett, et al., 2002). The reflex response at the spine (the first level of motor control) stabilizes joints and modulates movements from higher levels (Hewett et al., 2002). The lower brain (the next level) is responsible for timing movements, learning movements, and controlling complex, continuous, repetitive movements (Hewett et al., 2002). The cerebrum (the third level) is responsible for controlling voluntary movements (Hewett et al. 2002). Accurate sensory processing and attentiveness allow athletes to assess situations, while rapid reaction time and dual-tasking proficiency allow athletes to perform motor tasks in an efficient manner (Herman et al., 2015). Correct interpretation of proprioceptive feedback (awareness of joint position) and kinesthetic feedback (awareness of joint motion) allows athletes to make appropriate adjustments in motor activity to optimize task performance (Herman et al., 2015; Swanik et al., 1997). Impaired neurocognitive function may cause changes in motor responses that increase injury risk (Herman et al., 2015).

Broglio, Sosnoff, and Ferrara (2009) explored the relationships among self-reported concussion symptoms, objective measurements of neurocognitive performance, and postural control in collegiate athletes and found strong correlations between reported cognitive and balance issues and objective measures of cognitive and postural impairments. Dorman et al. (2013) evaluated postural stability and postconcussion symptoms in adolescents and found that postural stability improved as postconcussion symptoms diminished. They also incorporated a visual challenge (closing eyes) to reduce sensory feedback, and a cognitive challenge (reciting the months backward) during static balance testing to measure postural deficits and found that dual task interference provided additional value in assessing postural stability and recovery when compared to balance testing only (Dorman et al., 2013). Howell, Osternig, and Chou (2015) found that concussed high school athletes demonstrated impaired dynamic motor function while walking and performing a cognitive task immediately after concussion and during the course of their 2-month study, but controls and concussed adults did not. In another study, Howell, Osternig, and Chou (2014) found that concussed high school athletes demonstrated worsening of gait balance control during dual task walking upon their return to activity. This decline in neuromuscular performance during controlled conditions raises concerns that neuromuscular dysfunction may be more detrimental during complex athletic tasks (Lynall et al., 2015). DeBeaumont et al. (2011) examined the impact of concussion on motor function in collegiate football players 9 months post concussive injury and found differences between concussed athletes and controls in anterior-posterior postural sway and intracortical inhibition of the primary motor cortex, but no differences in rapid alternating pronation-supination movements of the hands. They also found that the amount of intracortical inhibition of the primary motor cortex was directly related to the number of concussions sustained (DeBeaumont et al., 2011). These findings suggest that subclinical changes in lower extremity motor performance persist after concussive injury (DeBeaumont et al., 2011). Barr, Prichep, Shabot, and McCrea (2012) found that abnormalities in brain electrical activity lingered among high school and college football players when standardized neuropsychological tests and postural stability tests indicated clinical recovery. This demonstrates that clinical tests may not be sensitive enough to reveal neurological deficits following concussive injuries (Barr et al., 2012; Howell et al., 2015).

Neurocognition and Musculoskeletal Injury

Hutchison et al. (2011) found cognitive deficits were evident in collegiate athletes who sustained concussions and those who sustained musculoskeletal injuries, 3 days post injury, but not in-uninjured collegiate athletes. Their findings demonstrate that thinking and reasoning can be disrupted without a direct injury to the brain, so other factors may be contributing to cognitive impairments during the early phases of recovery from concussion and musculoskeletal injuries (Hutchison et al., 2011). Swanik, Covassin, Stearne, and Schatz (2007) found collegiate athletes who sustained non-contact ACL injuries during the season, had lower baseline neurocognitive scores in the areas of verbal memory, visual memory, visual motor speed, and reaction time, than matched controls. Swanik et al. (2007) suggested, slower reaction times and processing speed may disrupt judgment and coordination and increase susceptibility to non-contact ACL injuries. They also suggested that impaired visual memory might make it more difficult for athletes to recognize, and respond to, conflicting visual information during unexpected events; and this could interfere with neuromuscular control mechanisms, and the ability to dynamically stabilize joints (Swanik et al., 2007).

Wilkerson (2012) posited the amount of time required for an athlete to visually perceive a stimulus, process that information, and respond to the stimulus might be linked to awareness and ability to produce the proper motor response. Wilkerson (2012) explored the association of reaction time, and forthcoming lower extremity injuries among college football players, and found slower reaction time predicted lower limb sprains and strains. Herman and Barth (2014) analyzed kinetics, (forces generating or changing motions) and kinematics (motions) as young adult female athletes performed jump landings onto varied targets in order to compare neuromuscular function between athletes with high and low baseline neurocognitive scores. The athletes, with low neurocognitive baseline scores, demonstrated kinetics, and kinematics which have been associated with higher risk for ACL sprains (Herman & Barth, 2014). This study shed light on the relationship between neurocognitive performance and neuromuscular performance (Herman & Barth, 2014).

Motor Control and Postural Stability

Information from somatosensory, visual and vestibular systems, influences control mechanisms to maintain joint stability during body movements (Dorman et al., 2013; Riemann & Lephart (2002a, 2002b). Postural stability involves controlling the position of one's center of gravity (Murphy et al., 2003). Ankle plantar flexors, and dorsiflexors primarily control anterior-posterior postural stability, while the hip abductors, and adductors primarily control medical-lateral postural stability when the feet are positioned side-by-side (Termoz et al., 2008). When the feet are placed at 45 degrees, the hip and ankle muscles work in concert in the medial-lateral direction, but they work against each other in the anterior-posterior direction (Termoz et al., 2008). Greater postural sway (less postural stability) has been shown to: (a) change neuromuscular control strategies, (b) increase forces between joint segments, and (c) increase forces generated around the joints' articular and soft tissue structures (Murphy et al., 2003).

Impaired postural control and balance have been associated with ankle, and knee sprains (Samaan et al., 2015; Wilkstrom et al., 2009). Wilkstrom et al. (2009) conducted a meta-analysis and determined: (a) postural stability decreases in individuals with a history of lateral ankle injury, (b) acute and chronic ankle injuries adversely influence balance, and (c) balance training enhances postural control after acute and chronic injuries. Hoch et al. (2012) also found, individuals with chronic ankle instability demonstrate limitations in dynamic postural control. McKeon and Hertel (2008) conducted a meta-analysis and noted postural dysfunction in the involved, and uninvolved lower extremities following ankle sprains which Wang et al., 2009 posited might be related to variations in motor control patterns.

Samaan et al. (2015) utilized the STAR Excursion Balance Test, (SEBT) and single leg hop test to assess dynamic postural control in a collegiate soccer athlete before and after ACL reconstruction (ACLR), then compared the results to baseline measurements utilizing the minimal detectable change method, and limb symmetry index calculations. Results revealed: (a) ACL injury affected lower extremity dynamic postural control, (b) although ACLR restored joint stability, dynamic postural control was still affected; and (c) at 27 months post ACLR, single leg hop performance returned to baseline levels but SEBT performance did not (Samaan et al., 2015). The authors noted the sensorimotor system must adjust after injury and surgery to restore postural control, and they suggested inhibition of the quadriceps muscle, and decreased lower extremity strength might have contributed to reduced dynamic postural control in this case (Samaan et al., 2015). They also suggested that compensatory processes at the hip, and ankle joints might have contributed to improvements in single leg hop performance following ACLR (Samaan et al., 2015).

Concussion and Lower Extremity Injury

Evidence is emerging regarding the relationship between concussion, and musculoskeletal injury. Intercollegiate athletes with musculoskeletal injuries have demonstrated impaired cognition, and individuals with histories of chronic ankle instability and ACL injuries have demonstrated changes in cortical function, which raises the possibility there may be a relationship between musculoskeletal injuries and impaired cortical function (Hutchison et al., 2011; Pietrosimone & Gribble, 2012; Pietrosimone et al., 2015b).

As part of a large, ongoing, prospective cohort study of European male professional soccer players, Nordstrom et al., (2014) analyzed data from a sample of 1665 players, over a period of 11 seasons, between 2001/2002 and 2011/2012, to determine if concussion increases the risk of another injury. Only injuries that kept players from training or competing were entered into the database (Nordstrom et al, 2014). Overall, the players who sustained concussions (n=66) were more susceptible to injury than players who did not sustain concussions (n =1599) (Nordstrom et al., 2014). Concussed athletes were about twice as likely to incur a musculoskeletal injury the year before and the year after the concussive injury (Nordstrom et al., 2014). After accommodating for the higher rate of musculoskeletal injury prior to the concussion, the concussed athletes were still at greater risk of sudden onset musculoskeletal injury one year post-concussion (Nordstrom et al., 2014). The majority of musculoskeletal injuries sustained by concussed and nonconcussed players involved the lower extremities (Nordstrom et al., 2014). Concussion was also associated with an incrementally increased risk of sudden and gradual onset musculoskeletal injuries, when compared with the risk following nonconcussive injuries (Nordstrom et al., 2014). The risk increased from 1.56 times within the first 3 months, to 2.78 times within the third to sixth months, to 4.07 times within the sixth to twelfth month period post-concussion, but the reason for this incremental increase was not evident (Nordstrom et al., 2014). The incrementally increasing risk of sustaining a musculoskeletal injury after athletes have returned to play raises concerns and highlights the need additional research to determine the cause of the increased risk of consequent injuries (Nordstrom et al., 2014).

Pietrosimone, et al. (2015a) analyzed data from a large cross sectional study of retired NFL players, in order to explore the association between concussion frequency and LEMI during the players' NFL careers. A 13-page survey was sent to 3647 former players who retired between 1930 and 2001 (Pietrosimone et al., 2015a). The players were asked to indicate if they sustained any concussions during their NFL careers by responding yes or no, and if they replied yes, they were instructed to indicate how many concussions they had incurred (Pietrosimone et al, 2015a). The players were also asked to specify how many times they had incurred 9 types of musculoskeletal injuries (Pietrosimone et al., 2015a). About 69% (n = 2552) of the surveys were returned, and statistical analysis revealed an association exists between self-reported concussions and musculoskeletal injuries in this population (Pietrosimone et al., 2015a). As the frequency of reported concussions increased, the odds of reporting a lower extremity musculoskeletal injury increased, but they were not able to determine the directional or temporal characteristics of the relationship (Pietrosimone et al., 2015a). Overall, the odds of reporting an ankle or knee injury increased irrespective of the number of concussions reported (Pietrosimone et al., 2015a).

Lynall et al. (2015) reviewed the EMRs of 44 concussed and 58 matched non-concussed collegiate athletes, who participated in a variety of sports at one University, over a two year period of time in order to determine the risk of lower limb musculoskeletal injuries post-concussion. Injury rate comparisons were calculated at 90 days, 180 days, and 365 days before and after the concussion occurred (Lynall et al., 2015). Injury rates were not significantly different between the concussed group and the non-concussed controls at the 90 day, 180 day, or 365 day pre-concussion comparisons, but at the 365 day post-concussion comparison the concussed athletes had significantly higher musculoskeletal injury rates than the non-concussed controls (Lynall et al., 2015). The concussed collegiate athletes were 1.97 times more likely (at 365 days post-concussion) and 2.02 times more likely (at 180 days post-concussion) to have sustained a musculoskeletal injury of a lower limb than they were before the concussive injury (Lynall, et al., 2015). At the 365-day post-concussion comparison, concussed collegiate athletes were also 1.64 times more likely than nonconcussed athletes were to have sustained a musculoskeletal injury of a lower limb (Lynall et al., 2015). Lynall et al. (2015) posited that alterations in cortical pathways after a concussive injury alter movement patterns, and result in neuromuscular control impairments that may increase the risk of musculoskeletal injuries.

Gilbert et al. (2016) investigated the association between a history of concussion (self-reported concussion, known but not reported concussion, possibly unrecognized concussion, and any concussion) and LEI (ankle sprain, knee injury, and muscle strain) rates by surveying 355 intercollegiate athletes, who played 13 sports, at 17 colleges or junior colleges. Athletes completed an electronic or paper survey, at the end of their final intercollegiate season (Gilbert et al., 2016). The investigators determined histories of reported concussions, unreported concussions and any concussions were associated with 2.08, 2.87, and 2.13 times greater risk of knee injuries respectively (Gilbert et al., 2016).

They also found reports of possibly unrecognized concussions were associated with 2.29 times greater risk of ankle sprains, and 1.9 times greater risk of muscle strains (Gilbert et al., 2016). Furthermore, reports of any concussions were associated with 1.79 times greater risk of ankle sprains, 2.13 times greater risk of knee sprains, and 1.61 greater risk of muscle strain (Gilbert et al., 2016). These findings were comparable to those reported by Lynall et al., 2015; Nordstrom et al., 2014; and Pietrosimone et al., 2015a). Gilbert et al. (2016) suggested undetected neurocognitive dysfunction and underreporting of concussions might be factors in the association between concussion and LEMI.

Strengths and Limitations of Existing Studies

Nordstrom et al. (2014), Pietrosimone et al. (2015a), Lynall et al. (2015), and Gilbert et al. (2016) studied samples of convenience (preexisting groups of professional and collegiate athletes, and found SRCs and LEMIs were associated. Crosby, DiClemente, and Salazar (2006) explained, when numerous studies reach the same conclusions about the same research topic, generalizability of results improves. However, the results of the studies by Nordstrom et al. (2014) and Pietrosimone et al. (2015a) may not apply to other groups of athletes because each study focused on a narrowly defined group of professional athletes. Gilbert et al. (2016) addressed this limitation by examining the relationship between concussion and LEMI in intercollegiate athletes who participated in 13 sports at17 institutions but they did not account for other factors that could have influenced their results. Lynall, et al (2015), addressed this limitation matching college athletes without SRCs and those with SRCs to examine acute LEMI rates pre and post-concussion. Their study also included collegiate athletes who participated in different sports, but the small sample (n = 44) only included athletes at one university (Lynall et al., 2015).

Nordstrom et al. (2014) provided early information regarding temporal relationships between SRCs and other SRIs, in professional soccer players, but acknowledged the concussive injuries entered into the "Union of European Football Association's" database could not be confirmed, and the diagnostic criteria for concussive injuries might have varied widely among teams and countries (p. 1447). Therefore, it is possible some concussions might not have been included in the database. Pietrosimone et al. (2015a), and Gilbert et al. (2016) relied on self-reported data, and medical records could not validate the responses, so recall bias might have influenced the results in those studies. Lynall et al. (2015) accessed, and analyzed data from EMRs that were completed by a certified athletic trainer at one University. This reduced the potential for recall bias, but some of the data in the EMRs could have been entered incorrectly (Aschengrau & Seage 2014; Lynall et al., 2015). The concussion management processes may have varied in the NFL, professional European soccer player, and multi-institution intercollegiate studies. However, Lynall et al. (2015) reduced the potential for this problem, in their study because the concussion management policy was the same for all athletes.

This study addressed the limitations of unconfirmed injuries, variations in diagnostic criteria, and recall bias described in the previous studies as the athletic injury data examined in this study were obtained from EMRs, that were completed by certified athletic trainers who received structured EMR training to facilitate consistency in coding and data entry across clinical sites (Lam et al., 2015). Additionally, the injury definitions, and coding options, were consistently delineated throughout the data collection sites. Furthermore, each site used the same EMR system and ICD-9 codes (ATSU, n.d.; Lam et al., 2015). This study also provided new information about the relationship between SRC and LEMI in high school athletes, so it could partially fill the gap in the literature, and serve a springboard for future prospective studies that could provide a more complete understanding of these common sports injuries in young athletes.

Summary and Transition

This literature review explored research pertaining to adolescent SRC and musculoskeletal injuries. Awareness of sports injury mechanisms and risk factors is essential for injury prevention (Meeuwisse et al., 2007). Athletes must continuously receive information, process information, direct their attention to appropriate situations, sort out extraneous information, and respond to rapidly changing environments while performing complex motor tasks (Swanik et al., 2007). During the acute and subacute phases of concussion recovery, alterations in the areas of the brain that control these tasks may make it more challenging for athletes to perform this tasks efficiently, and this may increase their risk of musculoskeletal injury (Herman et al., 2015; Lynall et al., 2015; Nordstrom et al., 2014; Pietrosimone et al., 2015a). The emerging evidence regarding the association between SRC, and LEMI among neurologically and skeletally mature, professional, and collegiate athletes may not be generalizable to high school athletes. To my knowledge the relationship between SRC and LEMI has not been examined in adolescent athletes (Gilbert et al., 2016; Lynall et al., 2015; Nordstrom et al., 2014; Pietrosimone et al., 2015a). Examining the association between SRC and LEMI among high school athletes could provide a better understanding of these sport related injuries in this population and address a gap in knowledge.

The third chapter includes research design and rationale, methodology, data analysis strategies for this study. The threats to validity and ethical procedures are also discussed. This chapter concludes with summary of this study's design, methodology, and transition to the fourth chapter.

Chapter 3: Methods

Introduction

Because SRC and LEIs account for most new and recurrent injuries reported in high school sports and the consequences of these injuries are pressing public health concerns, determining the relationship between SRC and LEMI could provide preliminary information to more completely understand the link between these sport-related injuries (SRI) in this population. The purpose of this retrospective quantitative study was to determine the association between SRC and LEMI among high school athletes. A quantitative cross-sectional retrospective study allowed a large, diverse sample of U.S. high school athletic injury data to be analyzed in a resource-sparing, cost-effective manner to provide a broad (national) snapshot of this public health situation.

This chapter includes justification of the study's design and rationale, methodology, and data analysis strategies. Threats to validity and ethical considerations are also presented. This chapter concludes with a summary and transition to the fourth chapter.

Research Design and Rationale

In this study, I examined the relationship between SRC and LEMI in high school athletes, so the dependent (outcome) variable was LEMI, and the independent (predictive) variable was SRC. The covariates included age, gender, and sport.

I accessed and analyzed an existing numeric data set, which consisted of a nationally representative sample of high school injury data, to test my hypotheses and answer my research questions. Because I examined the association between an independent variable (SRC) and a dependent variable (LEMI) in high school athletes in a defined period in time, a retrospective, quantitative, cross-sectional design was appropriate. The design of this study was consistent with research designs that advance public health knowledge, in that quantitative, retrospective, cross-sectional studies allow researchers to access large amounts of pre-existing numeric data from large, diverse samples to efficiently provide a snapshot of a public health problem without expending extensive human, time, or financial resources. The generalizability of the results from large, quantitative, retrospective, cross-sectional studies can be broader than results from small-scale studies, because larger samples are more likely to represent the populations from which they are obtained.

Methodology

Study Population

According to the U.S. Department of Education (n.d.), there are more than 24,000 public and 10,000 private high schools in the United States. Over 7.8 million athletes participate in high school sports and endure between 1.4 and 2 million injuries each year (Gottschalk & Andrish, 2011; National Federation of State High School Associations, n.d.; Powell & Barber-Foss, 1999; Yard et al., 2009). The population for this study consisted of U.S. high school athletes.

Sampling and Sampling Procedures

Information about population characteristics can be deduced from sample data, with inferential statistics, when the sample accurately represents the population (Ary, Jacobs, Sorensen, & Walker, 2014, Field, 2009). For this study, I obtained a convenience sample of high school athletic injury data from the AT-PBRN database (ATSU, n.d.). This database includes male and female athletic injury data imported from CORE-AT

EMRs that are completed by athletic trainers at universities, high schools, clinics, and other settings throughout the United States and Singapore (ATSU, n.d.). The sample for this study consisted of all available U.S. high school concussion, knee sprain, and ankle sprain data captured by the CORE-AT EMR and transmitted to the AT-PBRN database from the database's inception in September 2009 through December 2016 (ATSU, 2016). All cases in the data set that had one or more concussions, one or more musculoskeletal injuries, or one or more of each injury were analyzed.

The utility and validity of the AT-PBRN were addressed in the first chapter. The AT-PBRN utilizes the web-based CORE-AT system to capture high school athletic injury surveillance data and EMR data from more than 25 high schools throughout the United States., including schools in Alaska, Arizona, Kansas, Massachusetts, Minnesota, Missouri, North Carolina, New Hampshire, New Jersey, New York, and Wisconsin (ATSU, n.d., 2016). A concussion-specific evaluation form and a region-specific injury evaluation forms, which capture previous injury history, are included in the EMR, but prior concussion history is not captured (ATSU, n.d.). The CORE-AT system captures injuries that "1) result from participation in interscholastic practices or competitions, and 2) require medical attention by a certified athletic trainer or physician, and 3) result in restricted participation or performance for 1 or more days beyond the day of injury" (ATSU, n.d., p. 44). Each injury was coded by athletic trainers in accordance with the ICD-9 definitions and recorded in the EMR (ATSU, n.d..; CMS, n.d.). Because athletic trainers are not required to document exposures, a common denominator was not available to determine risk or rates of injury.

Sample Size

Sample size and sampling methods influence the precision of estimates derived from a sample (Ary et al., 2014). When other determinants are equal, larger samples are more likely to truly reflect the population of interest and detect significance (Ary et al., 2014; Crosby et al., 2006. I determined the appropriate sample size for this study by reviewing the literature and using a G power 3.1 calculator (Faul, Erdfelder, Buchner, & Lang, 2009; Field, 2009; Gilbert et al., 2016; Lipsey & Wilson, 1993; Lynall et al., 2015; Nordstrom et al., 2014; Pietrosimone et al., 2015a; Schoenfeld & Borenstein, 2005). Schoenfeld and Borenstein (2005) explained that the literature lacks recommendations for obtaining sample size when the covariates are discrete and continuous. The effect size (strength of the relationship between variables) and *r* values were not reported in the correlational concussion studies that were reviewed, so R^2 value (amount of variability in the main predictor explained by the covariates) was estimated by predicting that the covariates would have moderate association with concussion $(0.5)^2 = 0.25$. I selected a one-tailed test because the literature revealed that concussion is associated with musculoskeletal injuries in professional soccer players, retired NFL football players, and collegiate athletes (Gilbert et al., 2016; Lynall et al., 2015; Nordstrom et al., 2014; Pietrosimone et al., 2015a). I set the odds ratio (odds that the outcome will occur with exposure / odds the outcome will occur in the absence of exposure) at 1.59, the HO (probability of musculoskeletal injury when the athlete is not concussed) at 0.2, the alpha level (probability of rejecting a true null hypothesis or a type 1 error) at 0.05, and the power (probability of rejecting the null hypothesis when the alternate hypothesis is true or 1 - beta) at 80%. The *x* distribution was set to binomial, and the *X parm* π (proportion of concussed cases) was set at 0.12 based on the anticipated proportion of concussed cases in this data set and studies conducted by Valovich McLeod et al (2012), Nordstrom et al. (2014), Pietrosimone et al. (2015a), and Swenson et al., (2009). With these parameters, the appropriate sample size was determined to be 1,939 athletes with a critical *z* value of 1.6448536, and the actual power was 0.80000605 (Faul et al., 2009).

Data Extraction

I received de-identified data from the AT-PBRN database, following institutional review board (IRB) approval. I requested the full dataset, but only received the concussion, knee sprain, and ankle sprain data. All cases in the data set that met the definitions for one or more high-school-sport-related concussions or musculoskeletal injuries were analyzed.

Data Analysis Plan

The first step in my data analysis plan was to preserve the original data. All original data were stored on a portable hard drive and secured in a locked file cabinet, where they will remain for a minimum of 5 years. I had the only key and was the only person able to access the file cabinet. The analysis was conducted on a computer, which was located in a locked office at Old Dominion University (ODU). Security features included password access and automatic log offs. I examined, organized, and plotted the data to gain an appreciation of the information the dataset contained. This step included (a) sorting the data, (b) looking for missing data, and (c) identifying and managing outliers. The number of valid and missing observations was counted to determine if enough data existed to answer the research questions. All study data were stored and backed up on a portable hard drive and secured in the locked file cabinet with the original data.

The data were cleaned and coded for analysis. Descriptive and statistical analyses were conducted with SPSS software, version 23 (IBM Corp., 2015). In this study, the dependent variable was musculoskeletal injury, the independent variable was concussion, and the covariates were gender, age group, and sport type.

Dependent Variable

The dependent variable, LEMI, was operationalized as a knee sprain or ankle sprain with one of the following ICD-9 codes: Knee sprains were coded as follows:

- 844.0 (lateral collateral ligament [LCL] sprain of the knee) = 1
- 844.1(medial collateral ligament [MCL] sprain of the knee) = 2
- 844.2 (sprain of cruciate ligament; anterior cruciate ligament [ACL] or posterior cruciate ligament [PCL] of knee) = 3
- 844.9 (sprain of unspecified site of knee and leg) = 4

Ankle sprains were coded as follows:

- 845.00 (unspecified site of ankle sprain) = 5,
- 845.01 (deltoid ligament sprain of ankle) = 6,
- 845.03 tibiofibular ligament sprain of distal ankle = 7 (ATSU, n.d.; CMS, n.d.; Merrick, 2002; Williams, 1971)

The dependent (outcome) variable for this study was measured as absence of LEMI = 0, presence of LEMI =1. Additional strata were created to measure the absence or presence of knee and ankle injuries where the absence of knee injury = 0, the presence of knee injury =1, the absence of ankle injury = 0, and the presence of ankle injury = 1.

Independent Variable

The independent variable, concussion, was operationalized as an SRC delineated by one of one of the following ICD-9 codes: (a) 850.0 (concussion with no loss of consciousness), (b) 850.5 (concussion with loss of consciousness of unspecified duration), or (c) 850.9 (concussion—unspecified). All concussions (850.0, 850.5, and 850.9) were coded as 33 for this study. The independent variable was measured as absence of concussion = 0 or presence of concussion = 1. The frequency of concussion for each case was measured as absence of concussion = 0, one concussion = 1, or two concussions = 2.

Covariates

The athlete characteristics gender and age were analyzed because there is evidence that risk of concussion is influenced by these covariates (Gessel et al., 2007). Gender is a nominal variable that was defined as the high school athlete’s sex. Gender was categorized as follows: male = 1 or female = 2. Age is a scale variable, which was defined as age at the time of injury. For regression purposes, the age variable was converted to a categorical variable where 11-13 years = 1, 14-17 years = 2, and 18-19 years = 3.

Sports characteristics included team sports and individual sports. This covariate was analyzed to provide a broader perspective on sport-related injuries among high school athletes in light of the finding by Comstock et al. (n.d.) that one high school individual sport (wresting) had a higher injury rate per 1.000 athlete exposures (2.23) than the following team sports: boys soccer (1.87), girls volleyball (1.19), boys basketball (1.48), and girls basketball.2.14). Team sport was a nominal variable that was defined as sports that require team members to work together at the same time to achieve a common goal or outcome. Team sports were categorized as follows: baseball = 1, basketball = 2, cheerleading = 3, field hockey = 4, football = 5, hockey = 6, lacrosse = 7, soccer = 8, softball = 9, and volleyball = 10. Individual sports were defined as sports in which each athlete is responsible for achieving his or her own goals or outcomes. Individual sport was a nominal variable, which was categorized as follows: badminton = 11, cross country = 12, gymnastics = 13, swimming = 14, tennis = 15, track = 16, and wrestling = 17. Other sports that could not be identified as team or individual sports were coded as 18. Sports were categorized as follows: team sports = 1, individual sports = 2, and other sports = 3. All codes were recorded and safeguarded in a locked file cabinet.

Statistical Analysis Approach

The research questions guided the statistical analysis process (Creswell, 2014). The following research questions were explored in this study:

1. Is there an association between SRC and LEMI among high school athletes?

   H_{01}: There is not an association between SRC and LEMI among high school athletes while controlling for gender, age, and sport.

   H_{A1}: There is an association between SRC and LEMI among high school athletes while controlling for gender, age, and sport.

   1a. Is there an association between SRC and knee sprains among high school athletes?

H_{01a}: There is not an association between SRC and knee sprains among high school athletes while controlling for gender, age, and sport.

H_{A1a}: There is an association between SRC and knee sprains among high school athletes while controlling for gender, age, and sport.

1b. Is there an association between SRC and ankle sprains among high school athletes?

H_{01b}: There is not an association between SRC and ankle sprains among high school athletes while controlling for gender, age, and sport.

H_{A1b}: There is an association between SRC and ankle sprains among high school athletes while controlling for gender, age, and sport.

2. Is the number of SRCs associated with LEMI among high school athletes?

   H_{02}: The number of SRCs is not associated with LEMI among high school athletes controlling for gender, age, and sport.

   H_{A2}: The number of SRCs is associated with LEMI among high school athletes while controlling for gender, age, and sport.

3. Is the number of SRCs associated with knee injuries among high school athletes?

   H_{03}: The number of SRCs is not associated with knee injuries among high school athletes while controlling for gender, age, and sport.

   H_{A3}: The number of SRCs is associated with knee injuries among high school athletes while controlling for gender, age, and sport.

4. Is the number of SRCs associated with ankle injuries among high school athletes?

H_{04}: The number of SRCs is not associated with ankle injuries among high school athletes while controlling for gender, age, and sport.

H_{A4}: The number of SRCs is associated with ankle injuries among high school athletes while controlling for gender, age, and sport.

The frequencies and distributions were determined and reported for the following variables:

- age
- age group (11-13 years, 14-17 years, and 18-19 years)
- gender
- sport type (team sports, individual sports, and other sports)
- concussion absence/presence (0, 1)
- LEMI absence/presence (0, 1)
- knee sprain absence/presence (0, 1)
- ankle sprain absence/presence (0, 1)
- absence/presence of each type of knee sprain (MCL, LCL, ACL, PCL, unspecified [0, 1])
- absence/presence of each type of ankle sprain (unspecified, deltoid, tibiofibular [0, 1])
- concussion frequency (0, 1, 2, 3)
- LEMI frequency (0, 1, 2, 3)
- knee sprain frequency (0, 1, 2, 3)
- ankle sprain frequency (0, 1, 2, 3)

- frequency of each type of knee sprain (0, 1, 2)
- frequency of each type of ankle sprain (0, 1, 2+)

The mean, standard deviation, and range were presented for the scale characteristic (age).

Logistic regression models allow researchers to analyze categorical and continuous data to predict discrete outcomes (Faul et al., 2009; Field, 2009; Hsieh, 1989; Schoenfeld & Borenstein, 2005). Binomial logistic regression analysis provides information regarding the fit of the model, significance of the predictors in the model, and corroboration of predicted probabilities (Peng, Lee, & Ingersoll, 2002).

To answer each of the research questions identified above, I conducted chi square analyses to ascertain if each independent variable was related to the dependent variable to determine which independent variables should be included in the logistic regression model to reduce the chance of over specification (Bursac, Gauss, Williams, & Hosmer, 2008; Hosmer & Lemeshow, 2000). I also conducted Cramer's *V* post hoc tests to assess the strength of the relationship between those variables (Field, 2009). Since confounding factors that might influence the relationships could not be accounted for with these tests, I conducted binomial logistic regression analyses to provide a more complete picture of associations between the independent and dependent variables of interest in this study (Field, 2009). Only the covariates that were found to be associated with the dependent variables during the chi-square analyses were included in the respective logistic regression models.

Binomial logistic regression was an appropriate statistical test to answer each research question because this test allows dichotomous categorical outcomes to be predicted from a set of categorical and/or continuous independent variables (Field, 2009).

Wald statistics were calculated to determine if each predictor variable significantly contributed to predicting the outcome (Faul et al., 2009; Field, 2009). The odds ratio (estimate for the odds of the outcome based on the predictive variable) and 95% confidence interval (95% chance the true statistic is within the calculated interval) were also calculated (Field, 2009).

Threats to Validity

Validity refers to how well the research design supports the interpretation of the data (Aschengrau & Seage, 2014; Carlson & Morrison, 2009). Construct validity deals with a test's ability to measure what it is meant to measure while internal validity is concerned with the strength of inferences (Gerstman, 2008). Statistical conclusion validity is concerned with correct analysis, and external validity addresses generalizability of the study's results. Threats to construct validity, internal validity, statistical conclusion validity, and external validity should be addressed in cross sectional studies (Carlson & Morrison, 2009).

Construct Validity

In correlational studies, construct validity can be threatened if the independent, and dependent, variables are defined differently in a study's methodology, and the secondary data set. Construct validity may also be decreased when secondary data are analyzed, if pertinent variables are missing, or if it is unclear how and why the primary data were collected (Carlson & Morrison, 2009). The threats to construct validity were addressed in this study by: (a) aligning the definitions of the independent and dependent variables in this study with the definitions of pertinent variables in the data set, and (b) by reviewing the CORE-AT EMR user manual to clarify how, and why, the primary data were collected (ATSU, n.d.). There were no missing data in this data set.

Internal Validity

Internal validity pertains to the strength of inferences that are made from the study's results (Carlson & Morrison, 2009). Although cross sectional studies allow researchers to examine associations between an exposure and an outcome, I was not able to determine meaningful relationships between the independent and dependent variables in this study due to incomplete information and small sample sizes (Carlson, & Morrison, 2009; Mann, 2003). Therefore, internal validity was threatened. Additionally, temporal relationships could not be ascertained in this study because the exposure and outcome are examined at the same time (Aschengrau & Seage, 2014; Carlson & Morrison, 2009). Furthermore, there was potential for selective departure of injured participants, and continued participation of non-injured participants, so a negative impact of an exposure (concussion) could be reduced (Aschengrau & Seage, 2014). To overcome the limitations of internal validity in this study, future cohort studies should be conducted to determine if the relationship between SRCs and LEMIs in high school athletes is causal, as Cohort studies allow for evaluation of many effects of an exposure, and direct measurements of outcome incidence or risk (Aschengrau & Seage, 2014).

Statistical Conclusion Validity

Statistical conclusion validity is concerned with validity of the conclusions derived from statistical tests. I addressed this threat to validity by selecting the appropriate (chi-square and binomial logistic regression) statistical tests to answer the research questions.

External Validity

External validity addresses the generalizability of the study's results (Aschengrau & Seage, 2014). Generalizability of a study's results is determined by how well the sample represents the intended population (Ary, 2014; Field, 2009). Small, non-representative samples, from single locations, increase the threat of external validity (Carlson & Morrison, 2009). I addressed these threats to external validity by: (a) determining the appropriate sample size for this study, and (b) confirming the secondary dataset included data from U.S. high schools from multiple regions throughout the United States

Ethical Procedures

Prior to beginning the data collection and analysis aspects of this study, I obtained approval to proceed with this study from the institutional review boards (IRBs) at: (a) Walden University, (b) ATSU (in order to comply with the University's policies and procedures pertaining to human subjects research, and to gain access the secondary data for this study), and (c) ODU (in order to comply with my employer's policies and procedures related to human subjects research). I also ensured my Collaborative Institutional Training Initiative (CITI) Biomedical Research Basic Refresher training course remained current throughout the duration of this study (University of Miami, n.d.).

The secondary data set for this study was obtained from the AT-PBRN, which incorporates a Health Insurance Portability and Accountability Act (HIPAA) compliant electronic medical record and injury surveillance instrument. The de-identified raw data was secured and will be retained for a minimum of 5 years to comply with Walden University's (2015) IRB requirements.

The athletic trainers, in the AT-PBRN high schools, enter injury data into the EMR in accordance with routine patient care practice standards. Additionally, the AT-PBRN has a safe harbor agreement with the EMR vendor, which allows AT-PBRN researchers to access de-identified information while protecting patient confidentiality.

Summary

The process for conducting this retrospective, quantitative cross sectional study was described in this chapter. The research questions, hypotheses, and justification of the study's design and rationale were presented. The methodology and data analysis sections revealed how a secondary data set from the AT-PBRN was examined to determine if an association exists between SRC and LEMIs among high school athletes (ATSU, n.d.). Threats to validity, and ethical considerations were also explained. Descriptive statistics, quantitative analyses and results of this study are presented in chapter 4.

Chapter 4: Results

Introduction

SRCs and LEMIs are common in high school sports, and the consequences of these injuries can be debilitating. Therefore, understanding the factors that contribute to these SRIs is of paramount importance for preventing these injuries and their repercussions. Evidence is emerging regarding the relationship between SRC and LEMI in professional and collegiate athletes, but findings in adults may not be generalizable to adolescents. Therefore, the purpose of this study was to examine the association between SRC and LEMI in high school athletes to shed more light on the mounting public health problem of SRCs and address this gap in the literature. This study was conducted to seek answers to the following research questions by testing their hypotheses:

1. Is there an association between SRC and LEMI among high school athletes?

    H_{01}: There is not an association between SRC and LEMI among high school athletes while controlling for gender, age, and sport.

    H_{A1}: There is an association between SRC and LEMI among high school athletes while controlling for gender, age, and sport.

2. Is the number of SRCs associated with LEMI among high school athletes?

    H_{02}: The number of SRCs is not associated with LEMI among high school athletes while controlling for gender, age, and sport.

    H_{A2}: The number of SRCs is associated with LEMI among high school athletes while controlling for gender, age, and sport.

3. Is the number of SRCs associated with knee injuries among high school athletes?

H_{03}: The number of SRCs is not associated with knee injuries among high school athletes while controlling for gender, age, and sport.

H_{A3}: The number of SRCs is associated with knee injuries among high school athletes while controlling for gender, age, and sport.

4. Is the number of SRCs associated with ankle injuries among high school athletes?

H_{04}: The number of SRCs is not associated with ankle injuries among high school athletes while controlling for gender, age, and sport.

H_{A4}: The number of SRCs is associated with ankle injuries among high school athletes while controlling for gender, age, and sport.

In this chapter, I explain the data collection, reduction, transformation, aggregation, and analysis processes. In addition, I present the descriptions and demographic characteristics of the sample. The results are also reported. This chapter concludes with a summary and transition to the final chapter.

Data Collection

Data Collection Process

The IRB at Walden University granted permission for this study to be conducted (approval number 11-10-16-0168884) after my requests for exemption from IRB reviews were approved by ATSU (IRB # 2016-235) and ODU (project number 1015419-1). With verification of IRB approval for this study, I requested all available high school injury data captured by the AT-PBRN EMR from 2009 through 2016, to answer my research questions. I received a de-identified dataset, which consisted of data for the independent variable (concussion) and the dependent variables (ankle sprain, and knee sprain). The data were generated between 2009 and January 2017, in high school, college, and other settings.

As previously described, the AT-PBRN includes a nationally representative sample of high school, college, and other athletic injury data. The sample that I received contained 2,590 cases, reflecting the following variables: (a) injury ID (unique identifier), (b) patient ID (the same patient ID in different rows indicated the athlete had multiple injuries), (c) setting (high school, college, other, or unidentified), (d) gender (male or female), (e) injury year (year the injury occurred), (f) age (at time of injury), (g) injury days since injury demographic (number of days since injury), (h) injury height (athlete's height), (i) injury weight (athlete's weight), (j) sport name, (k) injured during name (in season, off season, conditioning, practice, game, etc.), (l) mechanism ID (mechanism of injury code), (m) mechanism name (mechanism of injury name), (n) body part name (ankle, knee, head), (o) diagnosis ID (diagnosis code), (p) diagnosis description (ICD-9 code with description), (q) severity name, (r) injury participation status (no participation, noncontact, light contact, other restrictions, no restrictions), and (s) number of cases (number of cases in the data set).

Data Reduction Process

I sorted and reduced the 2,590 cases in the original dataset to construct a working dataset. A summary of data inclusion and exclusion is presented in Table 1.

Table 1

Data Inclusion and Exclusion

	Included	Excluded
Setting	High school	College Null Other Unidentified
Injury year	2009-2016	2017
Age (years)	11-19	<11 and > 19
Body part code	Head Neck—with concussion ICD-9 code Ankle Knee	
ICD-9 code	844—Sprain LCL 844.1—Sprain MCL 844.2—Sprain cruciate ligament 844.9—Sprain/strain unspecified thigh distal end 845—Sprain/strain ankle unspecified 845.01—Sprain deltoid ligament 845.03—Sprain tibiofibular ligament 850.0—Concussion, mental confusion w/out loss of consciousness 850.5—Concussion w/ loss of consciousness 850.9—Concussion	
Gender	Males Females	
Sports	Badminton Baseball Basketball Cheerleading Cross country Field hockey Football Gymnastics Hockey Lacrosse Soccer	Recreational

(*table continues*)

	Included	Excluded
	Softball Swimming Tennis Track Volleyball Wrestling Other	
Injured during	In-season game In-season practice Preseason conditioning Preseason scrimmage Off-season practice Off-season conditioning.	Non-sport-related
n Cases		
Patient ID#		
Injury ID#		
		Height
		Weight
		Injury days since injury
		Injured during name
		Mechanism ID
		Mechanism name
		Severity name
		Injury participation status

First, I sorted the data by the setting variable to ensure that only the high school setting (*n* = 2,000) was included in the working dataset. Therefore, I excluded the college (*n* = 474), null (*n* = 22), other (*n* = 91), and unidentified (*n* = 3) settings. Then I sorted the data by the injury year variable. I excluded the 2017 cases and retained 2009-2016 cases, as approved by the IRB. Next, I sorted the data by the age variable. I retained 11- to 19-year-old high school athletes but excluded the cases outside that age range to ensure that the working dataset only contained adolescents. I also sorted the data by the body part variable and diagnosis description variable, which included the ICD-9 codes, to ensure that the data set contained concussions, ankle sprains, and knee sprains (CMS, n.d.). During this process, I found that the injured body parts, in all but one of the cases, were classified as head, knee, or ankle. Further exploration revealed that the body part in the case that was the single exception to this pattern was labeled as a neck injury but was described as an unspecified concussion with ICD-9 code 850.9. Because head and neck injuries can occur simultaneously and the injury was coded as a concussion in the original data set, I retained this case. I also sorted the data by the sport name variable and retained badminton, baseball, basketball, cheerleading, cross-country, field hockey, football, gymnastics, hockey, lacrosse, soccer, softball, swimming, tennis, track, volleyball, wrestling, and other sports. I excluded recreational athlete cases. Next, I sorted the data by the *injured during name* variable. I retained in-season game, in-season practice, preseason conditioning, preseason scrimmage, off-season practice, and off-season conditioning. All non-sports-related cases were excluded. I sorted the *n* cases and patient ID variables to determine which athletes had multiple injuries. Next, I sorted the data by the injury ID and patient ID variables to ascertain whether the dataset contained any duplicate cases. No duplicate cases were found. I also sorted the data by the height and weight variables to look for obvious errors and found 352 cases with recorded heights of 0-6 inches, as well as 267 cases of recorded weights of 0-6 pounds; these variables were excluded from the working data set. The injury days since injury demographic, injured during name, mechanism ID, mechanism name, severity name, and injury participation status variables were excluded because they were not variables of interest in this study.

Data Transformation

The working data set contained 1,726 cases, including athletes with multiple injuries; therefore, further data reduction was conducted to ensure independence of observations. The details of this process are presented below.

After sorting and cleaning the data to establish this working dataset, I retained the original numeric form for the scale variables age and injury year. In order to analyze the predictor variable, age, more completely, I stratified the age variable and created the age group code variable, classifying age as follows: (11-13 years = 1; (14-17 years = 2; and (18-19 years = 3. I transformed the gender variable to the gender code variable such that male = 1 and female = 2. To determine if the continuous independent variable (age) was linearly related to the logit of the dependent variables (LEMI ever), I transformed this variable into its natural log and completed the assessment with the Box-Tidwell (1962) procedure. I stratified the dependent variable (LEMI ever) into the *knee sprain ever* and *ankle sprain ever* variables, to understand the relationship between SRC and LEMI more clearly. I also transformed the *knee sprain ever* and *ankle sprain ever* variables into their natural logs and used the Box-Tidwell procedure to determine if the continuous independent variable (age) was linearly related to the logits of the knee sprain and ankle sprain variables.

For descriptive purposes, I transformed the diagnosis description variable (which included abbreviated ICD-9 codes) into the ICD-9 description variable (which included full ICD-9 codes as defined by CMS [n.d.]). Therefore, I made the following transformations:

- 844—Sprain LCL was transformed to 844.0—Knee sprain LCL.
- 844.1—Sprain MCL was transformed to 844.1—Knee sprain MCL.
- 844.2—Sprain cruciate ligament was transformed to 844.2—Knee sprain cruciate ligament.
- 844.9—Sprain/strain, unspecified thigh, distal end was transformed to 844.9—Knee sprain unspecified.
- 845—Sprain/strain was transformed to 845—Ankle sprain unspecified.
- 845.01—Sprain, deltoid ligament was transformed to 845.01—Ankle sprain deltoid ligament.
- 845.03—Sprain, tibiofibular ligament was transformed to 845.03—Ankle sprain tibiofibular ligament.
- 850.0—Concussion, mental confusion without loss of consciousness was transformed to 850.0—Concussion without loss of consciousness.
- 850.5—Concussion with loss of consciousness was transformed to 850.5—Concussion with loss of consciousness.
- 850.9—Concussion was transformed to 850.9—Concussion unspecified.

Next, I transformed the ICD-9 code description variable to the ICD-9 code variable for descriptive analysis as follows:

- 844.0—Knee sprain LCL = 1
- 844.1—Knee sprain MCL = 2
- 844.2—Knee sprain cruciate ligament = 3
- 844.9—Knee sprain unspecified = 4
- 845.00—Ankle sprain unspecified = 5
- 845.01—Ankle sprain deltoid ligament = 6
- 845.03—Ankle sprain tibiofibular ligament = 7
- 850.0—Concussion without loss of consciousness = 33
- 850.5—Concussion with loss of consciousness = 33
- 850.9—Concussion unspecified = 33

To prepare for chi-square and logistic regression analyses, I created a new variable by transforming the ICD-9 code variable to the body part variable so that 1-4 = knee, 5-7 = ankle, 33 = head. Then I transformed the body part variable to the body part code variable so that head = 1, ankle = 2, and knee =3. Next, I transformed the head code variable as follows: absence of head injury = 0 and presence of head injury = 1. I also transformed the ankle and knee code variables into a new variable labeled *lower extremity code*, where absence of a lower extremity (ankle or knee) injury = 0 and presence of lower extremity injury (ankle or knee) injury = 1. A knee code variable was created where absence of a knee injury = 0 and presence of a knee injury =1. An ankle code variable was also created where absence of an ankle injury = 0 and presence of an ankle injury = 1.

Because the unique identifier for this data set was the injury ID variable, each injury was captured in a single row, and I sorted the data by the patient ID variable to determine how many injuries each athlete had. Then I created a new variable labeled *injury order* to identify which injury occurred first, second, and third. First, or only, injuries were coded 1, second injuries were coded 2, and third injuries were coded 3.

To prepare for logistic regression analysis, I transformed the sport name variable into a new variable that was labeled *sport code*, where baseball = 1, basketball = 2, cheerleading = 3, field hockey = 4, football = 5, hockey = 6, lacrosse = 7, soccer = 8, softball = 9, volleyball = 10, badminton = 11, cross country = 12, gymnastics = 13, swimming = 14, tennis = 15, track = 16, wrestling = 17, and other = 18. Next, I created a new variable labeled *sport type*. I then transformed the sports coded 1-10 into a new variable labeled *team sports*, the sports coded 11-17 into a new variable labeled *individual sports*, and the sports coded 18 into a new variable labeled *other sports*. Then I transformed the sports type variable into the sports type code variable, where team sports = 1, individual sports = 2, and other sports = 3.

Data Aggregation

The injury ID variable indicated which injury occurred first, so new variables were created and coded, including the (a) concussion first variable, where concussion not first = 0 and concussion first =1; (b) LEMI first variable, where LEMI not first = 0 and LEMI first = 1; (c) knee injury first variable, where knee injury not first = 0 and knee injury first = 1; and (d) ankle injury first variable, where ankle injury not first = 0 and ankle injury first = 1. Additionally, I created the concussion ever variable, where absence of a concussion = 0 and presence of at least one concussion = 1, and the LEMI ever variable, where absence of a LEMI = 0 and presence of at least one LEMI = 1. Next, I created a variable labeled *n cases clean* to clarify how many cases each athlete had in the clean working data set, such that one case = 1, two cases = 2, and three cases = 3.

I aggregated the cases to ensure each athlete was only represented once in the data set. Next, I sorted the data by *patient* ID and injury order to clearly identify which athletes had more than one injury. For each *patient ID* with two or three injuries, I retained all data for the first injury (age, sport name, sport type, injury year), then I manually transferred the data from the second and third rows into the first row that contained the same *patient ID* in order to aggregate the data for the following variables: (a) *concussion ever,* so absence of concussion = 0 and presence of concussion = 1; (b) *LEMI ever,* so absence of LEMI = 0 and presence of LEMI = 1; (c) number of concussions so absence of concussion = 0; one concussion = 1; and two concussions = 2. To more thoroughly analyze the association between SRC and knee sprains, I transformed the *number of knee sprains* variable into a new variable labeled *knee sprain ever,* where absence of knee injury = 0, and presence of knee injury = 1. To more thoroughly analyze the association between SRC and ankle sprains I also transformed the *number of ankle sprains* variable into a new variable labeled *ankle sprain ever,* where absence of ankle injury = 0 and presence of ankle injury = 1. Finally, I stratified the *knee sprain ever* and *ankle sprain ever* variables by transforming the ICD-9 codes for each type of ankle and knee injury to create new variables to identify the presence or absence of specific type of knee and ankle injuries as follows: (a) *knee sprain LCL* ever where absence of an LCL injury = 0 and presence of an LCL injury = 1; (b) *knee sprain MCL ever* where absence of an MCL knee injury = 0 and presence of an MCL injury = 1; (c) *knee sprain cruciate ligament ever* where absence of a cruciate ligament injury = 0 and presence of a cruciate ligament injury = 1; (d) *knee sprain unspecified ever* where absence of a knee sprain unspecified ever = 0 and presence of a knee sprain unspecified = 1; (e) *ankle sprain unspecified* ever where absence of an ankle sprain unspecified ever = 0 and presence of an ankle sprain unspecified ever = 1; (f) *ankle sprain deltoid ligament ever* where absence of a deltoid ligament sprain = 0 and presence of a deltoid ligament sprain = 1; and (g) *ankle sprain tibiofibular ligament* where absence of a tibiofibular ligament sprain = 0 and presence of a tibiofibular ligament sprain = 1.

The sample (aggregated) dataset for this study consisted of concussion, ankle sprain, and knee sprain data from1613 high school athletes in the AT-PBRN. There were 1508 athletes with 1 injury, 95 athletes with 2 injuries and 10 athletes with 3 injuries.

Modifications in Data Collection

Valovich McLeod et al. (2012) reported ankle sprains, concussions, knee MCL sprains, and cruciate ligament sprains accounted for 17.9%, 12.0%, 2.1%, and 1.7% of the injuries, respectively, in the AT-PBRN database, which also captured other lower extremity, upper extremity, head, neck and back injuries. This description of the AT-PBRN database informed my selection of predictor and outcome variables, while the concussion, knee sprain and ankle sprain data I received from the AT-PBRN informed the modifications described below. Variations in my data collection plan are also summarized in Table 2.

Table 2

Variations in Data Collection

Preliminary data variables and codes	Final data variables and codes	Variable type
Data requested	Data received	
All available data	Concussion, knee, and ankle injury data	
Injury year	Injury year	
2009-2017	2009-2016	
Predictor variables	Predictor variables	
Age (years)	Age (years)	Continuous
14-19	11-19	
Age categories	Age categories	Nominal
14 = 1	11-13 = 1	
15 = 2	14-17 = 2	
16 = 3	18-19 = 3	
17 = 4		
18+= 5		
Gender	Gender	Nominal
Male = 0	Male = 1	
Female = 1	Female = 2	
Grade level	Not available	Ordinal
Ninth = 0		
Tenth = 1		
Eleventh = 2		
Twelfth = 3		

Comstock et al. (n.d.) revealed, among high school male athletes, 22.5%, 25.5%, 22.3% and 29.7% of interscholastic injuries occurred in ninth, tenth, eleventh, and twelfth graders respectively while among high school female athletes, 27.5%, 27.9%, 24.1%, and 20.6% of the injuries occurred in ninth, tenth, eleventh and twelfth graders respectively. The AT-PBRN database did not capture grade level data every year because this characteristic did not apply to every setting. Therefore, this variable was not available for analysis in this study. Golf data were not included in this dataset, but badminton cheerleading and ice hockey data were included. Therefore, I modified sport type coding that I had specified in chapter 3, as follows. I classified cheerleading and ice hockey as team sports and assigned codes 3 and 6 respectively. I did not retain golf as an individual sport since it was not included in this dataset, but I included badminton and assigned code 11 to that sport. The clean working data set also included “other” high school sports. I could not determine if this variable included team sports, individual sports, or a combination of both, so I assigned code 18 to the “other” sports category. As discussed previously, I retained 11-19 year old athletes, stratified the *age* variable, and created the *age group code* variable where (a) 11-13 years = 1; (b) 14-17 years = 2; and (c) 18-19 years = 3 in order to analyze the predictor variable, *age*, more completely.

For descriptive purposes, I stratified the *knee sprain ever* variable into types of knee injuries (LCL, MCL, cruciate ligament, and unspecified knee sprains) by transforming the respective *ICD-9 code* variable into the following variables: (a) *LCL ever* where no = 0 and b) yes = 1; (b) *MCL ever* where no = 0 and yes = 1; (c) *cruciate ligament ever* where no = 0 and yes = 1; and (d) unspecified knee sprain where a) no = 0 and b) yes = 1. I also transformed the *ankle sprain ever* variable into types of ankle injuries (unspecified, deltoid, and tibiofibular ligament sprains) by transforming the corresponding ICD-9 codes into: (a) *ankle sprain unspecified ever* where a) no = 0 and yes = 1; (b) *ankle sprain deltoid ligament ever* where a) no = 0 and b) yes = 1; and (c) *ankle sprain tibiofibular ligament ever* where no = 0 and b) yes = 1.

Descriptive and Demographic Characteristics of the Sample

There were 1613 valid observations and no missing data. The data set encompassed information from 1613 (100%) high school athletes. Analysis of the *gender* variable revealed 805 (49.9%) of the cases were males, and 808 (51%) of the cases were females. The measures of central tendency revealed the average (mean) *age* was 15.48 years, the central point (median) was 15 years and the most frequent *age* (mode) was 15 years. The measures of dispersion indicated the range was 11-19 years and the standard deviation (SD) was ±1.343 years for the scale characteristic (*age*). Analysis of the *age-group code* variable revealed 6.5% of the cases were between the ages of 11 and 13 years; the majority of the cases (88%) were between the ages of 14 and 17 years, and 5.3% of the cases were between 18 and 19 years of age.

Team sports (baseball, basketball, cheerleading, field hockey, football, lacrosse, soccer, softball, and volleyball) represented 84.3% of the sample. There were zero hockey injuries in this analysis. *Individual sports* (badminton, cross-country, gymnastics, swimming, tennis, track, and wrestling) represented 14.6% of this sample. Other sports represented 1.1% of this sample. The frequencies and distributions were also calculated for the following variables in this study. The *concussion ever* and *LEMI* variables represented 11.9% and 88.1% of the cases in the sample respectively. Descriptive analysis of the *number of concussions* and number of LEMI variables revealed 88% of the cases had no concussions, 11.7% had one concussion and 0.3% had 2 concussions, while 11% of the cases had no LEMIs, 83.3% of the cases had 1 LEMI, 5.1% of the cases had 2 LEMIs and 0.5% of the cases had 3 LEMIs. Further stratification of the LEMI variable revealed 82.7% of the cases had no knee sprains, 16.9% had 1 knee sprain and

0.4% had 2 knee sprains. The percentages of cases with 0, 1, 2, and 3 ankle sprains were 26.9%, 68.8%, 4.1%, and 0.2% respectively. The descriptive characteristics of the sample are summarized in Table 3.

Table 3

Characteristics of the Sample

Characteristics	Outcomes
	Mean (*SD*; range)
Age at injury (yr.)	15.48 (1.343; 11-19)
Age group (yr.)	% (*n/N*)
11-13	6.5 (105/1,613)
14-17	88.2 (1,423/1,613)
18-19	5.3 (85/1,613)
Gender	
Male	49.9 (805/1,613)
Female	50.1 (808/1,613)
Sport type	
Team sports	84.3 (1,360/1,613)
Baseball	1.8 (29/1,613)
Basketball	24.9 (410/1,613)
Cheerleading	3.3 (54/1,613)
Field hockey	0.3 (5/1,613)
Football	23.3 (375/1,613)
Hockey	0 (0/1,613)
Lacrosse	1.7 (27/1,613)
Soccer	13.8 (222/1,613)
Softball	3.2 (52/1,513)
Volleyball	14.6(194/1,613)
Individual sport	14.6 (235/1,613)
Badminton	1.0 (16/1,613)
Cross country	3.2 (52/1,613)
Gymnastics	0.2 (4/1,613)
Swimming	0.3 (5/1,613)
Tennis	0.8 (13/1,613)
Track	5.8 (93/1,613)
Wrestling	3.2 (52/1,613)
Other	1.1 (18/1,613)

(*table continues*)

Characteristics	Outcomes
Concussion	
Absent	88.1 (1421/1,613)
Present	11.9 (192/1,613)
LEMI	
Absent	11.0 (178/1,613)
Present	89.0 (1435/1,613)
Knee sprain	
Absent	82.7 (1,333/1,613)
Present	17.3 (280/1,613)
Ankle sprain	
Absent	26.9 (434/1,613)
Present	73.1 (1,179/1,613)
Knee sprain type	
LCL knee sprain	
Absent	98.3 (1,585/1,613)
Present	1.7 (28/1,613)
MCL knee sprain	
Absent	95.7 (1,544/1,613)
Present	4.3 (69/1,613)
Concussion frequency	
Zero	88 (1,420/1,613)
One	11.7 (189/1,613)
Two	0.3 (4/1,613)
Three	0 (0/1,613)
LEMI frequency	
Zero	11 (178/1,613)
One	83.3 (1,344/1,613)
Two	5.1 (83/1,613)
Three	0.5 (8/1,613)
Knee sprain frequency	
Zero	82.7 (1,334/1,613)
One	16.9 (273/1,613)
Two	0.4 (6/1,613)
Three	0.0 (0/1,613)

(*table continues*)

Characteristics	Outcomes
Ankle sprain frequency	
Zero	26.9 (434/1,613)
One	68.7 (1,109/1,613)
Two	4.1 (66/613)
Three	0.2% (4/1,613)
LCL sprain frequency	
Zero	98.2 (1,585/1,613)
One	1.8 (28/1,613)
Two	0
MCL sprain frequency	
Zero	95.7 (1,544/1,613)
One	4.3 (69/1,613)
Two	0
Cruciate ligament sprain	
Zero	92.7(1,495/1,613)
One	7.2 (116/1,613)
Two	0.1 (2/1,613)
Knee sprain unspecified	
Zero	96.8 (1,561/1,613)
One	3.0 (49/1,613)
Two	0.2 (3/1,613)
Ankle sprain unspecified	
Zero	45.4 (733/1,613)
One	51.4 (829/1,613)
Two or more	3.2 (51/1,613)
Deltoid ligament sprain	
Zero	97.6 (1,575/1,613)
One	2.2 (35/1,613)
Two or more	.0.2 (3/1,613)
Distal tibiofibular ligament sprain	
Zero	84.9 (1,369/1,613)
One	14.3 (230/1,613)
Two or more	0..8 (14/1,613)

Sample

About 7.8 million high school athletes participated in interscholastic sports in 2014-2015 (Comstock et al., n.d.). The sample in this study included (n = 1613) high school athletes (805 boys, and 808 girls) from several regions in the United States *(Figure 1).* Therefore, this sample represented about .0002% of U.S. high school athletes. Since the sample for this study was a small sample of convenience the results may only be may be generalizable to high school athletes in the regions of the U.S. that are included in this sample. When samples cannot be randomly selected, researchers should include participants from the group they intend to generalize to, and acknowledge their results may not be generalizable to other populations or environments (Ary et al., 2014).

Figure 2. Athletic training practice-based clinical practice sites. From "AT-PBRN Clinical Practice Sites," by Athletic Training Practice Based Research Network, 2017 (http://www.coreat.org/clinical-practice-sites.html). Copyright 2017 by A. T. Still University Athletic Training. Reprinted with permission.

Results

As previously explained, the secondary dataset examined in this study was obtained from adolescent male and female athletes who participated in interscholastic sports at AT-PBRN high schools in the U.S. This sample for this study contained concussion, knee sprain and ankle sprain data that were extracted from the larger AT-PBRN database, which included, head, neck, back, upper and lower extremity injuries. The statistics that describe this sample are reported above and summarized in Table 3.

Assumptions

Binomial logistic regression assumes the dependent variable is dichotomous (Field, 2009). Logistic regression also assumes: (a) linearity between each continuous independent variable and the logit of the dependent variable, and (b) independence of errors (Bewick, Cheek, & Ball, 2005; Field et al., 2009). Additionally, the independent variables should not be highly related to each other because this could lead to problems with estimation (Bewick, Cheek, & Ball, 2005; Field et al., 2009). To confirm the continuous independent variable, age, was linearly related to the logit (*LEMI*) I transformed the age variable into its natural log, completed the assessment with the Box-Tidwell procedure, and confirmed this assumption $p = .295$, ($p > .05$). The assumption of independence of errors requires each observation (case) to be independent. To ensure this assumption was met, I aggregated the data so each athlete was only represented once, as one data point, in the dataset. I also checked for multicollinearity (highly correlated independent variables) by reviewing the regression coefficients in the correlation matrices. I did not find any highly correlated predictor variables, so multicollinearity was not a problem in this dataset. Therefore, the assumptions of logistic regression were satisfied in this study.

Data Analysis Approach

The data were analyzed with SPSS software, version 23 (IBM Corp., 2015). For each research question, cross tabulation analyses were performed to determine if the dataset included all combinations of the variables. Binomial logistic regression analyses were also conducted to determine if the models, which included the independent variables afforded a better fit to the data than the null model for each research question. Wald statistics, odds ratios (OR), 95% confidence intervals (CI), and Cochran-Mandel-Haenszel tests were conducted.

Research Question 1

To answer my first research question, (Is there an association between SRC and LEMI among high school athletes?) I conducted a cross tabulation analysis with the *concussion-ever* and *LEMI ever* variables to determine if all possible combinations of *concussion ever* and *LEMI ever* existed. No cases were missing. However, the cell that contained the absence of concussion and absence of LEMI variables did not contain any cases because this data set only included SRCs, knee sprains, and ankle sprains. Therefore, every case in this data set had at least one of these injuries. The actual and expected case counts in this cell were zero and 156.8 respectively. The remaining cells in this cross tabulation contained more than ten actual and expected cases. Of all 1613 cases, the remaining cells revealed: (a) 178 cases had presence of concussion and zero LEMIs, 178/1613 = 11%; (b) 1421 cases had presence of LEMI and zero concussions, 1421/1613 = 88.1%; and (c) 14 had presence of SRC and LEMI 14/1613 = 0.9%. The *chi square* analysis revealed the *concussion ever* and *LEMI ever* variables were associated [$X^2 = 1480.796$, (1), $p = .000$ ($p < .05$)]. The post hoc Cramer's V (φ_c)

analysis revealed there was a strong association between the *concussion* ever *and LEMI ever* variables (φ_c = .958). However, ORs and 95% CIs could not be determined to demonstrate the odds or certainty of these findings. The results are depicted in Table 4.

Table 4

Chi-Square Analysis With Concussion Ever and Lower Extremity Musculoskeletal Injury Ever Variables

	LEMI ever	
	Absence of LEMI	Presence of LEMI
Concussion ever		
Absence of concussion		
Count	0	1,421
Expected count	156.8	1,264.2
% within concussion ever	0.0%	100%
Presence of concussion		
Count	178	14
Expected count	21.2	170.8
% within concussion ever	92.7%	7.3%

Note. Pearson chi-square = 1,480.796, degrees of freedom = 1, p-value = .000 ($p < .05$), Cramer's V = .958.

This cross tabulation analysis revealed one cell contained zero cases and clarified all combinations of data could not be examined. Therefore, incomplete information could cause the results from the statistical analyses to be misleading (Field, 2009; De Irala et al., 1997). Furthermore, I understood the standard errors (SE), coefficients, and other statistics calculated during the logistic regression analysis, to answer my first research question, might not be accurate.

In an effort to construct an accurate model, I conducted additional bivariate analyses to estimate the associations between each of the possible covariates, and the dependent variable *(LEMI)*. Categorizing a continuous variable, such as age, may reduce statistical power, so I analyzed the relationship between the covariate (age*)* and dependent variable (*LEMI).* This analysis showed there were zero cases of 11 year olds with absence of *LEMI*. Therefore, I converted the continuous variable (age) to a categorical variable (age group), and found no cells contained zeros when the relationship between the covariate (age group*)* and the dependent variable (*LEMI*) was tested. The *chi square analyses*, shown in Tables 5-8, indicated the possible covariates age *(p > .05),* age group *(p > .05*), gender *(p > .05),* and sport type *(p > .05)* were not associated with *LEMIs,* so these covariates were not included in the logistic regression analysis.

Table 5

Chi-Square Analysis With Age and Lower Extremity Musculoskeletal Injury Ever Variables

	LEMI ever	
	Absence of LEMI	Presence of LEMI
Age (years)		
11	0	6
% within age	0%	100%
12	3	6
% within age	33.3%	66.7%
13	8	82
% within age	9.9%	80.1%
14	38	248
% within age	13.3%	86.7%
15	54	369
% within age	12.8%	87.2%
16	41	355
% within age	10.4%	89.6%
17	29	289
% within age	9.1%	90.9%
18	5	77
% within age	6.1%	93.9%
19	0	3
% within age	0%	100%

Note. Pearson chi-square = 12.277, degrees of freedom = 8, *p*-value = .139 (*p* >.05), Cramer’s *V* = .087.

Table 6

Chi-Square Analysis With Age Group and Lower Extremity Musculoskeletal Injury Ever Variables

	LEMI ever	
	Absence of LEMI	Presence of LEMI
Age group (years)		
11-13	11	94
% within age group	10.5%	89.5%
14-17	162	1,261
% within age group	11.4%	88.6%
18-19	5	80
% within age group	5.9%	94.1%

Note. Pearson chi-square = 2.509, degrees of freedom (DF) = 2, *p*-value = .285 ($p > .05$), Cramer's $V = .039$.

Table 7

Chi-Square Analysis With Gender and Lower Extremity Musculoskeletal Injury Ever Variables

	LEMI ever	
	Absence of LEMI	Presence of LEMI
Gender		
Male	78	727
% within gender	9.7%	90.3%
Female	100	708
% within gender	12.4%	87.6%

Note. Pearson chi-square = 2.965, degrees of freedom (DF) = 1, *p*-value = .085 ($p > .05$), Cramer's $V = .043$.

Table 8

Chi-Square Analysis With Sport Type and Lower Extremity Musculoskeletal Injury Ever Variables

	LEMI ever	
	Absence of LEMI	Presence of LEMI
Sport type		
Team sports	157	1,203
% within sport type	11.5%	88.5%
Individual sports	20	215
% within sport type	8.5%	91.5%
Other sports	178	1,435
% within sport type	11.0%	89.0%

Note. Pearson chi-square = 2.435, degrees of freedom = 2, *p*-value = .296 ($p > .05$), Cramer's $V = .039$.

After determining the covariates were not associated with the dependent variable (*LEMI), I* conducted a binomial logistic regression analysis to examine the relationship between SRC and LEMI with only one independent variable (*concussion ever*). I intended to examine this relationship between these variables more completely than I could with the chi square statistic alone. However, the logistic regression model did not converge due to incomplete information in the dataset (zero cases in one cell). Therefore, the results were not valid, and were not reported in this study. I explain the reasons the model did not converge, in more detail, in the next chapter.

Chi square analysis revealed the relationship between SRC and LEMIs was significant, [$X^2 = 1480.796$, (1), $p = .000$ ($p < .05$), $\varphi_c = .958$] but this binomial logistic regression model did not converge so invalid results were generated. Therefore, I also conducted Cochran- Mandel-Haenszel (CMH) tests in another effort to understand the association between SRC and LEMI. The CMH test builds upon the chi square test by stratifying the data to control for other factors, which could produce misleading associations; and thus reduces the chance of deriving inaccurate conclusions in retrospective research (Mantel & Haenszel, 1959). The primary assumption for the CMH test is that the data represent the population specified for the study (Mantel & Haenszel, 1959). Although this assumption was met, CMH analysis of the association between the *concussion ever* and the *LEMI* variables did not yield any results for the tests of homogeneity of the odds ratio, or for the Mantel-Haenszel common odds ratio estimate due to incomplete information in the dataset (zero cases in one cell). Therefore the OR and 95% CI could not be calculated, so this test also failed. The reasons are explained, in more detail, in the next chapter.

Research Questions 1a and 1b

Because the dependent variable in this study, LEMI, was defined as a knee sprain (delineated by one of the following ICD-9 codes: 844.0, 844.1, 844.2, or 844.9), or as an ankle sprain (delineated by one of the following ICD-9 codes: 845.00, 845.01, or 845.03), I examined each variable (*knee sprain ever, and ankle sprain ever*) independently, in an effort to reduce the presence of zeros in cells, and understand the relationship between SRC and LEMI more clearly. Therefore, I sought answers to the following questions:

1a: Is there an association between SRC and knee sprains among high school athletes?

H_{01a}: There is not an association between SRC and knee sprains among high school athletes controlling for gender, age, and sport.

H_{A1a}: There is an association between SRC and knee sprains among high school athletes controlling for gender, age, and sport.

1b: Is there an association between SRC and ankle sprains among high school athletes?

H_{01b}: There is not an association between SRC and ankle sprains among high school athletes controlling for gender, age, and sport.

H_{A1b}: There is an association between SRC and ankle sprains among high school athletes controlling for gender, age, and sport.

Prior to conducting logistic regression analysis to determine if there was an association between SRC and knee sprains while controlling for gender, age, and sport, I examined the cross tabulations for the *concussion-ever* and *knee sprain-ever* variables and found the *concussion-ever* and *knee sprain ever* cells contained a least one case and five expected cases. Of all 1613 cases: (a) 71% had zero concussions and zero knee sprains; 1145/1613 =71%; (b) 17.1% had zero concussions and presence of a knee sprain, 276/1613 = 17.1%; (c) 11.7% had presence of concussion and zero knee sprains 188/1613 = 11.7%; and (d) 0.2% had presence of concussion and presence of knee sprain 4/1613 = 0.24%. The chi square analysis revealed the *concussion ever* and *knee sprain* variables were associated, and the post hoc Cramer's *V* analysis showed the strength of the association between these variables was very weak [$X^{2\,=}$ 35.450, (1) p = .000, ($p <$ .05) φ_c = .148]; but ORs and 95% CIs could not be determined to demonstrate the odds, or certainty, of these findings. Therefore, a definitive relationship could not be established. The results of the analysis are presented in Table 9.

Table 9

Chi-Square Analysis With Concussion Ever and Knee Sprain Ever Variables

	Knee sprain ever	
	Absence of knee sprain	Presence of knee sprain
Concussion ever		
Absence of concussion		
Count	1145	276
Expected count	1174.3	246.7
% within concussion ever	80.6%	19.4%
Presence of concussion		
Count	188	4
Expected count	158.7	33.3
% within concussion ever	97.9%	2.1%

Note. Pearson chi-square = 35.450, degrees of freedom (DF) = 1, *p*-value = .000, Cramer's *V* = .148.

In an effort to construct an accurate model, I conducted additional bivariate analyses to estimate the associations between each of the possible covariates *age*, *age group*, *gender* and *sport type* and the dependent variable *knee sprains*. The chi square analyses, as shown in Tables 10-13, revealed only the *age group* [p = .021 (p < .05)] and *gender* variables [p = .045 (p < .05)] were significant. Therefore, only the *age group* and *gender* covariates were included with the independent variable *concussion ever* in this model.

Table 10

Chi-Square Analysis With Age and Knee Sprain Ever Variables

	Knee sprain ever	
	Absence of knee sprain	Presence of knee sprain
Age (years)		
11	6	0
% within age	100%	0%
12	9	0
% within age	100%	0%
13	79	11
% within age	87.8%	12.2%
14	237	49
% within age	82.9%	17.1%
15	355	68
% within age	83.9%	16.1%
16	321	75
% within age	81.1%	18.9%
17	263	55
% within Age	82.7%	17.3%
18	60	22
% within age	73.2%	26.8%
19	3	0
% within age	100%	0%

Note. Pearson chi-square = 11.749, degrees of freedom = 8, p-value = .163 ($p > .05$), Cramer's $V = .085$.

Table 11

Chi-Square Analysis With Age Group and Knee Sprain Ever Variables

	Knee sprain ever	
	Absence of knee sprain	Presence of knee sprain
Age group (years)		
11-13	94	11
% within age group	89.5%	10.5%
14-17	1176	247
% within age group	82.6%	17.4%
18-19	63	22
% within age group	74.1%	25.9%

Note. Pearson chi-square = 7.772, degrees of freedom (DF) = 2, p-value = .021, ($p < .05$), Cramer's V= .069.

Table 12

Chi-Square Analysis With Gender and Knee Sprain Ever Variables

	Knee sprain ever	
	Absence of knee sprain	Presence of knee sprain
Gender		
Male	650	155
% within gender	80.7%	19.3%
Female	683	125
% within gender	84.5%	15.5%

Note. Pearson chi-square = 4.026, degrees of freedom (DF) = 1, p-value = .045 ($p < .05$), Cramer's V = .050.

Table 13

Chi-Square Analysis With Sport Type and Knee Sprain Ever Variables

	Knee sprain ever	
	Absence of knee sprain	Presence of knee sprain
Sport type		
Team sports	1,119	241
% within sport type	82.3%	17.7%
Individual sports	198	37
% within sport type	84.3%	15.7%%
Other sports	16	2
% within sport type	88.9%	11.1%

Note. Pearson chi-square = 1.041, degrees of freedom = 2, *p*-value = .594 ($p > .05$), Cramer's *V* = .148.

Next, I conducted a binomial logistic regression analysis to examine the relationship between SRC and knee sprains while controlling for age group and gender. The outcome variable was knee sprains. The potential predictor variables were age group, gender, and concussion ever. For each categorical predictor variable, I coded the first predictor (age group 11-13 years, male, and absence of concussion) as the comparison groups. The case processing summary showed no cases were missing. The classification table in block 0 of this model revealed 82.6% of the cases were classified correctly. The test of the null hypothesis revealed the unstandardized Beta weight for the constant B = -1.560, SE = .066, Wald = 563.410, ($p < .05$), Exp (B) = .210. The *age-group* (14-17 yr.) p = .997 ($p > .05$) variable was not predicted to contribute to the block 1 model. The *age group* (11 – 13 yr.) *p = .021* ($p < .05$), *age group* (18 – 19 yr.) *p* = .033, ($p < .05$), *gender*, p = .045 ($p < .05$), and *concussion- ever p = .000* ($p < .05$) variables were predicted to contribute to the block 1 model. Of the variables not in the equation, if only the *age group* (11-13 yr.) p = .021 ($p < .05$), *age group* (18 – 19 yr.*)* p = .033, gender, $p = .045$ ($p < .05$), or *concussion ever* $p = .000$ ($p < .05$) variable was added in the next step, this block predicted each of these variables, alone, would contribute to the new model.

The block 1 analysis included the *age group*, *gender* and *concussion-ever* variables. To clarify the findings, the full report follows. The iteration history stabilized at iteration 7. The Omnibus tests of model coefficients indicated addition of the independent variables significantly improved the accuracy of this model compared to the baseline model as there was a significant difference $p = .000$ ($p <.05$) between the -2 log likelihood ratios in block 0 (1488.904) and block 1 (1428.543). The Nagelkerke *R Square* (.061) indicated 61% of the variance in the model was explained by the independent variables. The Hosmer and Lemeshow goodness of fit test showed the model fit the data, as this test was not significant $p = .893$ ($p > .05$). The classification table revealed the overall percentage of correct predictions was the same as the block 0 predictions for knee sprain (82.6%). The variables in the equation *age group* (14-17 yr.) $p = .081$ ($p > .05$), and *gender* (female) $p = .152$ ($p > .05$) did not contribute to the model. However, the *age group* (11-13 yr.) $p = .044$ ($p < .05$) (reference group), *age group* (18-19 yr.) $p = .013$ ($p > .05$), and *concussion ever* $p = .000$ ($p < .05$) variables did contribute to this model. The unstandardized Beta weight for the predictor variable *age group* (18-19) B = -1.016, SE = .409, Wald = 6.163, $p < .05$ [Exp (B) 2.761, 95% CI (1.238-6.156)]. The unstandardized Beta weight for the predictor variable *concussion ever;* B = (-2.409), SE =.510, Wald = 22.318, $p < .05$, [Exp (B) = .090, 95% CI (.033, .244)].

In summary, a binomial logistic regression analysis was performed to determine if SRC and knee sprain were related in high school athletes while controlling for the effects of *age group*, and *gender*. The iteration history revealed the model stabilized at the seventh iteration, and the logistic regression model was significant [$X^2 = 60.361$ (4) $p =$ .000]. The Hosmer and Lemeshow goodness of fit test was not significant p = .893 ($p >$ .05) which indicated the model appeared to fit the data. The model revealed the independent variables *age group* (14-17 years), and *gender* did not contribute to the model. However, the age group (11-13 years) (reference group), age group (18-19 years) and *concussion ever* variables, did contribute to the new model ($p < .05$). Therefore, in this logistic regression analysis, while controlling for age group, and gender, the predictor variables *age group* (11-13 years) (reference group), *age group* (18-19 years) and *concussion ever* were determined to contribute to the model. The unstandardized Beta weight for the predictor variable *age group* (18-19) B = 1.016, SE = .409, Wald = 6.163, $p < .05$. The estimated OR favored an increase of nearly 176% [Exp (B) 2.761, 95% CI (1.238, 6.156)] for knee sprain every one unit increase of the age group (18-19 years). The unstandardized Beta weight for the predictor variable *concussion ever;* B = (-2.409), SE =.510, Wald = 22.318, $p < .05$, favored a decrease of 10% [Exp (B) = .090, 95% CI (.033, .244)] for a *knee sprain* every one unit increase of *concussion ever*.

This binomial logistic regression model revealed *concussion ever* and *knee injury* variables were related. However, these results may be misleading and inaccurate. Although the Hosmer Lemeshow goodness of fit test suggested the model appeared to fit the data well ($p > .05$), the sample size was small (four cases in one cell). Therefore, instead of the high *p*-value (.893) actually demonstrating the model fit the data well; it is feasible the high p-value could have resulted from the small sample size reducing the power of Hosmer-Lemeshow test to, correctly, identify the model's poor fit to the data (Chao-Ying et al., 2002; de Irala et al., 1997; Hosmer et al., 1991). Therefore, the null hypothesis (H_{O1a}) was not rejected. The results of the block 1 analysis of *concussion ever* and *knee sprain ever* variables are summarized in Table 14.

Table 14

Binomial Logistic Regression Analysis of the Concussion Ever and Knee Variables

Variable category	*B*	*SE*	Wald	*df*	Sig	Exp (B)	95% CI Lower	95% CI Upper
Age group (11-13 yr.)			6.230	2	.044			
Age group (14-17 yr.)	.574	.329	3.047	1	.081	1.776	.932	3.385
Age group (18-19 yr.)	1.016	.409	6.163	1	.013	2.761	1.238	6.156
Gender (female)	.193	.135	2.049	1	.152	.825	.634	1.074
Concussion ever	-2.409	.510	22.318	1	.000	.090	.033	.243
Constant	-1.903	.331	33.021	1	.000	.149		

Note. *B* = coefficient, *SE* = standard error, Exp (B) = odds ratio, CI = confidence interval.

Next, I examined the relationship between concussion ever and ankle sprain ever with chi square analyses. Cross tabulation calculations of the *concussion-ever* and *ankle sprain ever* variables revealed all cells contained at least ten actual and expected cases. Of all 1613 cases: (a) 15.8% had no concussion and no ankle sprain 256/1613 =15.8%; (b) 72.2% had no concussion but had an ankle sprain 1165/1613 = 72.2%; (c) 11% had a concussion but no ankle sprain 178/1613 = 11%; and (d) 14 had a concussion and ankle sprain 14/1613 = 0.86%. The chi square analysis for the *concussion ever* and *ankle sprain ever* variables revealed these variables were associated, and the post hoc Cramer's V analysis showed a moderate association between these variables [$X^2 =$ 479.826, (1) $p =$ .000, ($p < .05$), $\varphi_c = .545$, but the ORs and 95% CIs could not be determined to demonstrate the odds or certainty of these findings. The reasons are discussed in the next chapter. The results are presented in Table 15.

Table 15

Cross Tabulation With Concussion Ever and Ankle Sprain Ever Variables

	Ankle sprain ever	
	Absence of ankle sprain	Presence of ankle sprain
Concussion ever		
Absence of concussion		
Count	256	1165
Expected count	382.3	1038.7
% within concussion	18.0%	82.0%
Presence of concussion		
Count	178	14
Expected count	51.7	140.3
% within concussion	92.7%	7.3%

Note. Pearson chi-square = 479.826, degrees of freedom = 1, *p*-value = .000 ($p < .05$), Cramer's $V = -545$.

I attempted to create an accurate model, by conducting additional bivariate analyses to estimate the associations between each of the possible covariates (age, age group, gender, and sport type) and the dependent variable (ankle sprains). The chi square analyses, shown in Tables 16- 19, revealed the covariates *age (p > .05) age group (p >*

.05), gender (p > .05), and sport type (p > .05) were not associated with *ankle sprains* so none of these covariates were included in the binomial logistic regression analysis.

Table 16

Cross Tabulation With the Age and Ankle Sprain Ever Variables

	Ankle sprain ever	
	Absence of ankle sprain	Presence of ankle sprain
Age (years)		
11	0	6
% within age	0%	100%
12	3	6
% within age	33.3%	66.7%
13	18	72
% within age	20.0%	80.0%
14	82	204
% within age	28.3%	71.7%
15	111	312
% within age	26.2%	73.8%
16	112	284
% within age	28.3%	71.7%
17	81	237
% within age	25.5%	74.5%
18	27	55
% within age	32.9%	67.1%
19	0	3
% within age	0%	100%

Note. Pearson chi-square = 8.459, degrees of freedom = 8, *p*-value = .390 (p >.05), Cramer's V = .390.

Table 17

Cross Tabulation With Age Group and Ankle Sprain Ever Variables

	Ankle sprain ever	
	Absence of ankle sprain	Presence of ankle sprain
Age group (years)		
11-13	21	84
% within age group	20.0%	80.0%
14-17	386	1,037
% within age group	27.1%	72.9%
18-19	27	58
% within age group	31.8%	68.2%

Note. Pearson chi-square = 3.602, degrees of freedom (DF) = 2, *p*-value = .165 ($p > .05$), Cramer's *V* = .047.

Table 18

Cross Tabulation With Gender and Ankle Sprain Ever Variables

	Ankle sprain ever	
	Absence of ankle sprain	Presence of ankle sprain
Gender		
Male	222	583
% within gender	27.6%	72.4%
Female	212	596
% within gender	26.2%	73.8%

Note. Pearson chi-square = .368, degrees of freedom (DF) = 1, *p*-value = .544 ($p > .05$), Cramer's *V* = .015.

Table 19

Cross Tabulation With the Sport Type and Ankle Sprain Ever Variables

	Ankle sprain ever	
	Absence of ankle sprain	Presence of ankle sprain
Sport type		
Team sports	380	980
% within sport type	27.9%	72.1%
Individual sports	51	184
% within sport type	21.7%	78.3%%
Other sports	3	15
% within sport type	16.7%	83.3%

Note. Pearson chi-square = 4.936, degrees of freedom = 2, p-value = .085 ($p > .05$), Cramer's $V = .055$.

The chi square analyses of the covariates *age, age group*, *gender,* and *sport type* indicated these independent variables ($p > .05$) were not associated with the outcome variable (*ankle sprains*); so this binomial logistic regression analysis which examined the relationship between SRC and *ankle sprains* only included one independent variable (*concussion ever*). Since the chi square analysis shown in Table 15 revealed the *concussion ever* and *ankle sprain* variables were associated [$X^2 = 4.936$, (1), $p = .000$ ($p < .05$), $\varphi_c = .545$], it would be reasonable to expect this binomial logistic regression analysis, to yield the same results if the model was stable. The case processing summary showed no cases were missing. The classification table in block 0 of this model revealed 73.1% of the cases were classified correctly. The test of the null hypothesis revealed the unstandardized Beta weight for the constant; B = .999, SE = .056, Wald = 316.831, $p < .05$, Exp (B) = 2.717. If the variable not in the equation (*concussion ever*) was added in the next step, the *concussion ever* variable $p = .000$ ($p < .05$) was predicted to contribute to the new model.

The block 1 analysis tested the contribution of the *concussion ever* variable. The iteration history stabilized at the fifth iteration. The omnibus tests of model coefficients indicated addition of the independent variable changed the accuracy of the model from 73.1% in the baseline model to 34.6% in the block 1 model. There was a significant difference $p = .000$ ($p <.05$) between the -2 log likelihood ratios in block 0 (1878.582) and block 1 (1440.637). The Nagelkerke *R* Square (.346) indicated about 35% of the variance in the model was explained by the independent variable. The Hosmer and Lemeshow goodness of fit test revealed chi square = .000, with 0 degrees of freedom so the p-value could not be calculated. Therefore, it was not clear if the data fit the model. The classification table revealed the overall percentage of correct predictions increased from 73.1% in block 0 predictions for ankle sprain to 83.3% in block 1. The variables in the equation revealed the independent variable *concussion ever* $p = .000$ ($p < .05$), did contribute to the model. The unstandardized Beta weight for the predictor variable *concussion ever*; B = (-4.058), SE =.286, Wald = 201.288, $p < .05$. The estimated odds ratio favored a decrease of nearly 100% [Exp (B) .017, 95% CI (.010, .030)] for *ankle sprains* for every one-unit increase of *concussion ever*.

In summary, a binomial logistic regression analysis was performed to determine if SRC and ankle sprains were related in high school athletes. The iteration history revealed the model stabilized at the fifth iteration, and the logistic regression model was significant [$X^2 = 437.945$ (1) $p = .000$]. Since the *p*-vale in the Hosmer and Lemeshow goodness of fit test could not be determined, it was not obvious if the model fit the data well. The -2 log likelihood (1440.637) differed significantly from the baseline -2 log likelihood (1878.582) and the Nagelkerke *R* Square (346) showed only 34.6% of the variance in the model was explained by the independent variable. The model revealed the *concussion ever* variable was significant ($p < .05$). The unstandardized Beta weight for the predictor variable *concussion* ever: B = (-4.058), SE =.286, Wald = 201.288, $p < .05$. The estimated OR favored a decrease of nearly 100% [Exp (B) = 017 95% CI (.010, .030)], for ankle sprains every one unit increase of *concussion-ever*.

This binomial logistic regression analysis revealed concussion ever and ankle sprain were related [$p = .000$ ($p < .05$)]. The unstandardized Beta weight for the predictor variable *concussion* ever: B = (-4.058), SE =.286, Wald = 201.288, p < .05. The estimated OR favored a decrease of nearly 100% [Exp (B) = 017 95% CI (.010, .030)], for ankle sprains every one unit increase of *concussion-ever*.

Although the results of the logistic regression analysis were consistent with the chi square analysis shown in Table 15 [$X^2 = 479.826$ (1), $p < .05$, $\varphi_c = .545$], the validity of the model was questionable because the Hosmer and Lemeshow goodness of fit test in block one revealed chi square = .000, with 0 degrees of freedom so the p-value could not be calculated. Therefore, this analysis did not clarify if the model fit the data well (Chao-Ying, 2002; de Irala et al., 1997; Hosmer et al., 1991). Consequently, these results could be inaccurate and misleading, so the null hypothesis was not rejected. The results of the logistic regression analysis of *concussion ever* and *ankle sprain ever* variables are summarized in Table 20.

Table 20

Binomial Logistic Regression Analysis of Concussion Ever and Ankle Sprain Variables

Variable category	*B*	*SE*	Wald	*df*	Sig	Exp (B)	95% CI Lower	95% CI Upper
Concussion ever	-4.058	.286	201.288	1	.000	.017	.010	.030
Constant	1.515	.069	481.913	1	.000	4.511		

Note. *B* = coefficient, *SE* = standard error, Exp (B) = odds ratio, CI = confidence interval.

Research Question 2

To answer my second research question, (Is the number of SRCs associated with LEMI among high school athletes?) I conducted cross tabulation analysis followed by logistic regression analysis to examine the association between the number of concussions and lower extremity sprains. Cross tabulation of all 1613 cases with the *number of concussions* and *LEMI ever* variables showed: (a) 0% had zero concussions and absence of LEMI; (b) 88% had zero concussions and presence of LEMI 1420/1613 = 88%; (c) 10.8% had one concussion and absence of LEMI 175/1613 = 10.8%, (d) 0.9% had one concussion and presence of LEMI 14/1613 = 0.9%; (e) 0.2% had two concussions and absence of LEMI 3/1316 = 0.2%; and (f) 0.1% had two concussions and presence of LEMI. This cross tabulation analysis between the *number of concussions* and LEMI variables revealed these variables were associated [X^2 = 1473.222 (1) p = .000, (p < .05)]. The post hoc Cramer's *V* analysis revealed there was a very strong association between the *concussion* ever and LEMI variables (φ_c = .956). However, the ORs and 95% CIs could not be determined to demonstrate the odds or certainty of these findings. The results of this cross tabulation analysis are presented in Table 21. These results were problematic because one cell (zero concussions, absence of LEMI) contained zero cases and two other cells (two concussions with absence of LEMI, and two concussions with presence of LEMI) contained less than the expected count of five cases. Since 50% of the cells in this cross tabulation had incomplete information, (zero actual cases or less than five expected cases) statistical calculations with this data could be inaccurate, and misleading. Therefore, I anticipated problems might arise with the binomial logistic regression analysis of these variables.

Table 21

Cross Tabulation With Number of Concussions and Lower Extremity Musculoskeletal Injury Ever Variables

	LEMI ever	
	Absence of LEMI	Presence of LEMI
Number of concussions		
Zero concussions		
Count	0	1,420
Expected count		1,263.3
% within number of concussions	0.0%	100%
One concussion		
Count	175	14
Expected count	20.9	168.1
% within number of concussions	92.6%	7.4%
Two concussions		
Count	3	1
Expected count	0.4	3.6
% within number of concussions	75.0%	25.0%

Note. Pearson chi-square = 1473.222, degrees of freedom = 1, p-value = .000, Cramer's V = .956.

With this understanding, I conducted a binomial logistic regression analysis to examine the relationship between the *number of concussions* and the *LEMI* variables. Since the potential predictor variables *age*, *gender* and *sport type* were previously found not to be related to the outcome variable (LEMI), these covariates were not included in this model. As shown in Table 21, the logistic regression model did not converge due to incomplete information (zero cases in one cell). Therefore, the results were not valid, and were not reported in this study. The reasons the model did not converge are explained in more detail in Chapter 5.

Chi square analysis revealed significant relationships between the number of concussions (zero, one, or two) and LEMIs, [X^2 =1473.222, (1), p = .000 ($p < .05$), φ_c = .956] but this binomial logistic regression model did not converge so it generated invalid results. Therefore, I also conducted CMH tests in another effort to determine the association between the *number of concussions (one or two)* and *LEMI ever*. However, CMH analysis of the association between these variables did not yield any results for the tests of homogeneity of the odds ratio, or for the Mantel-Haenszel common odds ratio estimate due to incomplete information (low cell counts, and absence of covariates since no covariates were found to be associated with the dependent variable). Therefore, the OR and 95% CI could not be calculated. This test also failed, so the results were not reported.

Research Question 3

Prior to conducting logistic regression analysis to determine if there was an association between the number of concussions and knee sprains among high school athletes, I examined the cross tabulations for the *number of concussions* and *knee sprain ever* variables and found one cell (two concussions, absence of knee injuries) contained only four cases and one cell (two concussions and presence of knee injury) contained zero cases. Of all 1613 cases: (a) 71% had no concussions and no knee sprains, 11454/1613 =71%; (b) 17.1% had no concussion and presence of knee sprain, 276/1613

= 17.1%; (c) 11.5% had one concussion and zero knee sprains 185/1613 = 11.5%; and (d) four had one concussion and presence of a knee sprain 4/1613 = 0.02%; (e) 0.2% had two concussions and zero knee injuries 4/1613 = 0.2%; and (f) 0% had two concussions and presence of a knee injury. This cross tabulation with *number of* concussions and *LEMI ever* variables revealed these variables were associated as [X^2 = 35.723(2) p = .000, p < .05). The Cramer's V analysis revealed the association between these variables was very weak (φ_c = .149). Odds ratios and 95% Cis could not be calculated due to zero cases in some cells. The cross tabulation results are summarized in Table 22. Because 50% of the cells in the cross tabulation had less than five cases, I anticipated problems with the logistic regression analysis too.

Table 22

Cross Tabulation With Number of Concussions and Knee Sprain Ever Variables

	Knee sprain ever	
	Absence of knee sprain	Presence of knee sprain
Number of concussions		
Zero concussions		
Count	1,144	276
Expected count	1,173.5	246.5
% within number of concussions	80.6%	19.4%
One concussion		
Count	185	4
Expected count	156.2	32.8
% within number of concussions	97.9%	2.1%
Two concussions		
Count	4	0
Expected count	3.3	0.7
% within number of concussions	100%	0%

Note. Pearson chi-square = 35.723, degrees of freedom = 2, p-value = .000, Cramer's V = .149.

Previous bivariate analyses to estimate the associations between each of the possible covariates *age*, *age group*, *gender* and *sport type* and the dependent variable *knee sprains*, revealed only the *age group* p = .021 ($p < .05$) and *gender* variables $p = .045$ ($p < .05$) were significant (Tables 12-15); thus, only the *age group* and *gender* covariates were included with the independent variable *number of concussions* in logistic regression analysis that follows. Therefore, I conducted a binomial logistic regression analysis to examine the relationship between the number of SRCs and knee sprains while controlling for age group and gender. The outcome variable in this analysis was knee sprains. The potential predictor variables included *age group*, gender and *number of concussions*. For each categorical predictor variable, I coded the first category (age group (11-13) years, male, and zero concussions) as the control category.

Chi square testing revealed significant relationships between the number of concussions and LEMIs [$X^2 = 35.723(2)$ $p = .000$, $p < .05$, $\varphi_c = .149$), but ORs and 95% CIs could not be calculated. Additionally, this binomial logistic regression model did not converge so it generated invalid results, which were not reported. Therefore, I also conducted CMH tests with the covariates age group and gender an effort to determine the association between the number of concussions (one or two) and knee sprains. Because there were zero cases in the cell with two concussions and zero knee sprains, CMH analysis of this relationship did not yield any results for the tests of homogeneity of the odds ratio, or for the Mantel-Haenszel common odds ratio estimate, so these results were not reported.

Research Question 4

Before I conducted the binomial logistic regression analysis to answer my final research question: (Is the number of SRCs, associated with ankle injury?), I constructed and examined the cross tabulations for the *number of concussion cases* and *ankle sprain-ever* variables and found all cells contained at least one case, but two cells (two concussions and absence of ankle sprain, as well as the cell with two concussions and presence of ankle sprain) contained less than five expected cases. Of all 1613 cases: (a) 15.9 % had absence of concussions and absence of ankle sprains, 256/1613 = 15.9%; (b) 72.2% had absence of concussion and presence of an ankle sprain, 1164/1613 = 17.1%; (c) 10.8% had one concussion and absence of ankle sprain/1613 = 11.5%; and (d) 0.9% had presence of a concussion and presence of a knee sprain 14/1613 = 0.9%; (e) 0.2% had two concussions and absence of ankle injuries 3/1613 = 0.2%; and (f) 0.1% had two concussions and presence of an ankle injury. This cross tabulation analysis with *number of concussions* and *ankle sprains* revealed these variables were associated, and the post hoc Cramer's V analysis revealed there was a moderate association between these variables [X^2 = 476.260 (2), p = .000 (p = < .05), φ_c. = .543. ORs and 95% CIs could not be calculated due to low cell counts. The results are depicted in Table 23. Since more than 20% of the cells did not contain at least five actual and five expected cases, I anticipated the results of the logistic regression analyses could be misleading.

Table 23

Cross Tabulation With Number of Concussions and Ankle Sprain Ever Variables

	Ankle sprain ever	
	Absence of ankle sprain	Presence of ankle sprain
Number of concussions		
Zero concussions		
Count	256	1,164
Expected count	382.1	1037.9
% within number of concussions	18.0%	82.0%
One concussion		
Count	175	14
Expected count	50.9	138.1
% within number of concussions	92.6%	7.4%
Two concussions		
Count	3	1
Expected count	1.1	2.9
% within number of concussions	75%	25%

Note. Pearson chi-square = 476.260, degrees of freedom = 2, *p*-value = .000, Kramer's *V* = .543.

Tables 16-19 show the results of the bivariate analyses to estimate the associations between each of the possible covariates *age*, *age group*, *gender* and *sport type* and the dependent variable *ankle sprains*. The findings revealed none of the covariates were related to the *ankle sprain* variable ($p > .05$). Therefore, these covariates were not included in the logistic regression analysis that follows.

I conducted a binomial logistic regression analysis to examine the relationship between the *number of concussions* and *ankle sprains* without any covariates, as they were not significant. The outcome variable was ankle sprain. The case processing summary showed no data were missing. The classification table in Block 0 of this model revealed 73.1% of the cases were classified correctly. The test of the null hypothesis revealed the unstandardized Beta weight for the constant; B = .999, SE = .056, Wald =

316.831, $p < .05$, Exp (B) = 2.717. Of the variables not in the equation, if any one of the variables [*number of concussions* (zero) p = .000 ($p < .05$), *number of concussions* (one) p = .000 (p < .05), or *number of concussions* (two) $p = .030$ ($p < .05$) were added alone in the next step, this block predicted each of the *number of concussion* variables would contribute to the next model.

Block 1 included all of the variables identified above. This logistic regression analysis revealed the iteration history was stabilized at the fifth iteration. The omnibus tests of model coefficients indicated addition of the covariates significantly changed the accuracy of the model when compared to the baseline model as there was a significant difference p = .000 (p <. 05) between the -2 log likelihood ratios in block 0, (1878.582) and block 1 (1444.280). The Nagelkerke R Square (.343) revealed this model could explain about 34% of the variance in outcome. The Hosmer and Lemeshow test $p = .343$ (p, >.05) showed the model was a good fit to the data, as the results of this test were not significant. The classification table revealed an improvement over the previous model as 83.2% of the cases were identified correctly in this model versus 73.1% in the previous model. The variables in the equation [*number of concussions* (*one*) p = .000 ($p < .05$) and number of concussions (*two*) $p = .024$ (p < .05)] contributed to this model. The unstandardized Beta weight for the predictor variable *number of concussions (one)* B = -4.040, SE =.286, Wald = 199.284, $p < .05$. The estimated odds ratio favored a decrease of nearly 100% [Exp (B) = .018, 95% CI (.010, .031)] for ankle sprains every one unit of increase in number of concussions (*one*). Additionally, the *number of concussions* (*two*) variable contributed to this model. The unstandardized Beta weight for the predictor variable *number of concussions* (*two*) B = -2.613, SE = 1.157, Wald = 5.103, $p < .05$.

The estimated odds ratio favored a decrease of nearly 100% [Exp (B) = .073, 95% CI (.008, .708)] for ankle sprains every one unit increase of number of concussions (*two*).

In summary, a binomial logistic regression analysis was performed to determine if the number of SRCs and ankle sprains are related among high school athletes. The iteration history revealed the model stabilized at the fifth iteration, and the logistic regression model was significant [X^2 = 434.302 (2) *p* = .000]. The Hosmer and Lemeshow goodness of fit test was not significant p = 1.000 (*p* >.05) which indicated the model appeared to fit the data. However this test requires a sufficient sample size, and two of the cells in the 2 x 2 contingency table had less than five actual and expected counts. The -2 log likelihood, 1444.280, differed significantly from the baseline -2 log likelihood and the Nagelkerke R Square (.343) showed about 34% of the variance in the model was explained by the independent variables. The model revealed the *number of concussions* (*one*) *p* = .000 (*p* < .05) and number of concussions (*two*) contributed to this model. The unstandardized Beta weight for the predictor variable *number of concussions* (*one*) B = -4.040, SE =.286, Wald = 199.284, *p* < .05. The estimated odds ratio favored a decrease of nearly 100% [Exp (B) = .018, 95% CI (.010 – .031)] every one unit of increase in number of concussions (one) for ankle sprains. Additionally, the *number of concussions* (*two*) variable contributed to this model. The unstandardized Beta weight for the predictor variable *concussion* ever: B = -2.613, SE = 1.157, Wald = 5.103, *p* < .05. The estimated odds ratio favored a decrease of nearly 100% [Exp (B) = .073, 95% CI (.008, .708)] for ankle sprains every one unit increase of number of concussions (*two*).

These results may be misleading and inaccurate because the 2 x 3 contingency that contained the *number of concussions* (*two*) and *ankle sprain* variables revealed 2 cells contained less than 5 actual and expected cases. These conditions could reduce the accuracy of the statistical calculations, because the Hosmer-Lemeshow test requires the expected frequency to be greater than 5 in 95% of cells, and this model only had more than 5 expected cases in 66% of the cells (Chao-Ying, et al., 2002; Hosmer & Lemeshow, 2000; Hosmer, Taber, & Lemeshow, 1991). Although the Hosmer Lemeshow goodness of fit test revealed the model appeared to fit the data well ($p > .05$), it is feasible the non-significant *p*-value could be the result of the Hosmer-Lemeshow test having less power to correctly identify a poor fit instead of truly demonstrating a good fit (Chao-Ying, et al., 2002). Therefore, the null hypothesis was not rejected. The results of this logistic regression analysis are summarized in Table 24.

Table 24

Binomial Logistic Regression Analysis of the Number of Sport-Related Concussions and Ankle Sprain Ever Variables

Variable category	*B*	*SE*	Wald	*df*	Sig	Exp (B)	Lower	Upper
0 concussion cases			203.511	2	.000			
1 concussion case	-4.040	.286	199.284	1	.000	.018	.010	.031
2 concussion cases	-2.613	1.157	5.103	1	.024	.073	.008	.708
Constant	1.514	.069	481.292	1	.000	4.547		

Note. *B* = coefficient, *SE* = standard error, Exp (B) = odds ratio, CI = confidence interval.

Summary and Transition

The research questions and hypotheses were presented at the beginning of this chapter. Then the processes for data collection, reduction, transformation, aggregation, and logistic regression analysis were explained. The assumptions of logistic regression were tested and logistic regression analyses were conducted to test the hypotheses for each research question. Descriptive statistics of the sample and the results of the logistic regression, and CMH analyses were reported. The problems with the analyses were also identified.

A secondary set of de-identified high school athletic injury data, from the AT-PBRN, was analyzed to examine the association between SRC and LEMI (knee sprains and ankle sprains). The initial dataset contained 2, 590 cases from high school, college and other settings, and athletes with multiple injuries had multiple cases. Therefore, the data were reduced, cleaned and aggregated to ensure the sample only contained high school athletes, and that each athlete was only represented once in the data set. The sample for this study included 1613 cases of 11-19 year old (mean age = 15.48) male (n = 805) and female (n = 808) high school athletes with interscholastic sports injuries (concussions, knee sprains, and ankle sprains). The answers to the research questions are summarized below.

Question 1: Is there an association between SRC and LEMI among high school athletes?

H_{01}: There is not an association between SRC and LEMI among high school athletes controlling for gender, age, and sport type.

H_{A1}: There is an association between SRC and LEMI among high school athletes controlling for gender, age and sport type.

The chi square analysis revealed the *concussion ever* and *LEMI* variables were associated as [X^2 = 1480.796, (1), p = .000 (p < .05)], and the post hoc Cramer's V

analysis revealed there was a very strong association between these variables ($\varphi_c = .958$); but ORs and 95% CIs could not be calculated because one cell contained zero values. The covariates (gender, age, or sport type) were not associated with the dependent variable (LEMI), so the covariates were not included in the logistic regression analysis. The cross tabulations are depicted in Tables 4 – 8.

A binomial logistic regression analysis was performed in an effort to shed more light on the relationship between SRC and LEMI in high school athletes. Since the logistic regression model contained incomplete information (zero cases of the *concussion ever* variable and zero cases of *lower extremity sprain* variable), the maximum likelihood estimate (MLE) of the logistic regression slope of the coefficient did not occur, so the model did not converge. Lack of convergence led to inaccurate estimates in the block 1 model, Therefore the results were not valid, and were not reported in this study. CMH analysis was also performed in an effort to explain the association that was found between SRC and LEMI with chi square analysis. However, the CMH analysis did not yield results for the tests of homogeneity of the odds ratio, or the Mantel-Haenszel common odds ratio estimate, (due to zero cases with absence of concussion and zero cases with absence of lower extremity sprain) so the OR and 95% CI could not be determined.

Although the chi square analysis revealed SRC and LEMI were associated, the OR and 95% CI could not be calculated with chi square, binomial logistic regression or CMH analyses, because one cell in each analysis contained zero cases. Without the ability to calculate an OR to understand if the OR favors an increase or decrease for the dependent variable, and without having 95% confidence the range of values around the calculated chi square statistic contain the true statistic (population value), the significant chi square statistic alone does not provide enough information to answer this research question.

Question 1a: Is SRC associated with knee sprains among high school athletes?

H_{01a}: SRC is not associated with knee sprains among high school athletes controlling for gender, age, and sport type.

H_{A1a}: SRC is associated with knee sprains among high school athletes controlling for gender, age, and sport type.

The chi square analysis revealed the *concussion ever* and *knee sprain ever* variables were associated, and the post hoc Cramer's *V* analysis revealed a very weak association between these variables [$X^2 =$ 35.450, (1) $p = .000$, ($p < .05$) $\varphi_c = .148$], but the ORs and 95% CIs could not be calculated. The results of the cross tabulation analysis are presented in Table 9. The binomial logistic regression analysis showed the unstandardized Beta weight for the predictor variable *concussion ever;* B = (-2.409), SE =.510, Wald = 22.318, $p < .05$, favored a decrease of 10% [Exp (B) = .090, 95% CI (.033, .244)] for a *knee sprain* every one unit increase of *concussion ever*. Although this binomial logistic regression model showed *concussion ever* and *knee sprain ever* variables were related, the results could be misleading and inaccurate due to the small sample size (four cases) in one cell. The Hosmer-Lemeshow goodness of fit test, suggested the model fit the data, but the small sample size could have decreased the power of the test to detect the model's poor fit to the data (Chao-Ying et al., 2002; Hosmer & Lemeshow, 2000; Hosmer et al., 1991). Because the fit of the model was questionable, and the ORs and 95% CIs could not be determined for the chi-square analyses; the null hypothesis (H_{O1a}) was not rejected.

Question 1b: Is SRC associated with ankle sprains among high school athletes?

H_{01b}: SRC is not associated with ankle sprains among high school athletes controlling for gender, age, and sport type.

H_{A1b}: SRC is associated with ankle sprains among high school athletes controlling for gender, age, and sport type.

The chi square analysis for the *concussion ever* and *ankle sprain ever* variables revealed these variables were associated, and the post hoc Cramer's V analysis showed a moderate association between these variables [$X^{2} =$ 479.826, (1) $p = .000$, ($p < .05$), $\varphi_c =$ .545], but the OR and 95% CI could not be determined. The results are presented in Table 15. This binomial logistic regression analysis revealed the unstandardized Beta weight for the predictor variable *concussion* ever: B = (-4.058), SE =.286, Wald = 201.288, $p < .05$. The estimated OR favored a decrease of nearly 100% [Exp (B) = .017 95% CI (.010, .030)], for ankle sprains every one unit increase of *concussion-ever*. Although this binomial logistic regression model showed *concussion ever* and *ankle sprain* variables were related, the results could be misleading and inaccurate because the validity of the model is uncertain. The Hosmer and Lemeshow goodness of fit test in block one revealed chi square = .000, with 0 degrees of freedom so the *p*-value could not be calculated, so this analysis did not clarify if the model fit the data well (Chao-Ying, 2002; de Irala et al., 1997; Hosmer et al., 1991). Therefore, these results are questionable. Additionally, the OR and 95% CI could not be calculated for the significant chi square statistic. Therefore, the null hypothesis was not rejected.

Question 2: Is the number of concussions associated with LEMI among high school athletes?

H_{02}: The number of SRCs is not associated with LEMI among high school athletes controlling for gender, age and sport type.

H_{A2}: The number of SRCs is associated with LEMI among high school athletes controlling for gender, age, and sport type.

The chi square analysis of the *number of concussions* and *lower extremity sprains* variables revealed these variables were associated [$X^2 = 1473.222$ (1) $p = .000$, ($p < .05$)], and the post hoc Cramer's *V* analysis revealed there was a very strong association between the *number of concussions and lower extremity sprain* variables ($\varphi_c = .956$). The results are depicted in Table 21. No covariates were associated with the dependent variable (LEMI), so no covariates were included in the logistic regression analysis. The logistic regression model contained incomplete information, (zero cases in one cell). Therefore, the MLE of the logistic regression slope of the coefficient did not occur, so the model did not converge. Lack of convergence led to inaccurate estimates in the block 1 model. Therefore the results were not valid, and were not reported in this study. CMH analysis did not yield any results for the tests of homogeneity of the odds ratio, or for the Mantel-Haenszel common odds ratio estimate due to incomplete information (zero cases in one cell). Therefore, the OR and 95% CI could not be computed.

Although the chi square analysis revealed the number of concussions, and LEMI were associated, the OR and 95% CI could not be calculated with chi square, binomial logistic regression or CMH analyses, because one cell in each analysis contained zero cases. Without the ability to calculate an OR to understand if the OR favors an increase or decrease for the dependent variable, and without having 95% confidence the range of values around the calculated chi square statistic contain the true statistic (population value), the chi square statistic alone does not provide enough information to answer this research question.

Question 3: Is the number of SRCs associated with knee injuries among high school athletes?

H_{03}: The number of SRCs is not associated with knee injuries among high school athletes controlling for gender, age, and sport type.

H_{A3}: The number of SRCs is associated with knee injuries among high school athletes controlling for gender, age, and sport type.

The chi square analysis of the relationship between the *number of* concussions and *knee sprains* revealed these variables were associated as [$X^2 = 35.723(2)$ $p = .000$, $p < .05$), but the Cramer's *V* analysis revealed the association between these variables was very weak ($\varphi_c = .149$). The results are summarized in Table 22. A binomial logistic regression analysis was conducted to examine the relationship between the number of SRCs and knee sprains while controlling for age group and gender. The logistic regression analysis contained incomplete information, (low cell counts) so the MLE of the logistic regression slope of the coefficient did not occur. Therefore, the model did not converge. Lack of convergence led to inaccurate estimates in the block 1 model, Therefore the results were not valid, and were not reported in this study. CMH analysis did not yield any results for the tests of homogeneity of the odds ratio, or for the Mantel-Haenszel common odds ratio estimate due to incomplete information (zero cases in one cell). Therefore, the OR and 95% CI could not be calculated.

Although the chi square analysis revealed the number of concussions and knee sprains were associated the OR and 95% CI could not be calculated with chi square, binomial logistic regression or CMH analyses, because one cell in each of these analyses contained zero cases. Without the ability to calculate an OR to understand if the OR favors an increase or decrease for the dependent variable, and without having 95% confidence the range of values around the calculated chi square statistic contain the true statistic (population value), the chi square statistic alone did not provide enough information to answer this research question.

Question 4: Is the number of SRCs associated with ankle injuries among high school athletes?

H_{04}: The number of SRCs is not associated with ankle injuries among high school athletes controlling for gender, age, and sport type.

H_{A4}: The number of SRCs is associated with ankle injuries among high school controlling for gender, age, and sport type.

The chi square analyses of the relationship between the *number of concussions* and *ankle sprains* revealed these variables were associated, and the post hoc Cramer's *V* analysis revealed there was a moderate association between these variables [X^2 = 476.260 (2), p = .000 (p = < .05), φ_c. = .543. The results are depicted in Table 23.

A binomial logistic regression analysis was conducted to examine the relationship between the number of concussions and ankle sprains more thoroughly. The analysis showed the unstandardized Beta weight for the predictor variable *number of concussions* (one) was B = -4.040, SE =.286, Wald = 199.284, $p < .05$. The estimated odds ratio favored a decrease of nearly 100% [Exp (B) = .018, 95% CI (.010, .031)] for ankle sprains every one unit of increase in *number of concussions* (*one*). Additionally, the *number of concussions* (two) variable contributed to this model. The unstandardized Beta weight for the predictor variable *number of concussions* (*two*) showed: B = -2.613, SE = 1.157, Wald = 5.103, $p < .05$. The estimated odds ratio favored a decrease of nearly 100% [Exp (B) = 073, 95% CI (.008, .708)] for ankle sprains every one unit increase of number of concussions (two).

These results could be misleading and inaccurate. Although the Hosmer Lemeshow goodness of fit test revealed the model appeared to fit the data well ($p > .05$), it is feasible the non-significant *p*-value ($p = 1$) could be the result of the Hosmer-Lemeshow test having less power to correctly identify a poor fit instead of truly demonstrating a good fit (Chao-Ying et al., 2002). Additionally, the OR and 95% CI could not be calculated for the significant chi square statistic. Therefore, the null hypothesis was not rejected. The results of this logistic regression analysis are summarized in Table 24.

The results for each research question did not produce meaningful measures of association between the independent and dependent variables. Fifty percent of the binomial logistic regression models contained zero values in one of their cells, so the models did not converge. To reduce the number of zeros in some cells, I analyzed the relationship between SRC and knee sprains as well as the relationship between SRC and ankle sprains. Although, the Hosmer-Lemeshow goodness of fit tests, suggested the models fit the data well, the small sample size could have decreased the power of these tests to detect the model's poor fit to the data instead of truly demonstrating a good fit (Chao-Ying, et al., 2002).

The results are explained in more detail in the fifth chapter. The limitations of this study and recommendations are also discussed. Finally, the implications for positive social change are explained.

Chapter 5: Discussion, Conclusions, and Recommendations

Introduction

The purpose of this cross-sectional retrospective study was to examine the relationship between SRC and LEMI among high school athletes to provide early information about the relationship between these common injuries in high school athletes, fill a gap in the literature, and shed more light on these public health concerns. LEMIs were defined as knee sprains and ankle sprains in this study, so the relationships between SRC and knee sprains and the relationship between SRC and ankle sprains were examined independently in an effort to gain a better understanding of the relationship between SRC and LEMIs in this population.

Chi-square analyses revealed that SRC is associated with LEMIs, knee sprains, and ankle sprains; and Cramer's *V* analyses showed that the strengths of these associations were very strong, very weak, and moderate, respectively. Chi-square analyses also revealed that the number of concussions is associated with LEMIs, knee sprains, and ankle sprains; and Cramer's *V* analyses showed the strengths of these associations were also very strong, very weak, and moderate, respectively. However, the ORs and 95 CIs could not be ascertained for the chi-square statistics due to incomplete information in the dataset.

Three of six binomial logistic regression models could not converge in this study because "the maximum likelihood estimators of the slopes of the coefficients" did not occur due to incomplete information (zero cases in at least one cell; Allison, 2008, p. 4). Therefore, I was not able to answer the following questions:

1. Is SRC associated with LEMI in high school athletes?

2. Is the number of concussions associated with LEMI in high school athletes?
3. Is the number of concussions associated with knee sprains in high school athletes?

Additionally, three binomial logistic regression analyses generated results, but the findings indicated that the models might not have fit the data. Therefore, the following null hypotheses were not rejected:

H_{01a}: SRC is not associated with knee sprains among high school athletes controlling for gender, age, and sport type.

H_{01b}: SRC is not associated with ankle sprains among high school athletes controlling for gender, age, and sport type.

H_{04}: The number of SRCs is not associated with ankle injuries among high school athletes controlling for gender, age, and sport type.

The results of this study are explained and compared to the literature in terms of the lessons I learned as I attempted to answer each research question. The lessons are also explained in the context of the theoretical model that grounded this study. The limitations of this study are discussed, and recommendations are presented. Finally, the implications for positive social change are explained.

Interpretation of the Findings

Prior studies that examined the relationship between concussions and LEIs (sprains, strains, fractures, contusions) in professional and collegiate athletes demonstrated that SRCs were associated with increased odds of LEIs (Gibson et al., 2016; Lynall et al., 2015; Nordstrom et al., 2014; Pietrosimone et al., 2015a). I conducted chi-square analyses to prepare for the logistic regression analyses and determined that relationships existed between SRC and LEMIs (knee sprains and ankle sprains) and between the number of SRCs and LEMIs (knee sprains and ankle sprains) in high school athletes. Because there were not any cases in the dataset without a concussion, knee sprain, or ankle sprain, the ORs and 95% CIs could not be calculated. Additionally, three of the binomial logistic regression models in this study did not converge due to incomplete information. The remaining three models generated results that were not accepted because the analyses indicated that those models might not have fit the data well. I discuss the reasons for these outcomes in the following sections.

Consequences of Incomplete Information

Because LEMIs were defined as knee sprains and ankle sprains in this study and the secondary dataset only contained concussion, knee sprain, and ankle sprain data, all possible combinations of the variables could not be tested, in that there were not any cases without at least one of these injuries. De Irala et al. (1997) explained that when a cell in a contingency table does not contain any cases, statistical software programs are tasked with performing computations in situations where there are no specifiable outcomes, so it is not possible to approximate the coefficients or estimate the standard errors. Furthermore, de Irala et al., (2016) explained that it is not rational to estimate an OR (constant effect of each predictor on the odds of the outcome occurring) for a category of a variable with zero cases, but many statistical programs generate outcomes based upon the instant the program reaches the maximum number of iterations that are predetermined for the program. These authors also demonstrated how various statistical programs generate warnings that researchers should recognize as indications that there are problems with the data, such as failed convergence and inaccurate results including high coefficients (10+), high standard error values (10+), unusually high or missing ORs, and 95% CIs (de Irala et al., 2016). Even in studies with large samples, sparse data bias ("away from the null value") may occur if small quantities of cases in categorical strata do not all allow all possible combinations of predictor and outcome variables to be examined completely, so researchers should be aware that regression coefficients and odds ratios may be misleading in these situations (Greenland, Mansournia, &Altman, 2016; Greenland, Schwartzbaum, & Finkle, 2000, p. 531). Greenland et al. (2016) emphasized that if coefficient estimates move away from the null value as more variables are introduced into the regression model, this finding is indicative of small data bias.

There were several indications of problems with the binomial logistic regression analyses that were conducted to answer the following research questions:

1. Is there an association between SRC and LEMI among high school athletes?
2. Is there an association between the number of concussions and LEMI among high school athletes?
3. Is there an association between the number of concussions and knee sprains among high school athletes?

First, each of the three models failed to converge, so the results were invalid. Additionally, combinations of abnormally high standard error vales, unusually high ORs, unusually wide 95% CIs, and absence of upper boundaries in some 95% CIs also indicated that these logistic regression models were problematic.

De Irala et al. (2016) and Hosmer et al. (1991) underscored the importance of not accepting or publishing invalid results. Therefore, the results of the logistic regression analyses for the first, second, and third questions were not accepted or reported in this study.

Interpretation of the Goodness-of-Fit Test

I examined the relationship between SRC and knee sprains as well as the relationship between SRC and ankle sprains individually in an effort to gain a better understanding of the relationships between these common sports injuries. Research Questions 1a and 1b articulated each component of Research Question 1:

1a. Is there an association between SRC and knee sprains among high school athletes?

1b. Is there an association between SRC and ankle sprains among high school athletes?

Research Question 4 was as follows: Is the number of SRCs associated with ankle injuries among high school athletes? Although the Hosmer-Lemeshow goodness-of-fit test for Research Questions 1a and 4 suggested that the model fit the data, it is possible that the small size for each question decreased the power of the test to detect the model's poor fit to the data (Chao-Ying et al., 2002; Hosmer & Lemeshow, 2000; Hosmer et al., 1991). The 2x2 matrices contained four cases in one cell for Research Question 1a, contained 14 cases in one cell for Research Question 1b, and contained less than fiver actual and expected cases for Research Question 4, so these samples sizes were even smaller when the 2x2 matrices were stratified further for the Hosmer and Lemeshow goodness-of-fit test. Additionally, the Hosmer and Lemeshow goodness-of-fit test for Research Question 1b revealed that chi square = .000, with 0 degrees of freedom so that the *p*-value could not be calculated, so this analysis did not clarify whether the model fit the data well (Chao-Ying et al., 2002; de Irala et al., 1997; Hosmer et al., 1991).

Because it was not clear if the models fit the data well; I could not determine whether the results for Research Questions 1a and 1b (which suggested that SRCs in high school athletes are associated with 10% lower odds of knee sprains, and nearly 100% lower odds of ankle sprains for every unit increase in SRC) were accurate. For the same reasons, I could not determine if the results for Research Question 4 (which suggested that number of SRCs [one concussion or two concussions] in high school athletes were associated with nearly 100% lower odds of ankle sprains for every unit increase in the number of SRCs) were accurate. Therefore, the results were not accepted, and the null hypotheses for Research Questions 1a, 1b, and 4 were retained.

Justification for Additional Research

Because I was not able to determine whether SRCs, or the number of SRCs, were associated with LEMIs in high school athletes, it remained unclear whether findings in adult professional and collegiate athletes applied to adolescent athletes with less mature neurological and musculoskeletal systems. Nordstrom et al. (2014) revealed that professional European soccer players were more susceptible to injuries 1 year before and after sustaining an SRC. They also found that concussed players had 2.2 times greater risk of ensuing musculoskeletal injuries throughout the year following the SRC than players without concussions (Nordstrom, et al., 2014). Similarly, Lynall et al. (2015) found that concussed collegiate athletes were 1.97 [95% CI (1.19, 3.28)] times more likely to have sustained an acute injury of a lower limb one year postconcussion than they were preconcussion; and collegiate athletes with a history of an SRC were 1.64 [95% CI

(1.07, 2.51)] times more likely to have sustained an acute injury of the lower limbs 1 year postinjury than matched controls during the same time frame. Brooks, et al. (2016) built upon those studies and found that 90 days after resuming play, intercollegiate athletes with SRC had 2.48 higher odds of LEMIs than nonconcussed matched controls [OR = 2.48, 95% CI = (1.04, 5.91)]. Gilbert et al. (2016) also found that (a) reported concussions, (p = .003, OR = 2.08); (b) unreported concussions, (p = .002, OR = 2.87); and (c) any concussions (p = .002, OR = 2.13) were associated with knee injuries, while unrecognized concussions (p = .001, OR = 2.29) and any concussions (p = .012, OR = 1.79) were associated with lateral ankle sprains in college and junior college athletes when their college sports careers were finished. They also found that any concussions (p = .031, OR = 1.61) and unrecognized concussions (p = .006, OR = 1.90) were associated with ankle sprains, knee sprains, and muscle strains. Most recently, Herman et al. (2017) found that concussed collegiate athletes had 3.39 times [95% CI (1.90, 6.05)] greater risk of sustaining a LEMI than nonconcussed athletes. Ongoing literature searches did not reveal any studies in high school, collegiate, or professional athletes with findings contrasting with the results of the studies reported above.

Pietrosimone et al. (2015a) revealed that the odds of players reporting a LEI increase as the frequency of self-reported concussions increases. They found that retired NFL players with a history of one SRC had 18%-63% greater odds, while players with a history of two SRCs had 15%-126% greater odds, and players with a history of three, or more, SRCs had 73%-165% higher odds of reporting lower limb injuries throughout their professional careers (Pietrosimone et al., 2015). Ongoing literature searches did not reveal additional articles that agreed or disagreed with their results.

Findings in the Context of the Theoretical Model

The dynamic model of etiology in sport injury by Meeuwisse et al. (2007) accounts for fluidity of sports injury risk factors, including the impact of repeated exposures and how each exposure may lead to adaptations (which may reduce injury risk), or mal-adaptations (which may elevate injury risk). These adaptations or mal-adaptations may lead to no injury or to an injury, and injured athletes may or may not be able to resume playing (Meeuwisse et al., 2007). This model allows athletes to enter and re-enter the cycle and participate with modified intrinsic and extrinsic risk factors in any of the following phases: predisposed athlete phase, susceptible athlete phase, injury phase, or no injury phase (Meeuwisse et al., 2007).

Emerging evidence suggests that SRCs may increase the risk of LEIs in collegiate and professional athletes (Brooks et al., 2016; De Beaumont et al., 2011; Gilbert et al., 2016; Herman et al., 2017; Lynall et al., (2015) Nordstrom et al., 2014; Pietrosimone et al., 2015a). However, the findings in those studies were not confirmed or disconfirmed by this study, as 50% of the logistic regression models failed to converge and the remaining 50% of the models might not have fit the data well.

Although there were indications that the results generated for Research Questions 1a and 1b were inaccurate, the results raised the possibility that concussions could be associated with lower odds of knee sprains and ankle sprains in high school athletes. Problems with the dataset indicate one explanation for those results. Other potential explanations follow in terms of the dynamic model of etiology in sport injury by Meeuwisse et al. (2007). One possible explanation for the unexpected logistic regression results for Research Questions 1a, 1b, and 4 pertains to the injury phase of this model, in that athletes with known concussions could have been removed from training, practice, and competition for longer periods of time than athletes with LEIs, or may not have been able to RTP following a concussive injury. All U.S. states have legislation that requires athletes with suspected concussions to immediately be removed from play, but there are inconsistencies among states regarding concussion education and training, authority to clear athletes to RTP, and RTP protocols (Bretzin, Moffit, Mansell, & Russ, 2017). Gradated RTP programs should not be initiated until the athlete's symptoms have resolved, physical exam findings are normal, and baseline motor control and neurocognitive test scores are achieved (Broglio et al., 2015). About 10% of high school and college athletes demonstrated postconcussion symptoms that lingered more than 7 days postinjury, and almost 25% of those athletes reported persistent symptoms 6-12 weeks postconcussion (McCrea et al., 2012). Howell et al., 2015) found that concussed high school athletes demonstrated impaired dynamic motor function while walking and performing a cognitive task immediately after concussion and during the course of their 2-month study. In another study, these researchers found that concussed high school athletes demonstrated worsening of gait balance control during dual task walking upon their return to activity (Howell et al., 2014). Therefore, if postconcussion symptoms lingered and physical deficits persisted concussed athletes in this dataset might not have RTP, and this could partially explain reduced odds of LEIs.

Another explanation pertains to the predisposed athlete phase, in that it is also possible all concussions will not have been captured in this dataset, if athletes underreported concussions. Studies by McCrea (2004), Register-Mihalik et al. (2013), and Wallace, Covassin, Nogle, Gould, and Kovan (2017), supported this by revealing that

51-55% of high school athletes did not report concussions primarily because they did not believe their injuries were serious or they did not want to be removed from play.

Limitations of the Study

Several limitations of this study pertained to the data. The main limitation of this study was my inability to ascertain meaningful relationships between the independent and dependent variables due to incomplete information and small sample sizes. Because the dataset only contained the injuries of interest (SRCs, knee sprains, and ankle sprains), 50% of the cross tabulations that I constructed in preparation for chi square analyses had a cell with zero cases. Therefore, I could not determine the ORs and 95% confidence intervals with the chi square analyses. In logistic regression analyses, the MLE is used to select parameters for the coefficient that maximize probability of the observed values occurring (Allison, 2008; Field, 2009). However, when a cell does not contain any cases, it was not possible for the MLE of the logistic regression slope of the coefficient to exist (Allison, 2008). Therefore, the models with zeros could not converge during the iteration phases of the logistic regression analyses (Allison, 2008). Consequently, I could not ascertain the relationships between the following variables: (a) SRC and LEMI, (b) the number of SRCs and LEMI, or (c) the number of concussions and knee sprains. Furthermore, although the dataset for this study contained over 1,600 cases, the remaining cross tabulations revealed there were only four cases with an SRC and a knee sprain, 14 cases with an SRC and an ankle sprain, and one case with two SRCs and an ankle sprain. Therefore, the power may not have been sufficient for the Hosmer-Lemeshow tests to accurately ascertain how well those models fit the data during the logistic regression analyses (Chao-Ying et al., 2002). Moreover, the dataset did not include athlete exposures to training, practices, and competitions, so I was not able to determine risk or rates of injury in this study. Additionally, the dataset did not include prior concussion and LEMI histories, so I was not able to determine the directions of the associations.

This cross sectional study could not establish a causal effect, so the relationships identified in this study could have been influenced by untested variables such as the playing surfaces, or athletes' levels of skill (Abrahams et al., 2014). Since quantitative cross sectional studies examine exposure and outcome concurrently, temporal relationships were not determined in this study. There was also potential for bias toward including more athletes without concussion or without musculoskeletal injuries, if athletes, who sustained either one of these injuries, were unable return to play.

Because this study examined the relationship between SRC and LEMI among U.S. high school athletes, generalizability of the findings to other athletic, or non-athletic, populations may not be possible. Therefore, external validity (generalizability of the study's results) could be threatened. I addressed this limitation by not generalizing the results of this study beyond population represented by this sample. While the design of this study was aligned with the research questions and methods, and my interpretations did not exceed the data, findings, or scope of this study, the threats to internal validity (strength of inferences), and limitations described above could not be overcome in this study. However, many of the limitations in this study could be addressed if this study serves as a springboard for future large-scale prospective studies.

Recommendations

As de Irala et al. (2016), Hosmer and Lemeshow, (2000), and Hosmer et al., (1991) emphasized, it is important not to accept or publish invalid results. The three logistic regression models that were conducted to answer Research Questions 1, 2, and 3, failed. Additionally, the validity of the logistic regression models generated, for the remaining three Research Questions (1a, 1b, and 4), was uncertain. Therefore, I was not able to determine the association between SRCs and LEMIs in high school athletes. I recommend replication of this study with a dataset that is not limited to the injuries of interest in order to overcome the problems associated with analyzing incomplete information. Large-scale prospective studies should also be conducted to determine if there is a causal relationship between SRCs and LEIs in U.S. high school athletes. Cohort studies should be conducted to follow athletes through their high school, college and professional careers to shed light on the relationship between adolescent and adult sport-related injuries.

Implications

This study facilitates positive social change by reminding researchers, although computer programs can generate results that may appear to be significant, it is important to evaluate the results thoroughly to ensure that invalid conclusions are not accepted or disseminated. This study also facilitates social change by demonstrating the need for future studies to be conducted to determine whether a relationship exists between SCR and LEMI in high school athletes. The problems with this study have inspired me to conduct another retrospective study, with an expanded dataset, to address the problems related to incomplete information in this study, and provide early information regarding the relationship between SRCs and LEMIs in high school athletes. Disseminating the results of a follow-up study may inspire researchers to conduct additional studies to clarify whether a relationship exists between SRC and LEMI in high school athletes, and if so, whether it is causal in nature. New knowledge may be used to guide practices and policies, to reduce sports injuries in high school athletes, which may lead to fewer SRIs among adolescents, fewer school absences, more physical activity, and better, health, well-being, and quality of life throughout the lifespan, thereby promoting a more active, productive, and healthy society.

Conclusion

Sports injuries can be foreseen and averted when mechanisms and risk factors are completely understood. An appreciation of the relationship between SRC and LEMI is emerging among professional and collegiate athletes, but findings of such a relationship in adults may not be generalizable to younger populations. To my knowledge, this was the first study to investigate the relationship between SRCs and LEMIs in high school athletes. Although, I was not able to attain meaningful measures of association between the independent and dependent variables, as incomplete information led to lack of convergence, and small sample sizes reduced the power of the Hosmer-Lemeshow tests to determine how well the models fit the data during the logistic regression analyses; this study exposed a gap in the literature. Thereby, this study highlighted the need for future cross sectional studies to uncover the relationship between SRCs and LEMIs in high school athletes, as well as cohort studies to clarify the causes and effects of these common sports injuries in adolescent athletes.

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Appendix A: Permissions

Permission for Figure 1

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If you need additional information, please do not hesitate to contact me.

Sincerely,

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