Effects of Sport Related Concussion on

Academic Performance in High School Athletes

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ABSTRACT
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Background. Concussive impacts to the head are a natural part of most athletic competition. Even in sports that do not permit player contact, incidental contact that can result in concussion often occurs. This dissertation addresses the general hypothesis that sport related concussions have a negative impact on academic performance in high school athletes.

Study Design. A systematic review of current literature on the post-acute neurocognitive effects of concussion provides an introduction to the importance of this study. A retrospective cohort of athletes participating in school sports in a public school district is assessed for changes in school attendance and academic performance following concussion compared to ankle or leg injury.

Methods. The systematic review included meta-analytic methods. Analysis of the retrospective cohort included longitudinal graphical and multivariable random coefficient methods that characterized changes in academic performance over time in high school athletes with and without concussion. Random coefficient models were used to assess effect modification by predictor variables including gender and age.

Results. Researchers have shown that adolescent athletes experience a range of neurocognitive symptoms six or more days following concussion injury. In the retrospective cohort analyses, athletes with concussion injuries have greater odd

of being grade 9 (OR=2.2, p<0.001, 95%CI 1.5-3.2) or grade 10 (OR 2.1, p<0.001, 95%CI 1.5-3.1) than grade 12 and had greater odds of an increase in the number of days absent from school (OR=1.7, p<0.011, 95%CI 1.3-2.2) when compared to athletes with ankle or leg injury. Analyses of a subgroup of younger athletes (grades 9 and 10) with more severe injuries indicate a 16% greater decline in academic performance for the group with concussion injury than those with ankle or leg injury (coeff= -0.18, p=0.017, 95% CI= -0.32 to -0.03).

Conclusions. These analyses suggest that young athletes with concussion injury are at risk for decline in academic performance. Increased absence from school results in decreased instruction time, social isolation, and other factors that may negatively impact academic achievement. Future research is warranted, examining academic performance in high school athletes with concussion injury.

CHAPTER 1: DISSERTATION OVERVIEW

1.0 Concussion Research Background and Definition

Concussive head impacts are a natural part of most athletic competition. Even in sports that do not permit player contact, incidental contact with other players, equipment, or the playing surface that may result in injury. Sport-related concussions, a subgroup of mild traumatic brain injury (MTBI), are accompanied by a constellation of poorly defined short and long-term physical and cognitive consequences for the athlete. In 2001(1), 2004(2), 2008(3), and 2012(4) several sport governing bodies convened international symposia to develop a consensus statement and recommendations regarding the safety and health of athletes who suffer concussion injuries. The agreement statements from this group provide a concise and consistent definition of concussion, a description of clinical issues, assessment tools, and return to play protocol. The consensus definition of sport-related concussion is "a complex pathophysiological process affecting the brain, induced by a traumatic biomechanical force." (1-4) This definition is accompanied by several common symptoms that are used in defining the severity of a concussion.

Concussions are characterized by acute and long-term changes in the brain resulting in a variety of physical (e.g. balance problems, loss of consciousness), cognitive (e.g. slowed reaction time, memory loss, concentration difficulty), and emotional (e.g. emotional lability) symptoms.(3, 5) These symptoms may present immediately at the time of injury, or appear in the hours and days following the injury.(6-10) The clinical symptoms used to diagnose concussion have been described in detail(2, 3, 6, 9, 11-16). The acute symptoms that have been

validated as prognostic of poor injury progression and slower recovery include

amnesia, loss of consciousness, headache, dizziness, blurred vision, attention

deficit, and nausea.(14, 17, 18) Additional subjective symptoms have been

described, but have not been proven as prognostic features of concussion

recovery.(18)

1.1 Concussion in Adolescent Athletes

Participation in structured activity during adolescence is associated with

positive psychological, social, and educational outcomes.(19-21) The structure

provided by athletics and other extracurricular activities allows for an

appropriate expression of normal adolescent urges such as risk-taking and

sensation-seeking behavior that is otherwise uncontrolled and potentially

dangerous.(22, 23) Additionally, participation in structured activity encourages

development of positive time management and leadership skills(23-28) and

engaging in sports and other athletic endeavors expose adolescents to

experiences that increase confidence and competence in problem solving.(29)

Participation in high-school athletics is predictive of lower substance abuse rates,

increased probability of graduation from college, and higher occupational

achievement than non-participants.(19, 30)

Despite the positive health and social outcomes associated with physical

activity and sports participation, there is an assumed risk for the athletes.

Recently, intense, year-round, single-sport training has become increasingly

common in younger athletes who have aspirations of competition at the highest

level.(30, 31) This training often does not accommodate the quickly changing physical structures of adolescence, and leads to increases in injury related to overuse and overtraining.(30, 31) Sport-related injury negates some of the positive emotional and social benefits of participation. Athletes with injury are more likely to show depressive symptoms and experience social isolation than non-injured athletes.(32)

Adolescents who chose to participate in athletics and other structured programs are different in many ways than those who do not. They are more likely to be of higher social economic class(20, 32, 33), have a more positive orientation toward education (resulting in better academic performance)(20, 22, 32, 34), and be of nonminority ethnicities(20, 22, 34) than those who do not participate in structure athletic programs. These characteristics make research of outcomes related to sports participation difficult, as it is challenging to detangle the effects of participation from the factors that predispose athletes to participate.(26) Moderators of the effect of athletic participation on academic performance include gender, ethnicity, age, and academic environment.(26) Athletic participation is variable across these subgroups and effects of participation may also impact these groups differentially.

Sport-related concussion injuries are of particular concern in young athletes. Approximately 30 million children and adolescents in the United States participate in sports every year.(33, 35) Surveillance in emergency departments between 2001 and 2005 indicates that among patients examined for sport-related concussion, a majority were pediatric patients. The highest rates were seen in

young athletes aged 10 to 19.(33) Given the physical and cognitive changes
occurring during puberty, adolescents are particularly vulnerable for concussion
injuries. Injury surveillance and other research consistently find the highest
rates of adolescent sport-related concussion in football, wrestling, soccer, and
basketball.(36-40)

1.1.1 Incidence of Concussion in Adolescent Athletes

In the United States, over 7.5 million adolescents participate in high
school athletic programs each year.(41) American football, alone, accounts for 1.1
million high school participants every year.(41) The incidence of sport-related
concussion varies greatly by sport and performance level, and has been
historically hard to estimate. The Centers for Disease Control incidence estimate
of approximately 300,000 head injuries attributable to high school athletics
every year is widely referenced in the literature. (42) Recent studies of large,
nationally representative samples that include athletes in a wide range of sports
are beginning to offer a better estimate of the true injury burden in adolescent
athletes. Extrapolation from US Census data and estimates of incidence from
several studies to account for underreporting and undiagnosed injury produce
rates of up to 300 concussion injury per 100,000 for children age 15-19
participating in athletics.(43)

Two recent longitudinal studies have produced an estimated concussion
rate of approximately 2.5 injuries per 10,000 athletic exposures (AE)(44, 45),
with concussions representing up to 15% of reported athletic injuries. Athletic

exposure (AE) are defined as one athlete participating in one practice or competition. Both studies, one a longitudinal study of athletes in a large public high school system over ten years(44) and the other a study of a national sample of high school athletic injury data during the 2008-2010 academic years(45), indicate that while overall rates of concussion are higher in boys than in girls, with a majority of concussions resulting from football, risk of concussion is higher in girls than in boys in gender-comparable sports.(44, 45) Overall, the rate of concussion injuries in high school athletics is increasing.(44, 46) This trend could be due to increased awareness of the consequences of concussion injuries, improvements in diagnostic processes, and/or an actual increase in the number of injuries. Since concussion analysis, management, and diagnosis became a priority in the 1990's, there has been an overall decrease in serious brain injuries in most sports.(44, 47)

1.1.2 Predictors of Concussion Severity and Prolonged Recovery

As early as the 1960's, researchers noted that the effects of even the mildest concussion may linger for an extended period, or even be irreversible.(48, 49) There are competing schools of thought regarding persistent symptoms following concussion. Whether the symptoms are a direct consequence of the initial injury or manifestations of psychological or emotional after effects, there is increasing concern that these symptoms represent a largely unnoticed and untreated syndrome resulting in significant disability.(18) There is insufficient data available to quantify the proportion of injuries or individual

characteristics that result in lingering post-concussive symptoms. However, female gender, younger age, history of concussion, and presentation of acute concussion symptoms appear to be predictive of injury severity and prolonged recovery from the injury.

Adolescent brains do not follow the same general recovery pattern as adults following concussion injuries. While adults generally resolve symptoms within the first week after injury, recent research indicates that young athletes may begin *showing* new cognitive symptoms 7-10 days following injury.(33, 35) The adolescent brain may be more sensitive to metabolic changes following injury than adult brains. This imbalance may impact recovery time, partially explaining the delayed recovery trajectory observed in adolescents compared to adults.(33, 50) History of previous concussion also increases recovery time in adolescents. Subsequent concussions demonstrate more severe immediate symptom presentation and are associated with long-term neurological deficits.(33, 36, 51)

1.1.2.1 Gender

Female athletes appear to be at greater risk for concussion and experience a longer duration of symptoms than male athletes in gender-comparable sports.(52, 53) A recent prospective cohort study describes sex differences in memory, postural stability, and symptom scores following concussion, with female athletes performing significantly worse than male athletes up to a week following injury.(54) It is unclear, however, if these results are due to an actual

disparity in risk and recovery, or if the findings can be explained by other non-biological factors. For example, female athletes may be more likely to report symptoms and honestly engage in recovery efforts instead of masking symptoms to hasten return to play.(55, 56)

1.1.2.2 Age

While adolescent changes that influence risk of athletic injury are most visible in physical transitions in body shape and size, concurrent change in cognition, emotion, and social development also influence risk of injury and can be adversely impacted as a result of injury.(27, 57) Change in brain structure and function during this phase is not readily apparent, but occurs at a rapid rate. During puberty, brain maturation is characterized by reduction of neuronal axons and increased myelination.(22) It is estimated that during adolescence synapses can be generated and lost on the magnitude of 30,000 per second.(23)

The changing adolescent brain is particularly vulnerable to injury. During adolescence, shifting activation of frontal regions of the brain are associated with changes in cognitive control.(57) Risk taking behavior and emotional reactivity are associated with developmental change in the subcortical limbic regions.(22, 57) These changes are nonlinear and highly individual. Damage to changing structures during development could have lasting consequences on behavior and cognition. There is evidence that these pubertal changes in brains and hormones interact with contextual factors (such as injury) to influence academic achievement.(20, 27)

While most cognitive detriments associated with concussion are the same in children as in adults, the fact that the adolescent brain is actively maturing may result in significant secondary consequences in children as their ability perform day-to-day tasks impacts their educational and social attainment.(58) Even in the absence of immediate presentation of clinical symptoms commonly observed in adult concussion, injury to the adolescent brain occurs at a lower energy threshold than in adults that manifest in the presentation in symptoms in the post acute period.(59, 60) It is also suspected that despite normal neuropsychological presentation following sport concussion, some children may suffer a variety of behavioral and cognitive sequelae.(59, 61)

The effectiveness of adolescent concussion assessment and diagnosis is influenced by maturing cognition in children. In early adolescence, healthy children are rapidly developing choice reaction time, working memory, and new learning(58). This has implications for baseline and post-concussive cognitive assessments as the developmental changes are of a comparable magnitude to post-concussive impairments, potentially confusing assessment of symptoms(58, 62, 63).

1.1.2.3 History of Concussion

A small study of high school and collegiate athletes by Iverson and colleagues assessed neuropsychological measures in athletes with three or more concussions and found significant memory deficits compared to athletes with no previous concussion.(64) This study was small (n=38), but provides convincing

preliminary evidence of significant cumulative effect of multiple concussion in adolescent athletes using a validated, computerized assessment tool. The researchers chose a sample of athletes with multiple concussions in an effort to replicate and expand upon previous research that found athletes with 3 or more concussions present increased concussion-like symptoms at baseline than athletes without concussion.(65-67)

In an attempt to characterize the prolonged effects of concussion in high school athletes, a study in New Jersey found that athletes who had sustained recent concussions had poorer concentration and memory function than athletes with no history of concussion.(68) The study collected neurophysical information on 223 athletes in three groups: those with no concussion history, symptom free athletes with one or more concussions more than six months prior to testing, and those who experienced concussion 1 week prior to testing. Athletes with history of two or more concussions and those with recent concussion demonstrated poorer attention and concentration than athletes with no concussion history. Additionally, the researchers found that athletes with recent concussions and currently asymptomatic athletes who had a history of two or more concussions had lower cumulative grade point averages than athletes without concussion.(68) The correlation between low GPA and concussion incidence must be studied in a larger sample with longitudinal data collection before assertions can be made.

Existing literature documents cognitive decline following concussion, but is limited by application of neurocognitive tests that are not predictive of long-

term function. Additionally, most studies have had small sample size and do not follow athletes over long periods to assess function in the post-acute period following injury.

1.1.2.4 Other prognostic factors

Several characteristics of acute injury have been validated as prognostic of injury progression and recovery include amnesia, loss of consciousness, headache, dizziness, blurred vision, attention deficit and nausea.(14, 17, 18) Additional subjective symptoms have been described, but have not been proven as prognostic features of concussion recovery.(18)

1.2 Concussion Assessments and Diagnosis

Diagnosis of concussion in sports is complicated on many levels. Assessment of injured athletes is hindered by the inherent challenges of diagnosing a condition that relies largely on self-report of symptoms.(11, 69)   It is not uncommon for an athlete to hide or lie about symptoms to avoid being "benched" for a seemingly minor injury, opting instead to "play through the pain."(11, 69) Additional challenges to diagnosis and assessment of symptoms include stress(11, 33, 37, 70, 71), learning disabilities(11), and hormonal fluctuations(11, 72) that affect response to concussion assessment queries.

No universally accepted concussion symptom assessment tool has been developed for diagnosing concussion at the time of injury. Many have been proposed and are used in practice.(2, 3, 6, 11-16, 73) In 2004, the International

Conference on Concussion in Sport published the Sideline Concussion

Assessment Tool (SCAT), which offers patient education in addition to a

mechanism for assessing cognitive features, typical symptoms, and physical signs

of concussions.(2) SCAT was developed through a collaborative and iterative

process consolidating and standardizing existing tools.(2) The SCAT tool has

been revised several times, including a version to accommodate assessment of

concussion symptoms in children.(4) Another frequently used tool is the

Standardized Assessment of Concussion (SAC) assessment tool(16) for on-field

assessment. The SAC is a series of questions in four sections that evaluate areas

of orientation, memory, concentration and delayed recall. The test is

administered immediately following injury and the cumulative score is compared

to a baseline value. Multiple versions of the evaluation are available to minimize

the potential for practice effects. Deficits of 1 or more points on a 30 point scale

are indicative of impaired cognitive function.(6, 16)   Additional assessment tools

are in use, and all rely on measures of memory, balance, and self-report of

symptoms. All of these tools are useful in initial assessment of injuries and can

inform clinical management during recovery. Additional research regarding the

predictive value of these tools in an athletes recovery trajectory is necessary.(74)

1.3 Academic Impact of Sport-Related Concussion

Concussion injuries may have significant impact on academic performance in high school athletes. In adolescent athletes with concussion, attention must be paid to balancing the required cognitive rest with academic demands. Minor attention deficit or impaired information processing can have a significant impact on an adolescent's ability to function academically(58) and evidence suggests that early return to school (before resolution of symptoms) may delay recovery.(33, 75) Studies have noted a lack of research documenting specific outcomes when assessing the impact of head injuries on scholastic abilities.(76-78) The few existing studies of academic outcomes focus on severe head injuries and do not translate to the large number of athletes suffering from concussive symptoms.(77, 79)

For athletes with concussion, cognitive rest may be as important as physical rest for recovery.(80, 81) Poor communication between healthcare providers and school administration make it difficult for athletes to get the rest they need to heal.(9, 33, 71, 81) Assessing the impact of concussions on academic outcomes will help with future identification of athletes at high-risk for prolonged recovery and allow educators opportunity for targeted intervention to prevent negative academic consequences. Currently, many athletes are expected to return to school environments that require focused attention over long periods and exposure to loud environments within days of injury.(57, 82, 83)

Administrative policies allowing for cognitive recovery periods and individualized academic rehabilitation plans may allow full recovery from injury, minimizing academic consequences.

1.4 Dissertation Aims

The aims of this dissertation focus on evaluating the effects on academic performance of sport-related concussion in high school athletes. The dissertation provides a systematic literature review of the post-acute cognitive effects of concussion in adolescents as well as analyses of academic performance in a population of high school athletes with concussion injury and lower leg injury. A discussion of the policy implications of the research is included.

Aim 1: Provide a systematic review of the literature regarding the post-acute neurocognitive effects of concussion in adolescent athletes.

Aim 1a: Use meta-analytical statistical methods to estimate the overall effects of concussion in observational studies of the post-acute neurocognitive symptoms in adolescent athletes.

Aim 2: Describe the injury rates and distribution of academic variables in a population of high school athletes with concussion injury and lower leg injury.

Aim 3: Characterize the impact of sport-related concussion on academic performance in high school athletes by describing the functional form of recorded grade trends over time.

Aim 3a: Examine the functional form of academic performance trends over time in a group of athletes with concussion and a group of athletes with ankle and knee injuries.

Aim 3b: Estimate the effect of sport-related concussion on academic performance in high school athletes using random coefficient models.

1.5. Dissertation Organization

This dissertation contains five chapters. This chapter (Chapter 1) provides an overview of background information relevant to sport-related concussions and current literature. In Chapter 2, a systematic literature review and meta-analysis of the post-acute effects of concussion in adolescent athletes is presented. Chapter 3 describes the injury and academic data from a population of high school athletes used to achieve the aims of this dissertation. Chapter 4 investigates the longitudinal effects of sport related concussion injury on academic performance. Finally, the fifth chapter is a summary of the dissertation and discussion of the findings with emphasis on the policy implications and directions for further research.

The research presented in this dissertation was designed to increase the body of information regarding the impact of concussion in adolescent athletes. Prolonged cognitive impairment following concussion is of concern in adolescent athletes, but poorly understood in the context of variables that may impact long-term outcomes. Academic performance in high school influences later academic

opportunities and is association with health standing later in life. The analyses

rely on a restricted data set from a large study population for retrospective

analyses of effects. Results from this dissertation provide a foundation for future

research in this area, including prospective analyses and investigation of more

complete population data.

CHAPTER 2: LITERATURE REVIEW - POST-ACUTE COGNITIVE EFFECTS OF SPORT-RELATED CONCUSSION IN HIGH SCHOOL AND COLLEGIATE ATHLETES

Abstract

Background. Adolescent athletes do not follow the same pattern of recovery following concussion injury that adults demonstrate. Adolescents may have prolonged or new symptoms that appear beyond the post-acute period following injury. Understanding the recovery of adolescent athletes following concussion is essential to minimize the consequences for the future health of the athletes. The aim of this study was to provide a systematic review of the literature regarding post-acute (six or more days following injury) neurocognitive effects of concussion in adolescent athletes.

Study Design. A systematic review of current literature addressing cognitive effects of concussion in adolescents was conducted. Searches were conducted in PubMed and Ovid to identify studies published in English between January 1995 and May 2013. Studies were included in the review if neurocognitive results for high school age subjects were reported six or more days following concussion injury.

Methods. Results from neurocognitive tests were pooled where possible to present overall effects. Pooled standardized mean differences were calculated using Cohen's method and DerSimonian and Laird random effect weighting with heterogeneity estimates taken from the inverse-variance fixed effects model. Where pooling of study results was not possible, results were presented as a systematic review with no quantitative summary estimate.

Results. Twelve studies were included in the systematic review. Eight were cohort studies reporting results from ImPACT testing (a computerized neurocognitive test of concussion symptoms), four studies reported results of other neurocognitive tests. Adolescent athletes experience a range of neurocognitive symptoms six or more days following concussion injury. Athletes in the reviewed studies demonstrated declines in the domains of reaction speed, memory, and total symptom scores at the time of follow up.

Conclusions. Many domains of cognition remain impaired in adolescent athletes in the post acute period (six or more days after injury). These findings support the need for further study of cognitive effects of concussion in adolescents following the acute period of injury rehabilitation.

2.1 Introduction

Concussive head impacts are a natural part of most athletic competition. Even in sports that do not permit player contact, incidental contact with other players, equipment, or the playing surface that may result in injury. Sport-related concussions, a subgroup of mild traumatic brain injury (MTBI), are accompanied by a constellation of poorly defined short and long-term physical and cognitive consequences for the athlete. In 2001(1), 2004(2), 2008(3), and 2012(4) several sport governing bodies convened international symposia to develop a consensus statement and recommendations regarding the safety and health of athletes who suffer concussion injuries. The agreement statements from this group provide a concise and consistent definition of concussion, a description of clinical issues, assessment tools, and return to play protocol. The consensus definition of sport-related concussion is "a complex pathophysiological process affecting the brain, induced by a traumatic biomechanical force." (1-3) This definition is accompanied by several common symptoms that are used in defining the severity of a concussion.

Concussions are characterized by acute and long-term changes in the brain resulting in a variety of physical (e.g. balance problems, loss of consciousness), cognitive (e.g. slowed reaction time, memory loss, concentration difficulty), and emotional (e.g. emotional lability) symptoms.(3, 5) These symptoms may present immediately at the time of injury, or appear in the hours and days following the injury.(6-10) The clinical symptoms used to diagnose concussion have been described in detail(2, 3, 6, 9, 11-16). The acute symptoms that have been

validated as prognostic of injury progression and recovery include amnesia, loss of consciousness, headache, dizziness, blurred vision, attention deficit, and nausea.(14, 17, 18) Additional subjective symptoms have been described, but have not been proven as prognostic features of concussion recovery.(18)

Sport-related concussions are of particular concern in young athletes. Approximately 30 million children and adolescents in the United States participate in sports every year.(33, 35) Surveillance in emergency departments between 2001 and 2005 indicates that among patients examined for sport-related concussion, a majority were pediatric patients. The highest rates were seen in young athletes aged 10 to 19.(33) Given the physical and cognitive changes occurring during puberty, adolescents are particularly vulnerable for concussion. Injury surveillance and other research consistently find the highest rates of adolescent sport-related concussion in football, wrestling, soccer, lacrosse and basketball.(36-40)

While most cognitive detriments associated with concussion are the same in children as in adults, the fact that the adolescent brain is actively maturing may result in significant secondary consequences in children as their ability perform day-to-day tasks impacts their educational and social attainment.(58) Even in the absence of immediate presentation of clinical symptoms commonly observed in adult concussion, injury to the adolescent brain occurs at a lower energy threshold than in adults that manifest in the presentation in symptoms in the post acute period.(59, 60) It is also suspected that despite normal

neuropsychological presentation following sport concussion, some children may suffer a variety of behavioral and cognitive sequelae.(59, 61)

In addition to different injury mechanics, there is also evidence that adolescent brains do not follow the same general recovery pattern as adults. While adults generally resolve symptoms within the first week after concussion injury, recent research indicates that young athletes may begin *showing* new cognitive symptoms 7-10 days following injury.(33, 35) The adolescent brain may be more sensitive to metabolic changes following injury than adult brains. This imbalance may impact recovery time, partially explaining the delayed recovery trajectory observed in adolescents compared to adults.(33, 50) History of previous concussion also increases recovery time in adolescents. Subsequent concussions demonstrate more severe immediate symptom presentation and are associated with long-term neurological deficits.(33, 36, 51)

Understanding the recovery of adolescent athletes following concussion is essential to minimize the consequences for the future health of the athletes. Implementation of neurocognitive testing has improved the evaluation and management of individual sport related concussion and has also allowed study of the neurocognitive symptom presentation and progression following injury. An increasing number of published studies present results from computerized neurocognitive tests, allowing for examination of trends in differing populations of athletes.

This section of the dissertation reviews the current literature related to adolescent concussion injuries, summarizing the neurocognitive effects of

concussion at six or more days following injury in adolescent athletes. This review evaluates the evidence for persisting symptoms and cognitive deficits in adolescent athletes following concussion injuries.

2.2 Methods

A review of current literature addressing cognitive effects of concussion in adolescents was accomplished employing the following terms: "cognitive effects" or "neurocognitive effects" combined with "concussion," "postconcussion" and/or "mild traumatic brain injury" and "adolescent". Searches were conducted in PubMed and Ovid to identify studies published in English between January 1995 and May 2013. A two-step screening process was used to identify studies for inclusion in the review. First, studies were reviewed at the abstract level and restricted to those that reported neurocognitive test results for high school age subjects following concussion or MTBI. A full text review of the remaining studies restricted papers further and studies reporting results only from the immediate period following injury (within 5 days) were excluded to focus on symptoms that persist beyond the acute period. Papers were further excluded during the full text review if they did not report neurocognitive outcomes or did not define concussion exposure.

A standardized protocol was used to abstract information from the studies identified for review on study design, study population, covariates, concussion diagnosis and definition, outcome measurement, results, and relative study quality. Use of quality scores in meta-analyses of observational studies is not

standard practice due to lack of demonstrated validity.(84) For this review, assessments of study quality based on components of study design were noted during the abstraction process, but quality scores were not integrated in the pooled analyses. Results from neurocognitive tests were pooled where possible to construct overall effects. This was not possible for all studies due to differences in study populations, lack of standardized outcome testing, or incomplete data presented in the paper. Where pooling was not possible, results were presented as a systematic review with no compilation.

Several domains of cognition were measured by standard neurocognitive testing tools. Eight of the included studies reported results from Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) assessment, a computerized test of neurocognitive function commonly used to assess symptoms following concussion. Four reported results from other neurocognitive testing tools. Regardless of the test, these tools measure neurocognitive function in several domains. Cognitive function consists of the common domains of memory, attention, and executive function. Different aspects of these domains are assessed by computerized neurocognitive testing tools. The results presented in the studies reviewed here included assessment of function in the following subdomains: Verbal, Visual, or Composite Memory; Processing Speed; Reaction Time; and Total Symptom Score.

2.2.1 Statistical Methods

Studies reporting neurocognitive results from ImPACT were considered for pooled analysis. Results were pooled where ImPACT results were reported for the group with concussion during followup and for baseline (pre-injury) or a control group. Pooled standardized mean differences (SMD) were calculated using Cohen's method and DerSimonian and Laird random effect weighting with heterogeneity estimates taken from the inverse-variance fixed effect model.(85, 86) The random effects model allows for variation between studies and results and provides a more conservative result than fixed effects models. Cornfield's confidence intervals were calculated.(87)

Heterogeneity was assessed through the I^2 statistic and visualization of a Galbraith radial plot. In the case of heterogeneity, sensitivity and influence analyses were conducted by re-estimating the meta-analysis by omitting each study in turn. An individual study may contribute excessive influence to the analysis if the estimate of its omitted analysis falls outside the pooled result confidence interval.

Publication bias was considered by visualizing a funnel plot and performing the Beggs and Mazumdar adjusted rank correlation test (a statistical analog to the funnel plot) and the Egger regression asymmetry test for publication bias. Begg's method and Egger's tests assess the asymmetry of funnel plots with correlation tests; Begg's method uses rank correlation and Egger's test applies a regression to the standard normal deviate on precision.(88) All analyses were performed using Stata/IC 11.2 for Mac (StataCorp, College Station, TX).

2.3 Results

After resolving duplicates, the search produced 152 unique publications. Reference lists from each were also searched, yielding 9 additional publications. Studies were excluded where concussion was not the exposure studied (n=101), review papers or studies not designed to report neurocognitive results (n=33), studies that did not report neurocognitive testing results 5 or more days following concussion injury (n=14). The remaining twelve studies were included in the review. Eight of the studies were cohort studies reporting results using ImPACT testing. Three additional cohort studies and a cross sectional study reported results from other neurocognitive tests. A schematic of the selection of publications for review is presented in Figure 2.1.

The included studies are summarized in Table 2.1, presenting information on demographics, methodological information, as well as primary findings. Eleven of the studies were prospective or retrospective cohort studies and one was cross sectional. A majority of the participants in all studies were male, and the average age of participants was 15-17 years. Included studies represent results for adolescent participants from across the United States and from Denmark. Six of the studies reported baseline neurocognitive results for comparison, three presented neurocognitive test results for a control group, and three offered no comparison group. Collins et al(89) compared results between two concussed groups – one with headache at the time of follow-up and one group without headache at follow-up.

2.3.1 Studies reporting results from ImPACT neurocognitive testing

Eight studies reporting results from the ImPACT testing tools were highlighted in Table 2.2. ImPACT results were presented for the following domains: total symptom score, verbal memory, visual memory, composite memory, processing speed, and reaction time.

2.3.1.1 Total Symptom Score Results

Table 2.2 provides information from studies reporting ImPACT total symptom scores (N=7), with results ranging from 3.2(89) to 23.6(90). The ImPACT total symptom score is a count of symptoms present at the time of testing. Control and baseline results for studies presenting results range from 4.2(91) to 9.9(35). The "normal" range for total symptom scores on the ImPACT test is 1-6 (49 to 76th percentile, as defined by ImPACT test creators)(92). Average change from baseline or difference from control total symptom scores ranging from a decrease of 3.3 points(35) (one study reported an improvement in symptoms) 7 days following injury, to an increase of 7.9 points(93) 6-14 days following injury (four studies(54, 89, 91, 93, 94) report a worsening of symptoms). These average changes were summarized in Figure 2.2, a forest plot showing the average change in each study and a quantitative summary measure (SMD=0.52, 95% CI 0.05-0.99) Moser, et al(90) does not present baseline or comparison group information, but presents a mean total symptom score of 23.6 (standard deviation 21.5) for subjects 8 to 30 days following injury. This result was much greater than the normative range of 1 to 6.(92)

2.3.1.2 Verbal Memory Score Results

In the domain of verbal memory, four studies (54, 90, 93, 95) reported a range of scores in subjects with concussion from 75.88(93) to 85(95). Average baseline results were reported in two of the studies as 82.96(54) and 85.75(93). The two studies(54, 93) reporting baseline results demonstrated a decrease in verbal memory score 7 days following injury, although results from Covassin, et al(54) were not statistically significant. Thomas, et al(95) and Moser et al(90), did not report baseline results and offered no comparison group. The average results for these studies fell within normal ranges defined by test creators. The "average" range for males age 13 to 18 years is 80 to 92, for females age 13 to 18 the range is 84 to 93(92). The forest plot in Figure 2.3 was constructed to illustrate the mean change in score for the two studies with baseline results and a quantitative summary change (SMD= -0.66, 95% CI = -0.88 to -0.45)

2.3.1.3 Visual Memory Score Results

In four studies(54, 90, 93, 95), visual memory scores reported for subjects with concussion range from 63.11(54) to 77(95) with two studies reporting baseline scores of 71.25(54) and 74.04(93). There was a statistically significant decrease in visual memory following injury in the two studies providing baseline data. Thomas, et al(95) and Moser, et al(90), did not provide baseline data or a comparison group. The results for these studies were with in the normal range for visual memory test scores in adolescents. The "average" range for males age 16 to 18 years is 71-88, for males age 13 to 15 is 69 to 86, and for females age 13 to

18 is 70 to 88(92). In Figure 2.4, a forest plot presents the average change in visual memory scores for the two studies that included baseline data as well as an overall measure of change following injury (SMD= -0.5, 95% CI -0.71 to -0.29).

2.3.1.4 Composite Memory Score Results

Three studies(35, 89, 91) reported composite memory scores, rather than individual verbal and visual memory scores. In subjects with concussion, results ranged from 74.9(89) to 84.1(91) with baseline results reported in two of the studies as 83.4(91) and 83.9(35). ImPACT does not provide average or normal ranges for this score. Two studies report baseline composite memory scores, one showing a decline on average in scores following injury(35), the other showing a slight improvement on average in scores following injury(91). The third study(89) reporting composite memory scores provided data on two groups with concussion, one group with headache and the other without headache at follow-up. The group with headache had statistically significant lower average composite memory scores than the group without headache.(89)

2.3.1.5 Processing Speed Score Results

Processing speed in subjects with concussion was reported in six studies(54, 89-91, 93, 95) with a range from 30.7(89) to 36.55(54). Processing speed is measured by ImPACT as the number of tasks completed in a given time with higher scores representing better performance. Baseline scores reported in the included for processing speed ranged from 28.3(91) to 35.43(54). The

"average" range for males age 16 to 18 is 33.7-42.5, for males age 13 to 15 is 30.2 to 37.8, and for females age 13 to 18 is 32.8 to 42.3(92). In Figure 2.5, the average change in processing speed scores was illustrated in a forest plot.

2.3.1.6 Reaction Time Score Results

Finally, reaction time in subjects with concussion ranged from 0.56(95) to 0.68(94) in seven studies(54, 89-91, 93-95). Control and baseline scores ranged from 0.573(93) to 0.63(91). Reaction time is measured by ImPACT in seconds with higher scores indicating poorer performance. Two studies presented statistically significant results indicating a poorer reaction time following injury.(93, 94) One study showed an increased reaction time that was not statistically significant(54), and one study showed a decreased reaction time(91). Thomas, et al(95) did not provide baseline data or a comparison group. Results for this study group were within the normal range for reaction time in adolescents. Moser, et al(90) did not provide baseline or comparison group data for their study group. Results for this study were greater than the average range for reaction time in adolescents. The "average" range for males age 16 to 18 year is 0.50 to 0.58, for males age 13 to 15 is 0.53 to 0.60, and for females is 0.51 to 0.60.(92) Average change in reaction time is presented in a forest plot, Figure 2.6, with an overall measure of change (SMD=0.66, 95% CI -0.14 to 1.45)

2.3.1.7 ImPACT Scores Pooled Analysis Results

Table 2.3 presents the pooled SMD in each cognitive domain as well as for each study included in the analysis. Total symptom score (pooled SMD= 0.524, 95% CI 0.054 to 0.993, p=0.029), verbal memory (pooled SMD=-0.662, 95% CI -0.877 to -0.0445, p=0.006), and visual memory (pooled SMD=-0.500, 95% CI -0.712 to -0.288, p<0.001) all resulted in statistically significant standardized mean difference when pooled. Verbal memory and visual memory pooled analyses were based on only two studies each. We observed no statistically significant difference for standardized mean difference for processing speed (pooled SMD=0.182, 95%CI -0.231 to 0.595, p=0.388) or reaction time (pooled SMD=0.657, 95%CI -0.139 to 1.453, p=0.106).

Fixed effects models produced similar results to the random effects model, however the more conservative estimates from the random effects model is presented as the Galbraith plots and I^2 statistics (TSS I^2 = 85.6%, Verbal Memory I^2= 77.0%, Processing Speed I^2= 77.6%, Reaction Time I^2=92.9%) provided evidence of significant heterogeneity among the studies. For the domain of visual memory, the models appeared to have no heterogeneity (Visual Memory I^2= 0.0%), however, only two studies were included in this analysis and the result is unreliable. Publication bias was assessed through visualization of funnel plot symmetry. Funnel plot asymmetry was assessed statistically using Begg's method and Egger's test. However, with small numbers of studies included in these analyses, the power of the test was low and the results are not reliable. Sensitivity analysis was performed due to the indication of heterogeneity between the

studies. In analyses with four or more studies included, the influence of each study on the SMD was determined by re-estimating the analysis while omitting each study in turn. Each estimated SMD was still within the confidence interval for the pooled SMD so the analysis was not modified to account for influence.

2.3.2 Studies reporting results from other neurocognitive tests

Teasdale, et al(96) reported results for men who suffered concussion between the ages of 16 and 24 (n=700). Neurocognitive testing was the Broge Prien Prove assessment tool administered by the draft board anywhere from 3 to 500 days following injury. Of this group, fourteen men were tested between seven and thirty days following injury and eight were tested three to six days following injury. Raw test scores were not presented, and results were dichotomized as above or below the normal range defined by the Denmark draft board. In the first week following concussion, injured men were more likely (Relative Risk 2.45, 95%CI 1.23 – 4.90) to be classified as below normal range on the neurocognitive battery.

Field, et al(97) used the Post Concussion Symptom Scale, Hopkins Verbal Learning Test (HVLT), Brief Visual Spatial Memory Test-Revised (BVMT-R) and Symbol Digit Modality Test to assess neurocognitive function following injury. The study included 183 male high school varsity athletes and controls matched by sport, age, grade point average, history of learning disability, and history of previous concussion. In this population high school athletes had significant verbal learning and memory impairment as measured by the HVLT compared to

controls remaining 7 days following injury. While a decline in visual memory (measured by BVMT-R) compared to controls was noted, it was not statistically significant (p=0.09).

Sim, et al (98) reported neurocognitive function based on the ANAM testing tool. The prospective study included 419 athletes in Nebraska (14 with concussion during the study period) who participated in the Nebraska Concussion Study. The study participants were students in grades 9 through 12 in 9 public high schools. The study population consisted of mostly Caucasian males with a mean age of 15.69 years. Compared to the control group, the subjects with concussion had statistically significant deficits in reaction speed, processing speed, and memory 2.5 days following injury. At approximately six days following injury participants with concussion continued to show significant memory impairments and score differences remained in processing speed and reaction time, but were not statistically significant.

In a cross sectional study, Moser, et al(99) reported neurocognitive function from the Repeatable Battery for the Assessment of Neuropsychology Status (RBANS) on 35 athlete volunteers (14 with recent concussion) from a highly academically competitive private school. The study population had a mean age of 16.65 years and approximately 80% were male. Compared to a control group with a history of zero or 1 concussions (not within the preceding 6 months), athletes with recent concussion (one week prior to assessment) had poorer attention and memory scores.

2.4 Discussion

This review presents findings from studies that examined cognitive effects six or more days following concussion in adolescent athletes. The review is currently very relevant given the volume of research regarding the effects of MTBI. The reviewed studies provide evidence that adolescent athletes experience a range of neurocognitive symptoms six or more days following concussion injury. Analysis of the published literature supported declines in the domains of reaction speed, memory, and total symptom scores at the time of follow up among adolescent athletes with sport-related concussion.

These studies support the current understanding of adolescent athlete recovery from concussion injury. Another recent systematic review found that younger adolescents had more severe neurocognitive impairment following concussion prepared to college athletes and adults.(100) These results are also reinforced by a recent report indicating that females, adolescents, and athletes with 10 or fewer years of education demonstrated larger cognitive deficits than males, adults, and athletes with more than 16 years of education in the first week following injury.(101) While adults generally resolve symptoms within the first week after injury, research indicates that young athletes may begin *showing* new cognitive symptoms 7-10 days following injury.(33, 35) The adolescent brain may be more sensitive to metabolic changes following injury than adult brains, impacting recovery time and partially explaining the delayed recovery trajectory observed in adolescents compared to adults.(33, 50) Adolescents with subsequent

concussions demonstrate more severe immediate symptom presentation and may experience longer-term neurological deficits.(33, 36, 51)

Recovery trajectories following concussion injuries are highly individual and difficult to predict. Severity and duration of neurocognitive and other symptoms are influenced by individual characteristics, injury conditions, and return to play progression.(71, 81, 102, 103) Deficits in different cognitive domains may be the result of injury site, as different parts of the brain control different cognitive function.(104, 105) On average, however, evidence is increasing that adolescents will experience symptoms that persist beyond the acute period of the injury.

This systematic review is complicated by several limitations. The body of literature that the studies were pulled from is limited by factors such varying definitions of concussion, and different measures of neurocognitive function. While many studies report results from ImPACT, the current literature includes results from several other neurocognitive test batteries. Publication bias is also of concern, as the presented studies (no matter how systematically reviewed and presented) may not present the full range of study results available on the subject.

The meta-analyses of studies including ImPACT results are additionally limited by factors that include small study populations, heterogeneity of results, and residual confounding. With the exception of visual memory scores, analyses indicate significant heterogeneity of reported results. The indication of no heterogeneity in the visual memory results is likely an artifact of having only two

studies included in the test. Statistical and visual assessment of funnel plots to assess the potential for publication bias are also questionable due to the small number of studies included.

Heterogeneity between the studies could be explained in part by differences in the study populations, and by the small number of studies included in each test. These studies were conducted across the United States and include subject with a wide range of demographic characteristics. Additionally, documentation of ImPACT assessment protocols are not available, meaning that the testing conditions may not be standardized across or within study populations. Finally, the heterogeneity of results could also be explained in part by the variability in time lapsed between injury and assessment.

Statistical tests do not indicate significant publication bias. However, the analyses include a small number of observational studies reporting moderate change in scores, leaving room for residual confounding. Residual confounding in the meta-analysis could result from a number of potential factors that are not included in study results including age, race, history of concussion, sport played, severity of injury, and other factors.

Despite the limitations noted, results of this review and pooled analysis support the current understanding of the trajectory of cognitive recovery following concussion injuries in adolescent athletes. Many domains of cognition remain impaired in adolescent athletes in the post acute period (>5 days after injury). These findings support the need for further study of cognitive effects of concussion in adolescents following the post acute period. These findings

support the importance of the research presented in this dissertation. Lingering

cognitive symptoms in adolescent athletes have the potential to impact academic

performance following concussion injuries.

2.5 Tables and Figures

Database search keywords:
     "concussion" or "postconcussion" or "mild traumatic brain injury"
     "cognitive effects" or "neurocognitive effects"
     "adolescent"
Dates searched: January 1995 to May 2013

Number of unique publications: 152

Exclude studies
     Concussion not exposure studied: 101
     Review papers: 9
     Studies not reporting neurocognitive results: 24
     Studies not reporting results >5 days following injury: 14

Articles for full review: 12

Cohort Studies reporting results using ImPACT testing: 8

Studies reporting results from other neurocognitive tests
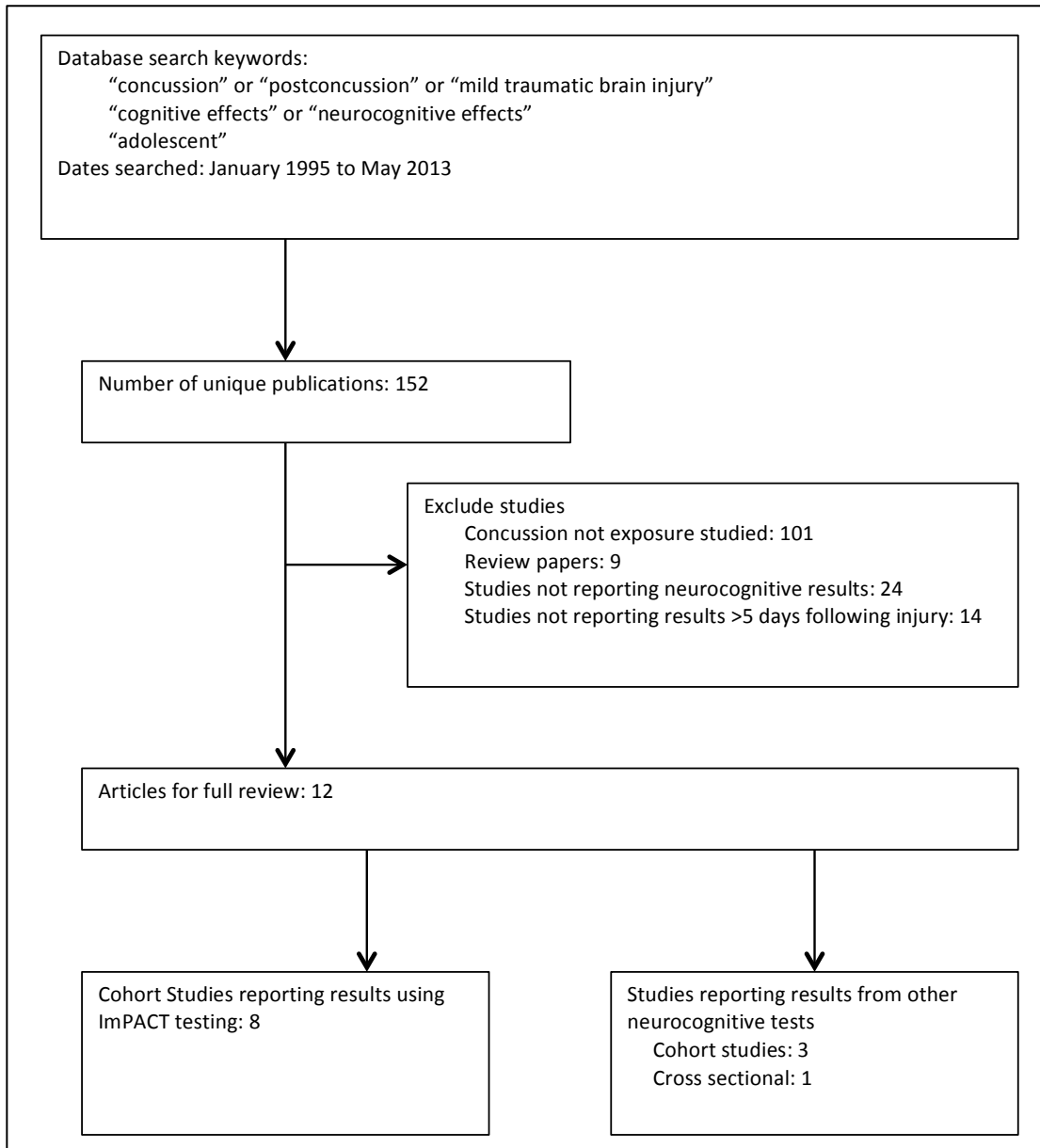   Cohort studies: 3
     Cross sectional: 1

Figure 2.1. Schematic illustrating the process of selecting publications for the systematic review.

Table 2.1. Summary of included study demographics, methodology, and primary findings.

Study:	N	Follow-up Period	Age range or mean (sd)	Gender (% male)	Assessment Tool(s)	Primary Findings
Field, 2003	183	7 days	14 – 18 years	100%	HVLT, BVMT-R, SDMT	Verbal learning and memory impairment (p<0.04) and visual memory impairment (p<0.09) in athletes with concussion compared to controls
Moser, 2002	35	7 days	14 – 19 years	80%	RBANS	Decreased attention (p=0.018) and memory scores (p-0.023) in athletes with recent concussion compared to athletes with no recent concussion
Sim, 2008	419	4-7 days; 8-11 days	15.5 (1.09) conc; 15.69 (1.16) no conc	75%	ANAM	At 4-7 days: significant impairment in simple reaction time (p=0.0001), information processing speed (p=0.005) and delayed memory (p=0.006) in concussed athlete compared to noninjured control and their own baseline.
Teasdale, 1997	700	3-500 days	16-24 years	100%	Broge Prien Prove	In the first week following concussion injured men were more likely to be classified below normal range on the neurocognitive assessment (Relative Risk 2.45, 95%CI 1.23 – 4.90)
Collins, 2003	109	5-10 days	15.8 (1.2) years	84.5%	ImPACT	Athletes with concussion who present with headache perform worse in total symptom score, composite memory, and reaction time compared to concussed athletes with no concussion
Covassin, 2012	72	7 & 14 days	14 – 25 years	71%	ImPACT	Compared to preinjury results, athletes with concussion had a statistically significant decline in the domains of total symptom score, visual memory, and reaction time and had nonsignficant decline in verbal memory and processing speed.
Lovell, 2003	64	7 days	High School	94%	ImPACT	Compared to preinjury results, athletes with concussion had a statistically significant decline in composite memory scores.
Lovell, 2004	43	6 days	13 – 18 years	81%	ImPACT	Compared to baseline, athletes with concussion had statistically significant decline in the domains of total symptom score, composite memory, processing speed, and reaction time.
McClincy, 2006	104	7 days	16.11 (2.22) years	81.5%	ImPACT	Compared to baseline, athletes with concussion had statistically significant decline in total symptom score, verbal memory, visual memory, and reaction time.
Maugans, 2012	24	14 days	11 – 17 years	75%	ImPACT	Compare to a control group, athletes with concussion had poorer scores on total symptoms and reaction time.
Moser, 2012	49	8-30 days	14 – 23 years	67%	ImPACT	With no baseline or control group for comparison, athletes with concussion had reaction time scores outside the "normal" range.
Thomas, 2011	36	6 days	11 – 17 years	78.3%	ImPACT	All scores were within the "normal" range. No baseline or control group results available for comparison.

Table 2.2. Summary of included studies reporting neurocognitive results from ImPACT.

Study:	N	Comparison	# days after injury	TSS (sd)	Verbal Memory (sd)	Visual Memory (sd)	Composite Memory Score (sd)	Processing Speed (sd)	Reaction Time (sd)
Collins, 2003		None	7						
Headache	36			21.7 (22.3)*§			74.9(16.2)*§	30.7(7.5)	0.64(0.09)*§
No Headache	73			3.2 (6.8)			82.4(10.7)	33.3(8.7)	0.57(0.09)
Covassin, 2012	72	Baseline	7						
Post-injury				11.18(14.69)*§	77.61(16.02)§	63.11(15.85)*§		36.55(9.4)§	0.609(0.149)§
Baseline				6.29(7.23)	82.96(10.38)	71.25(14.49)		35.43(6.68)	0.592(0.075)
Lovell, 2003	64	Baseline	7						
Post-injury				6.6(13.9)*			80.2(13.1)*§		
Baseline				9.9(12.9)			83.9(8.6)		
Lovell, 2004	43	Baseline	6						
Post-injury				8.7(13.1)*§			84.1(8.8)*	32.8(8.5)*§	0.59(0.09)*
Baseline				4.2(8.6)			83.4(9.4)	28.3(5.3)	0.63(0.07)
McClincy, 2006	10	Baseline	7						
Post-injury				13.08(15.55)*§	75.88(13.79)*§	66.96(15.92)*§		33.99(8.1)	0.635(0.121)*§
Baseline	4			5.14(7.87)	85.75(8.59)	74.04(13.82)		35.05(6.9)	0.573(0.076)
Maugans, 2012		Control Group	14						
Post-injury	12			11.17(4.41)*§					0.68(0.03)*§
Control Group	12			4.08(1.26)					0.59(0.02)
Moser, 2012	49	None	8-30	23.6(21.5)	82.6(11.5)	69.7(7.9)		33.8(7.4)	0.634(0.09)
Thomas, 2011	36	None	6		85	77		36.11	0.56
ImPACT "normal" range[1]				1-6					
Males (13-18y)					80-92	69-88		30.2-42.5	0.50-0.60
Females (13-18y)					84-93	70-88		32.8-42.3	0.51-0.60

*Statistically significant difference between groups (p<0.05).
§Results indicate a decline in performance following concussion or compared to control group
[1] Normal ranges for ImPACT test in uninjured adolescents are provided for comparison.

Table 2.3. Standardized mean differences for ImPACT cognitive domains.

Cognitive Domain	N	SMD	95% CI	Weight	p-value	I-squared
Total Symptom Score		0.524	(0.054-0.993)		0.029	85.6%
Covassin, 2012	72	0.422	(0.092-0.753)	22.42		
Lovell, 2003	64	-0.246	(-0.0594-0.102)	22.15		
Lovell, 2004	43	0.406	(-0.021-0.833)	20.86		
McClincy, 2006	104	0.644	(0.365-0.923)	23.16		
Maugans, 2012	12	2.186	(1.158-3.215)	11.41		
Verbal Memory		-0.662	(-0.877- -0.4447)		0.006	77.0%
Covassin, 2012	72	-0.396	(-0.726- -0.066)	48.29		
McClincy, 2006	104	-0.859	(-1.143- -0.575)	51.71		
Visual Memory		-0.500	(-0.712- -0.288)		<0.001	0.0%
Covassin, 2012	72	-0.536	(-0.869- -0.203)	40.72		
McClincy, 2006	104	-0.475	(-0.751- -0.199)	59.28		
Processing Speed		0.182	(-0.231-0.595)		0.388	77.6%
Covassin, 2012	72	0.137	(-0.190-0.464)	34.12		
Lovell, 2004	43	0.635	(0.202-1.069)	29.36		
McClincy, 2006	104	-0.141	(-0.413-0.131)	36.52		
Reaction Time		0.657	(-0.139-1.453)		0.106	92.9%
Covassin, 2012	72	0.144	(-0.183-0.471)	28.07		
Lovell, 2004	43	0.496	(-0.925- -0.067)	27.14		
McClincy, 2006	104	0.614	(0.335-0.892)	28.45		
Maugans, 2012	12	3.530	(2.215-4.845)	16.33		
Note: Pooled standardized mean differences (SMD) were calculated using Cohen's method and DerSimonian and Laird random effect weighting with heterogeneity estimates taken from the inverse-variance fixed effect model.						

Figure 2.2. ImPACT Total Symptom Score Forest Plot.

Note: Pooled standardized mean differences for ImPACT Total Symptom Score calculated using Cohen's method and DerSimonian and Laird random effect weighting with heterogeneity estimates taken from the inverse-variance fixed effect model.
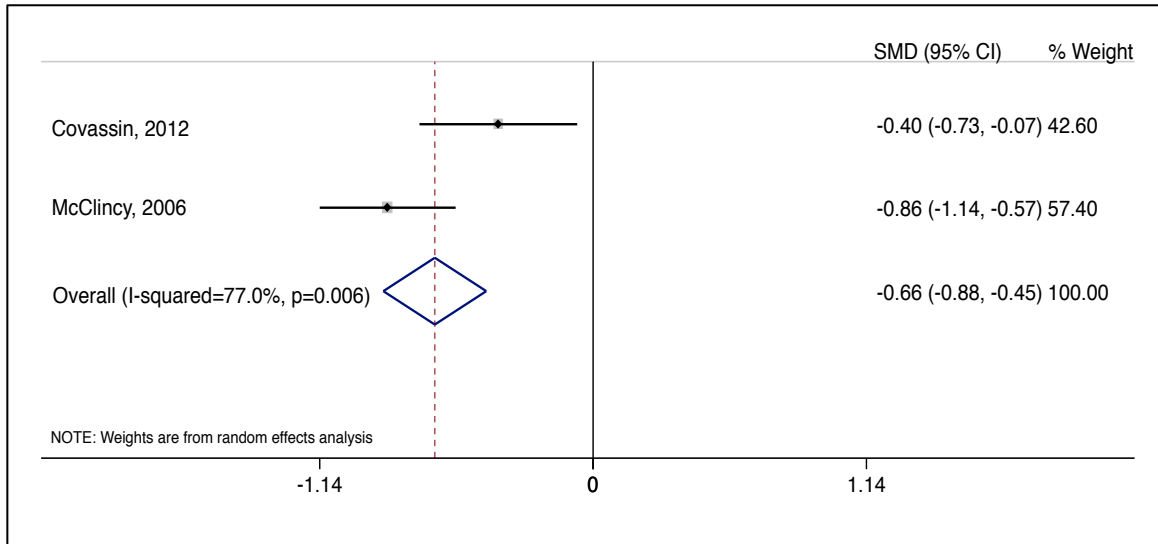
Figure 2.3. ImPACT Verbal Memory Score Forest Plot.

Note: Pooled standardized mean differences for ImPACT Verbal Memory Score calculated using Cohen's method and DerSimonian and Laird random effect weighting with heterogeneity estimates taken from the inverse-variance fixed effect model.
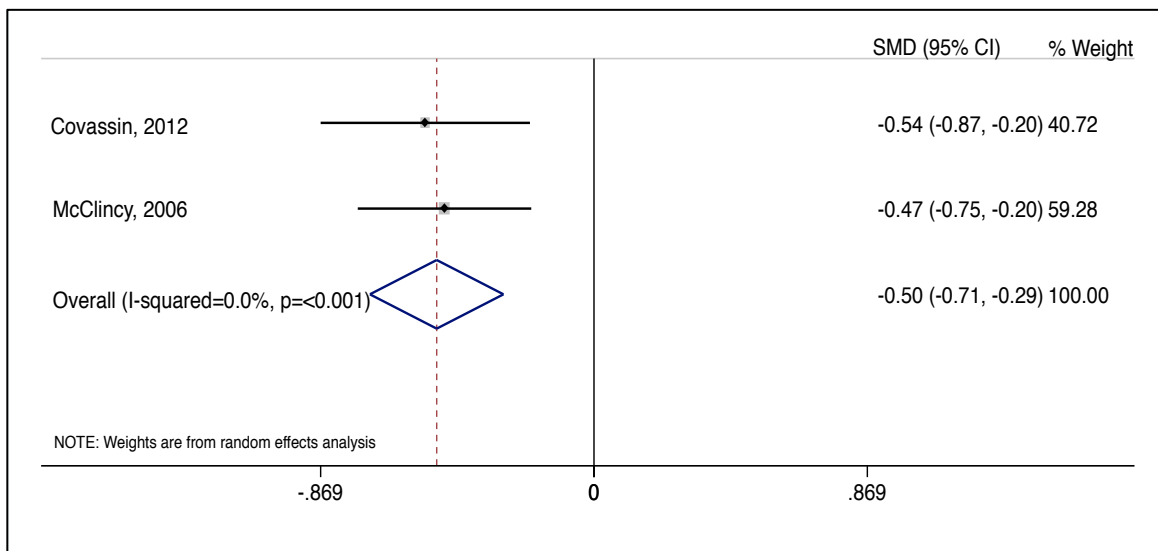
Figure 2.4. ImPACT Visual Memory Score Forest Plot.

Note: Pooled standardized mean differences for ImPACT Visual Memory Score calculated using Cohen's method and DerSimonian and Laird random effect weighting with heterogeneity estimates taken from the inverse-variance fixed effect model.
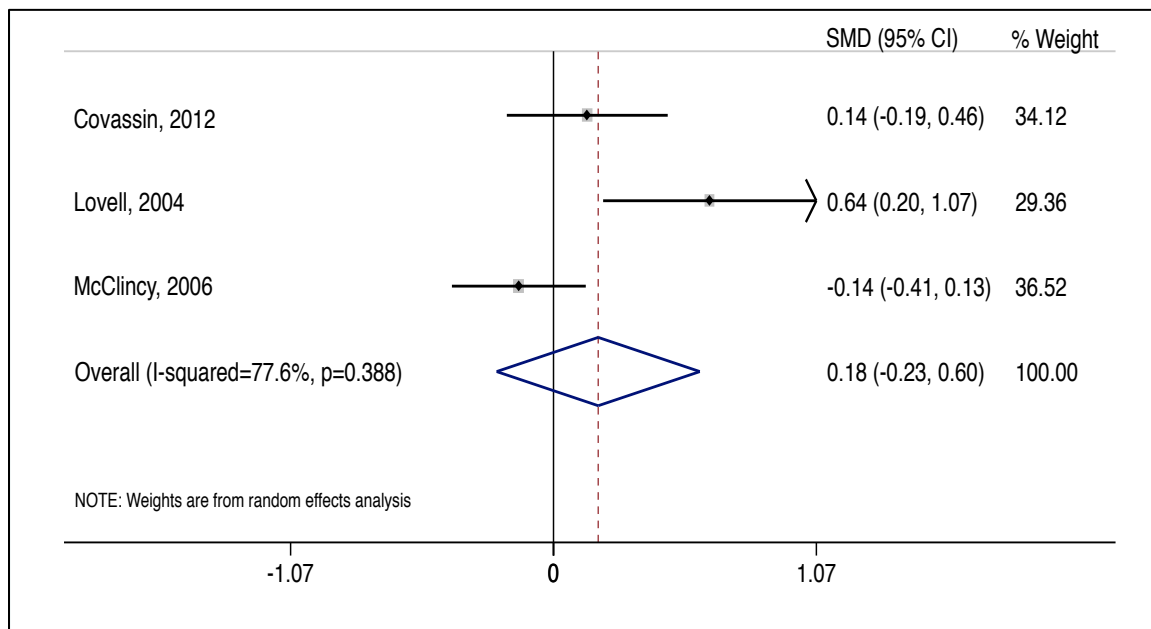
Figure 2.5. ImPACT Processing Speed Score Forest Plot.

Note: Pooled standardized mean differences for ImPACT Processing Speed Score calculated using Cohen's method and DerSimonian and Laird random effect weighting with heterogeneity estimates taken from the inverse-variance fixed effect model.
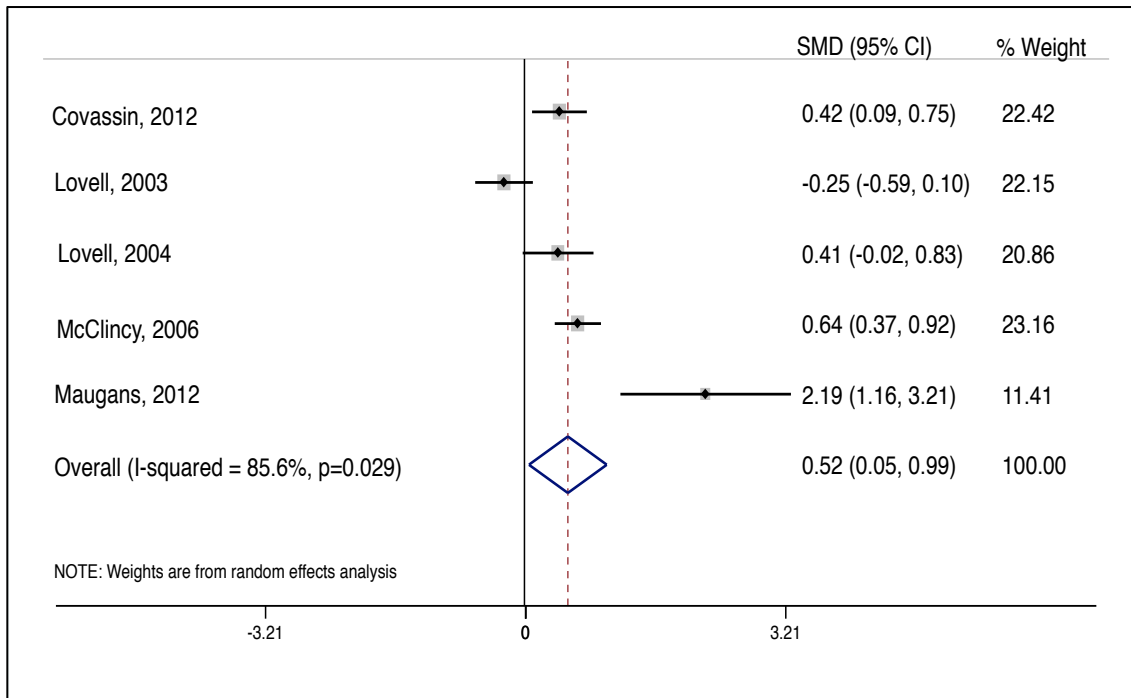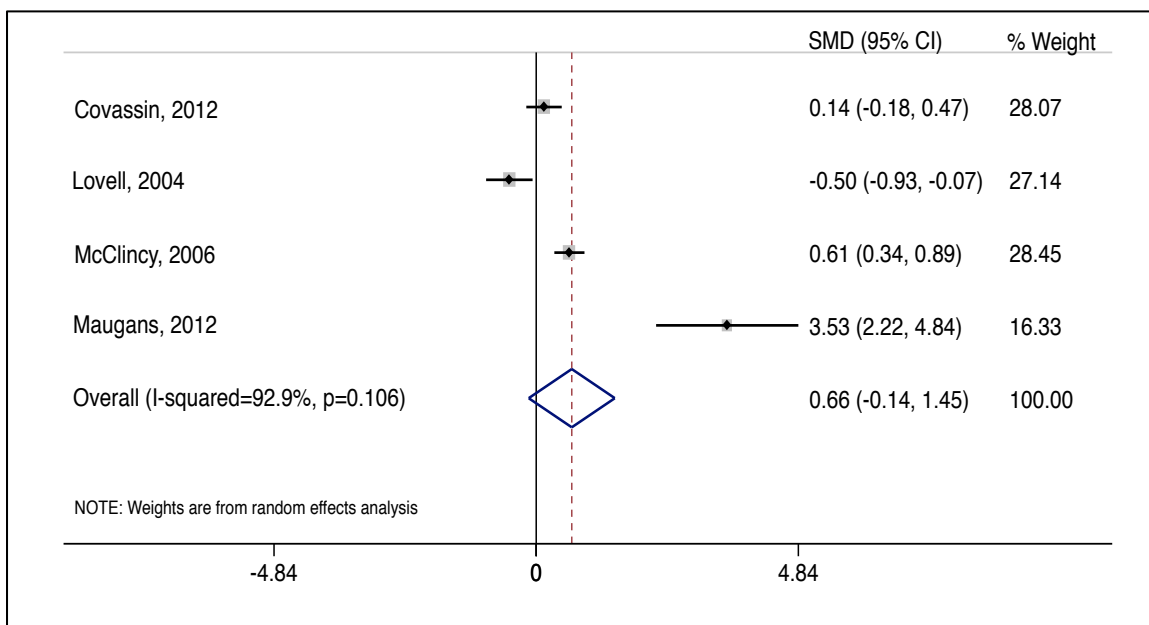
Figure 2.6. ImPACT Reaction Time Score Forest Plot.

Note: Pooled standardized mean differences for ImPACT Reaction Time Score calculated using Cohen's method and DerSimonian and Laird random effect weighting with heterogeneity estimates taken from the inverse-variance fixed effect model.

CHAPTER 3: RELATIONSHIP BETWEEN CONCUSSION INJURY OR LOWER LEG INJURY AND ACADEMIC PERFORMANCE IN HIGH SCHOOL ATHLETES

Abstract

Background. Research indicates that adolescents may have prolonged or new neurocognitive symptoms that appear beyond the post-acute period following concussion injury. The aim of this study was to estimate the incidence of injury and distribution of academic variables (including school attendance) in a population of high school athletes with concussion injury and lower leg injury.

Study Design. A retrospective cohort of athletes participating in school sports in a large suburban school district during the 2009-2010 academic year was analyzed. A group of athletes with sport-related concussion recorded in the electronic medical record and a comparison group who experienced ankle or leg injuries during the study period were included in analyses of injury incidence rates.

Methods. Incidence of injury during the study period was calculated as the number of injuries per 10,000 athletic exposures. Rate ratios were calculated comparing the rates of injury in concussion and ankle/leg injury and between male and female athletes in comparable sports. Pearson correlation, chi-square, and t-test statistics were used to compare injury severity in athletes with concussion and ankle/leg injury. Odds ratios were calculated for odds of injury by grade level, severity of injury by gender, and change in school attendance.

Results. A total of 494 concussion and 472 ankle/leg injuries were recorded during the study period. Football accounted for the greatest proportion of concussion (36%) and ankle/leg (23%) injuries as well as the highest rates of concussion (5.19/10,000AE, 95%CI 4.42-5.96). Football (RR=1.69, 95%CI 1.32-2.18) and lacrosse (RR=1.95 95%CI 1.30-2.96) had significantly higher rates of concussion compared to ankle/leg injury. There was an increased odds of concussion injury for athletes in grade 9 (OR=2.2, 95% CI 1.5-3.2) or grade 10 (OR=2.1, 95%CI 1.5-3.1), than grade 12 when compared to athletes with ankle/leg injuries. We observed an increase in the number of days absent from school for athletes with concussion (OR=1.7, 95% CI 1.3-2.2). The odds of severe concussion was increased in female athletes compared to male athletes (OR=2.4, 95% CI 1.4-4.3).

Conclusions. Concussion injury rates in this population follow patterns similar to other study populations with contact sports, female, and younger athletes demonstrating higher rates of concussion. Athletes with concussion injuries had greater odds of increased absence from school compared to athletes with ankle or leg injuries. As school attendance is highly correlated with academic performance, an increase in school absence may put athletes with concussion at risk for poor academic achievement.

3.1 Introduction

Concussive head impacts are a natural part of most athletic competition. Even in sports that do not permit player contact, there is incidental contact with other players, equipment, or the playing surface that may result in injury. Sport-related concussions, a subgroup of mild traumatic brain injury (mtbi), are accompanied by a constellation of poorly defined short and long-term physical and cognitive consequences for the athlete.

Concussions are characterized by acute and long-term changes in the brain resulting in a variety of physical (e.g. balance problems, loss of consciousness), cognitive (e.g. slowed reaction time, memory loss, concentration difficulty), and emotional (e.g. emotional lability) symptoms.[3, 5] These symptoms may present immediately at the time of injury, or appear in the hours and days following the injury.[6-10] Although the clinical symptoms used to diagnose concussion have been described in detail[2, 3, 6, 9, 11-16].

Sport-related concussions are of particular concern in young athletes. Approximately 30 million children and adolescents in the United States participate in sports every year.[33, 35] Surveillance in emergency departments between 2001 and 2005 indicates that among patients examined for sport-related concussion, a majority were pediatric patients. The highest rates were seen in young athletes aged 10 to 19.[33] Given the physical and cognitive changes occurring during puberty, adolescents are particularly vulnerable for concussion. Injury surveillance and other research consistently find the highest rates of

adolescent sport-related concussion in football, wrestling, soccer, and basketball.(36-40)

While most cognitive detriments associated with concussion are the same in children as in adults, the fact that the adolescent brain is actively maturing may result in significant secondary consequences in children as their ability perform day-to-day tasks impacts their educational and social attainment.(58) Even in the absence of immediate presentation of clinical symptoms commonly observed in adult concussion, injury to the adolescent brain occurs at a lower energy threshold than in adults that manifest in the presentation in symptoms in the post acute period.(59, 60)

There is also evidence that adolescent brains do not follow the same general recovery pattern as adults. While adults generally resolve symptoms within the first week after concussion injury, recent research indicates that young athletes may begin *showing* new cognitive symptoms 7-10 days following injury.(33, 35) The adolescent brain may be more sensitive to metabolic changes following injury than adult brains. This imbalance may impact recovery time, partially explaining the delayed recovery trajectory observed in adolescents compared to adults.(33, 50) History of previous concussion also increases recovery time in adolescents. Subsequent concussions demonstrate more severe immediate symptom presentation and are associated with long-term neurological deficits.(33, 36, 51)

Understanding the recovery of adolescent athletes following concussion is essential to minimize the consequences for the future health of the athletes.

Implementation of neurocognitive testing has improved the evaluation and management of individual sport related concussion and has also allowed study of the neurocognitive symptom presentation and progression following injury. An increasingly number of published studies present results from computerized neurocognitive tests, allowing for examination of trends in differing populations of athletes.

In this section of the dissertation, the distribution and rates of concussion injuries and ankle or leg injuries in a high school athlete population from a large school district were examined. The analyses presented here provide descriptive statistics for sport-related concussion in high school athletes during the 2009-2010 academic year and their social and educational characteristics in comparison to a population of athletes with lower extremity injury.

3.2 Methods

3.2.1 Subjects.

This retrospective study includes 966 participants that were grade 9 through 12 during the 2009-2010 academic year, from one school district consisting of 25 schools. The school district serves a county with approximately one million residents characterized by a an average median household income nearly twice the national average.(106) The school district enrolls over 175,000 students annually and those students perform at a higher level than other students in their state and in the US on standardized tests.(107) [Note: the name of the school district has been omitted from this text and blinded in the references as a condition of IRB approval of this project.] The school district

employs certified athletic trainers to support all athletic programs. The athletic trainers monitor all athlete participation in sport practice and competition, documenting all injuries in an electronic medical record (EMR).

The study population for this research was restricted to students who were participating in scholastic athletics and had records in the electronic medical records maintained by district employed athletic trainers for injuries documented during the 2009-2010 academic year. Inclusion criteria were students with documented sport-related concussion or ankle/lower leg injury during the study period. For inclusion in the study, athlete records were required to include academic information for the study period and data available on injury recovery and return to play. Academic records were not available for students who were not enrolled in the study district prior to the quarter of their injury. For example, an athlete in the ninth grade with an injury during the fall quarter would not have prior academic data available (n=211). These subjects were included in analyses that did not consider prior academic data. During this period, concussion assessment and rehabilitation protocols were consistent across all schools in the district. Additional information regarding time lost from sport and academic time lost was collected. Data regarding injury type, severity, time lost, sport, and date were pulled from the district EMR. Academic data including absence from school, and grade level were extracted from district academic records. The institutional review board of Drexel University and the Research Screening Committee of the study school district approved the study prior to obtaining student records.

3.2.2 Concussion Definition.

Athletes were categorized as exposed for analyses if they had a documented concussion during the academic year 2009-2010. District employed athletic trainers monitor all athlete participation in sports practice and competition, and document all athletic injuries in an electronic medical record (EMR) system for students participating in 27 club and varsity sports. Athletic trainers at official scholastic games and practices diagnose concussion according to a standardized protocol. The assessment tool used has been adapted from the Standardized Assessment of Concussion (SAC).(15, 16) The SAC is administered immediately following injury by a certified athletic trainer and assesses orientation, immediate and delayed memory, concentration, exertional maneuvers, and a brief neurological screening. If the injured athlete scores below a previously measured baseline, the athlete is not returned to play and is referred for follow-up and rehabilitation with athletic trainers. Injury assessment and rehabilitation information is recorded in the EMR by the athletic trainer on a daily basis. Annual in-service sessions provide ongoing training in concussion recognition and management. The athletic trainers have frequent contact with athletes, increasing recognition of changes in behavior associated with concussion. Athletes with complicated presentation of symptoms are referred to physicians for care. Reevaluation and rehabilitation services are provided at the school's athletic training facility by district trained athletic trainers.

3.2.3 Comparison Group Definition

Athletes without concussion during the study period who had sport-related ankle or lower leg injuries documented in the district EMR were included in analyses as a comparison group. To be included in the comparison group, athletes must have a documented ankle or lower leg injury during the 2009-2010 academic year, no concussion during the study period, and academic information available for the study period.

3.2.4 Variables

Variables used in analyses include athletic exposure, time lost from sport (injury severity), absence from school, grade level, gender, and sport played at the time of injury.

To calculate injury rates for the population, the number of times the athlete is at risk for injury (either during athletic training sessions or competitions) was included as the denominator measure of exposure to represent person-time. Athletic exposure (AE) was calculated as the number of athletes participating in a sport multiplied by the number of sport training sessions or competitions for a season. For example, a sport with 50 athletes competing in 100 practices or competitions would result in denominator of 5000 AE in the injury rate calculation.

For these analyses, average annual athletic exposure was based on the participation data for 2010-2011 and 2011-2012 academic years, as participation

data for the 2009-2010 study period was not available. Participation numbers do not fluctuate substantially from year to year.

Absence from school was included in study data as the raw number of days that a student was not in school during an academic period. For stratified analyses, a change in school attendance was calculated as the difference in the number of days a student was absent from school during the academic period of injury compared to the academic period prior to injury. The change in school attendance was categorized as "less" if the athlete had fewer days absent in the period of injury compared to the period prior to injury, "same" if the number of days absent was the same, and "more" if the athlete had more days absent from school in the period of injury compare to the period prior to injury.

Time lost from sport was calculated as the number of days elapsed from the date of the injury to the date the athlete was returned to play. Time lost from sport was used as a measure of injury severity, with more severe injuries requiring a longer period of time before the athlete returns to play. This measure is a good indication of time required for recovery from injury and is used in these analyses to represent the severity of the injury. Gender was not reported directly in study data and was inferred in a subset of the study population from the sport played where gender was indicated in the name of the sport. For example, athletes coded as playing "Girls Soccer" were inferred to be female, while those playing "Boys Soccer" were inferred to be male.

Missing data were identified for each variable. School absences were missing in the quarters prior to injury for students who were not enrolled in the

district high school system prior to the quarter of their injury. These subjects were included in calculation of incidence rates, but not in analyses of change in absence from school.

3.2.5 Statistical Analysis.

Injury rates were calculated for each sport and stratified by gender when possible. Injury rates per 10,000 athletic exposures were calculated as a measure of the incidence of injury during the study period. Using athletic exposures as the denominator allows for comparison of injury rates between populations. Rate ratios were calculated to compare the rates of injury in concussion and ankle/leg injury populations as well as between male and female athletes in comparable sports. Pearson chi-square statistics and student t-tests were used to compare injury severity (measured by time lost from sport) in athletes with concussion to athletes with ankle/leg injury. Odds ratios were calculated for odds of injury severity by gender and odds of increased absence from school by injury type. All analyses were performed with Stata/IC 11.2 for Mac. Results for comparative statistics were considered statistically significant at a *p* value <0.05.

3.3 Results

A total of 494 concussion injuries and 472 ankle/leg injuries were recorded during the study period, inclusive of injuries without prior academic data available. Information about injury severity and academic information was not available for all subjects. 86 athletes with concussion and 47 athletes with

ankle or leg injury did not have prior academic data available for analyses. These subjects were included in calculation of injury rates, but not in calculations that require academic variables prior to injury. Ten athletes with concussion and five athletes with ankle or leg injury did not have information on time lost from sport. These subjects were excluded from calculation of injury severity.

Football accounted for the greatest proportion of concussion injuries (36%) and ankle/leg injuries (23%) and the highest concussion injury rate (5.19/10,000AE 95%CI 4.42-5.96). Football (Rate Ratio=1.69 95%CI 1.32-2.18) and lacrosse (Rate Ratio=1.95 95%CI 1.30-2.96) both resulted in statistically significant higher rates of concussion than ankle/leg injuries. Basketball (Rate Ratio=0.56 95%CI 0.33-0.93), cross country/track (Rate Ratio=0.20 95%CI 0.10-0.37), and soccer (Rate Ratio=0.69 95%CI 0.48-1.00) resulted in statistically significant lower rates of concussion injuries compared to ankle/leg injuries (Table 3.1). Among concussion injuries, football, baseball/softball, basketball, and wrestling had a higher proportion of injuries that resulted in more than 14 days of time lost than injuries that resulted in less than 10 days of time lost (Table 3.2).

Table 3.3 provides information about the distribution of injuries by type and grade level. Ankle and leg injuries were evenly distributed by grade level with approximately 25% of injuries occurring in athletes at each grade level. In the group with concussion injuries, however, a higher proportion of injuries occurred in younger athletes. There were increased odds of concussion injury in

athletes in grade 9 (OR=2.2, p<0.001, 95% CI 1.5-3.2) or grade 10 (OR=2.1, p<0.001, 95%CI 1.5-3.1), when compared to athletes in grade 12.

The mean (standard deviation) number of days absent from school in the quarter prior to injury was 1.57 (1.93) for athletes with concussion and 1.48 (1.82) for athletes with ankle or leg injury. In the quarter of injury, the mean (standard deviation) number of absences for athletes with concussion was 2.29 (2.84, p<0.001) and 1.54 (2.00, p=0.53) for athletes with ankle or leg injury. Athletes with concussion injury had an odds of missing more days of school in the academic period of injury that is 1.7 times that of having the same or fewer days missed in the academic period of the injury (OR=1.7, p<0.011, 95% CI 1.3-2.2).

For 164 athletes with concussion (34% of athletes with concussion), gender could be inferred from the sport played (67 male athletes, 97 female athletes). In this subpopulation of athletes female athletes account for a greater proportion of concussion in each sport with the exception of lacrosse. Table 3.5 details the distribution of concussion injuries by gender and sport. Rate ratios for sports where gender could be inferred illustrate that females have a greater rate of concussion injuries than male athletes (basketball Rate Ratio=3.72(95% CI 1.43-11.38), cross country/track Rate Ratio=2.69(95% CI 0.72-12.22), lacrosse Rate Ratio=1.10(95% CI 0.67-1.78), soccer Rate Ratio=3.11(95% CI 1.65-6.20). Female athletes were more likely to have more severe concussions than male athletes participating in comparable sports (Table 3.6). Female athletes had a mean time lost from sport of 25.79 days (standard deviation 1.81) with concussion and 20.21 days (standard deviation 6.08) with ankle or leg injury.

Males had a mean time lost form sport of 21.85 days (standard deviation 1.55) with concussion and 14.5 days (standard deviation 1.48) with ankle or leg injury. While the difference in mean days lost from sport was not statistically significant for female athletes compared to male athletes, odds ratios comparing days lost from sport indicated that female athletes had higher odds of concussion injuries with time lost from sport of more than 14 days than injuries with time lost of less than 10 days compared to male athletes with concussion playing comparable sports (OR=2.4, p=0.002, 95% CI 1.4-4.3). This association is not evident when athletes with ankle and leg injuries were compared (OR=1.25, p=0.89, 95%CI 0.81-1.93), there was not a statistically significant difference in the number of days lost from sport based on gender.

3.4 Discussion

These descriptive analyses confirm that the study data are consistent with other study populations and provide information about subpopulations, injury severity, and comparative results for the two populations of athletic injury.

During this study period, 494 concussion injuries and 473 ankle or leg injuries were recorded. Many of the results presented here are consistent with other studies examining concussion injuries and recovery in high school athletes. First, football (36% of concussion injuries, injury rate=5.19/10,000AE, 95%CI 4.42-5.96) and lacrosse (15% of concussion injuries, injury rate= 4.77/10,000AE, 95%CI 3.68-5.89) account for a large proportion of concussion injuries in this population. These result align with results from a 10 year prospective study

(between academic years 1997-1998 and 2007-2008) of concussion rates in the same study population that found high rates of concussion in athletes participating in these collision sports (39). This trend is true in other study populations, as well.(37, 45) In a sample of 100 US high schools, Gessel et al(37) studied injury rates in 9 sports during the 2005-2006 academic year. Their study documented an overall concussion rate of 2.3 injuries per 10,000 AE with the highest rate occurring in football participants (4.7 concussion injuries per 10,000 AE). (37) Marar et al calculated an injury rate of 2.5 concussions per 10,000AE for a national sample of high school injuries in 20 sports, with the highest concussion rates resulted from participation in football (6.4), boys' hockey (5.4) and boys' lacrosse (4.0) and a higher rate of concussion in girls than boys (RR=1.7, 95%CI 1.4-20).(45)

Additionally, concussion severity results in this study are consistent with data from other populations, as well.(45, 108, 109) These studies presented data indicating that concussions in football, baseball, basketball, and wrestling are more likely to have prolonged recovery compared to concussions occurring in other sports. In this study, football (mean 21.68, sd 2.27, p=0.004), baseball/softball (mean 31.79, sd 6.72, p=0.037), basketball (mean 18.12, sd 3.04, p=0.005), and wrestling (mean 27.6, sd 2.76, p=0.030) had a higher proportion of concussion injuries that resulted in more than 14 days of time lost from sport than concussion injuries that resulted in less than 10 days of time lost.

Finally, in the subpopulation where gender could be inferred from the sport played, female athletes experienced rates of concussion approximately 3

times higher than male athletes in each sport except lacrosse. It should be noted that lacrosse rules are different for females and males, female athletes are not allowed as much direct contact as male athletes, making lacrosse less comparable between genders than sports that do not have rule modification by gender. The rate ratio for female:male concussion rates in basketball (Rate Ratio=3.72, p=0.0014), cross country/track (Rate Ratio=2.69, p=0.54), and soccer (Rate Ratio=3.11, p=0.001) indicated higher rates of concussions experienced by female athletes. Female athletes had higher odds of more severe concussion than male athletes participating in equivalent sports (OR=2.4, 95%CI 1.36-4.34). These trends are not evident when comparing athletes with ankle and leg injuries (OR=1.25, 95%CI 0.81-1.93).

In this study population, a significantly higher proportion of concussion injuries in younger athletes compared to ankle or leg injuries was observed. Odds of concussion injury were higher for athletes in grade 9 (OR=2.2, 95%CI 1.5-3.2) or grade 10 (OR=2.1, 95%CI 1.5-3.2) than in grade 12 when compared to athletes with ankle and leg injuries. This result is consistent with younger athletes being more susceptible to concussion injuries (33, 36), but could also be explained by younger athletes being more willing to openly report injury symptoms than older athletes. It is also possible that athletes at highest risk for concussion injury that experience concussion at younger age are no longer participating in sport at later grades.

Athletes in this study population with concussion injury were nearly twice as likely to have a significant increase in the number of days absent from school

than athletes with ankle or leg injuries. This result is of particular interest in the context of this dissertation as absence from school is closely tied to academic performance. Students who are absent from the classroom miss instructional time and are more likely to perform poorly on classroom and standardized assessment.(110)

The data from this population are frequently used in other athletic injury research and while the dataset used for these analyses was limited, the overall quality of the data is high with few missing records and a history of population data for comparison.

Limitations of this study include the limited data available on the study population and variables that could have contributed to the understanding of the data presented. For example, access to gender and calendar age were not available in the analytic data set. These variables were inferred from data available, which provide reasonable proxy measures. Where possible, gender was inferred from the sport played. Calendar age was not provided in the analytic data set. Instead, academic grade level is used to represent developmental age. Most state athletics regulatory associations have strict age eligibility rules, ensuring that athletes participating in high school athletics are under age nineteen.

Diagnosis of concussion is dependent on accurate self-report of symptoms by the injured athlete and the athletic trainer correctly recognizing symptoms. Underreporting of symptoms by athletes is well documented (39, 91, 111, 112) and necessarily means that not all cases are reported. Concussions that are diagnosed

and recorded may not be representative of all actual concussive incidents. These analyses were limited to subjects with injuries that were diagnosed and recorded in the EMR of the study school district, presenting a potential for selection bias. Athletes whose concussions were recorded in the EMR were likely more severe cases. Therefore, these results may not apply to athletes with less severe concussion injuries. Additionally, athletes with concussions that were not recorded due to unreported symptoms may differ from the subjects with a comparable level of symptoms who do report. These data do not capture the athletes whose injuries occurred outside of the district athletic programs, unless follow-up with a district athletic trainer was documented. There are likely other injuries that occurred during recreational activity or prior to enrollment in the district. These incidents of injury are not identified in the EMR. However, the study population represents the athletes accessible for intervention and follow-up by district personnel.

External validity of these results is of concern due to the fact that the study school district has committed resources and attention to athletic programs that are not present in other schools. The injury experience of athletes in this study may not be reflective of the experience of athletes in other school systems where athletic programs do not include medical support.

These analyses provide a foundational understanding of the distribution of injuries and injury rates experienced by athletes in the study population. The data from this population are frequently used in other athletic injury research and while the data did not provide specific measure of some potential

confounders, the overall quality of the data is high with few missing records and a history of injury rates in this population for comparison.

We found a higher proportion of concussion injuries in younger athletes compared to ankle or leg injuries and a higher rate and more severe concussions in female athletes compared to male athletes playing comparable sports. We also found a statistically significant increase in the number of days absent from school in the period of injury for athletes with concussion injury. This finding is of particular interest as absence from school is closely tied to academic performance(110, 113) and this population of athletes is at risk for decreased performance on classroom and standardized assessment due to missed instructional time.

Missed instructional time due to sport-related injury is of interest to educational and medical professionals treating high school athletes. Current concussion rehabilitation protocols recommend cognitive rest following injury to ensure full recovery. In high school athletes, prolonged cognitive rest may result in absence from school which impacts instructional time and may compound effects on academic performance. Further study of the association between academic performance and athletic concussion injury is important to understand this risk. Individual concussion rehabilitation plans may need to consider a balance between prolonged cognitive rest and return to classroom instruction to mitigate effects on academic performance.

3.5 Tables and Figures

Table 3.1. Distribution of injury by sport and injury type.

Sport	Average Annual Athletic Exposures	CONCUSSION INJURIES		ANKLE/LEG INJURIES			
		N (%)	Injury rate per 10,000 AE (95% CI)	N (%)	Injury rate per 10,000 AE (95% CI)	Rate Ratio (95% CI)	Rate ratio p-value
Baseball/Softball	117,484	19 (4)	1.62 (0.89-2.34)	18 (4)	1.53 (0.83-2.24)	1.06 (0.52-2.13)	0.44
Basketball	137,316	25 (5)	1.82 (1.11-2.53)	45 (10)	3.28 (2.32-4.24)	0.56 (0.33-0.93)	0.009
Cheer and Dance	99,715	36 (8)	3.61 (2.43-4.79)	27 (6)	2.71 (1.69-3.73)	1.33 (0.79-2.28)	0.13
Cross Country and Track[1]	511,510	12 (3)	0.23 (0.10-0.37)	61 (14)	1.19 (0.89-1.49)	0.20 (0.10-0.37)	<0.0001
Field Hockey	92,167	12 (3)	1.30 (0.57-2.04)	11 (2)	1.19 (0.49-1.90)	1.10 (0.44-2.73)	0.42
Football *	335,418	174 (36)	5.19 (4.42-5.96)	103 (23)	3.07 (2.48-3.66)	1.69 (1.32-2.18)	<0.0001
Lacrosse *	155,181	74 (15)	4.77 (3.68-5.89)	38 (9)	2.45 (1.67-3.23)	1.95 (1.30-2.96)	0.003
Soccer	146,086	53 (11)	3.63 (2.65-4.61)	77 (17)	5.27 (4.09-6.45)	0.69 (0.48-1.00)	0.018
Wrestling	66,776	30 (6)	4.49 (2.89-6.10)	21 (5)	3.14 (1.80-4.49)	1.43 (0.79-2.63)	0.11
Other sports[2]	266,805	45 (9)	1.69 (1.19-2.18)	44 (10)	1.65 (1.16-2.14)	1.02 (0.66-1.59)	0.46
TOTAL	1,927,738	480 (100)	2.49 (1.78-3.01)	445 (100)	2.3 (1.65-3.07)		

P-values were calculated from Pearson chi-square differences in injury rate by sport.

Average annual athletic exposures are based on 2010-2011 and 2011-2013 participation data for the study district.

"*" Indicates a statistically higher rate of concussion than ankle/leg injury

[1] Cross Country and Track includes cross country, indoor track, and outdoor track

[2] "Other" sports include tennis, swimming, volleyball, golf, crew, and injuries that happen outside of school sports

Table 3.2. Severity of concussion injuries (as represented by days lost from sport) by sport.

Sport	Mean (sd)	Days lost from sport N(%)			
		<10 days	10-14 days	>14 days	p-value[1]
Baseball/Softball*	31.79(6.72)	1 (5)	3 (16)	15 (79)	0.037
Male	*19*	*0*	*0*	*1*	
Female	*32.5(7.07)*	*1*	*3*	*14*	
Basketball	18.12 (3.04)	11 (44)	6 (24)	8 (32)	0.005
Male	*12.3 (3.78)*	*4*	*1*	*1*	
Female	*19.95 (3.77)*	*7*	*5*	*7*	
Cheer and Dance*	25.91(4.26)	8 (22)	5 (14)	23 (64)	0.0063
Cross Country and Track*	40.5 (9.05)	1 (8)	3 (25)	8 (67)	0.022
Male	*20.5(10.22)*	*1*	*2*	*1*	
Female	*50.5(11.30)*	*0*	*1*	*7*	
Field Hockey	26.92(6.69)	3 (25)	2 (17)	7 (58)	0.97
Football*	21.68(2.27)	48 (28)	52 (30)	74 (42)	0.004
Lacrosse*	22.61(2.04)	14 (19)	17 (23)	43 (58)	0.037
Male	*21.74(2.55)*	*10*	*11*	*21*	
Female	*23.93(3.41)*	*4*	*6*	*18*	
Soccer	21.35 (3.06)	10(19)	16 (30)	27 (51)	0.072
Male	*17.36 (3.29)*	*4*	*3*	*7*	
Female	*22.82 (4.01)*	*6*	*13*	*19*	
Wrestling*	27.6(2.76)	3 (10)	3 (10)	24 (80)	0.030
Other sports	31.79(6.72)	13 (22)	7 (12)	38 (66)	0.49
Male	*10*	*0*	*1*	*0*	
Female	*22(4.20)*	*2*	*3*	*6*	

P-values were calculated from Pearson chi-squared differences in the proportions comparing the proportion of athletes with the most severe injuries (>14 days lost from sport) with the least severe injuries (<10 days lost from sport)

"*" indicates sports with a statistically significant higher proportion of severe injuries than minor injuries (p<0.05)
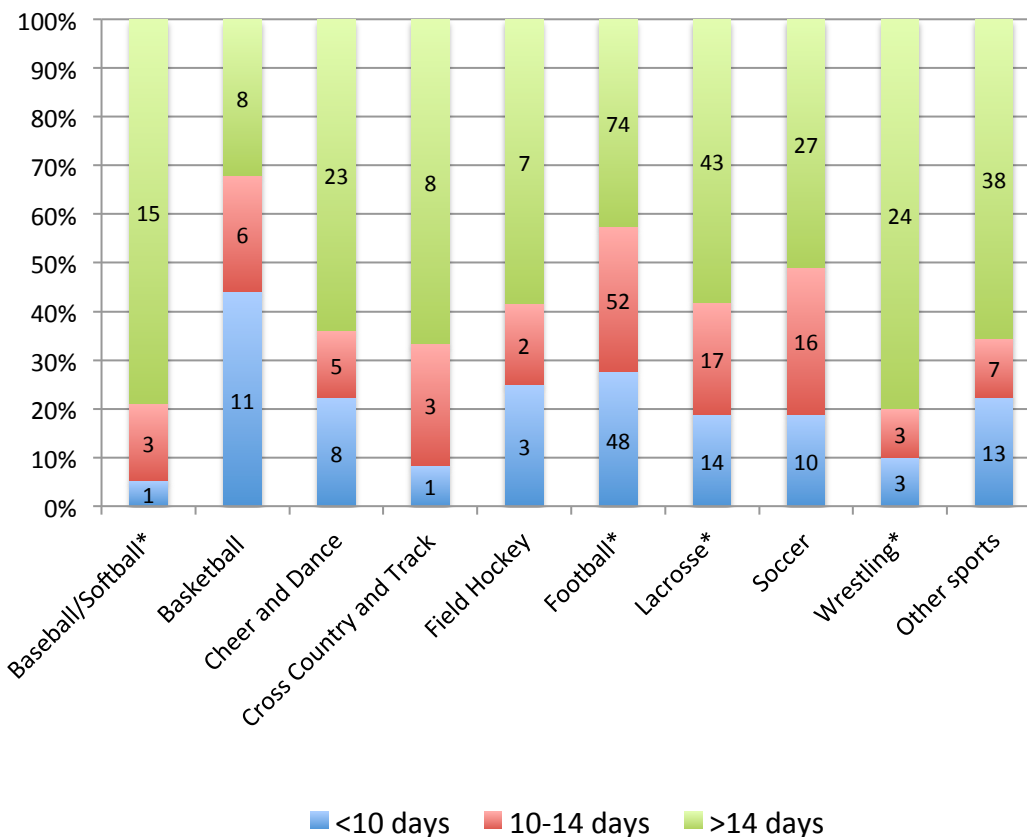
Figure 3.1 Severity of concussion injury by sport.

Note: Stacked bars represent the proportion of days lost from sport in each severity category: less than 10 days, 10-14 days, and more than 14 days. "*" indicates sports with a statistically significant($p<0.05$) higher proportion of severe injuries (>14 days lost) than minor injuries (<10 days lost).

Table 3.3. Distribution of injury by grade level.

Grade Level	Concussion Injuries N (%)	Ankle/Leg Injuries N (%)	OR (95% CI)	p-value
9 (Freshman) *	157 (32)	118 (25)	2.2 (1.5-3.2)	<0.001
10 (Sophomore)*	162 (33)	125 (26)	2.1 (1.5-3.2)	<0.001
11 (Junior)	105 (21)	114 (24)	1.5 (1.0-2.3)	0.05
12 (Senior)	70 (14)	116 (25)	REFERENCE	
TOTAL	494 (100)	473 (100)		
P-values were calculated from Pearson chi-square differences in proportion of each type of injury by grade level. "*" indicates with a statistically significant higher proportion of concussion injuries (p<0.05).				

Table 3.4. Change in school attendance by injury type.

| Change in school attendance	Concussion Injury	Ankle/Leg Injury	Odds Ratio (95% CI)	p-value
	Mean(sd)	Mean(sd)		
Absence prior to injury	1.57(1.93)	1.48(1.82)		0.46
Absence in period of injury	2.29 (2.84)	1.54(2.00)		<0.001
	N(%)	N(%)		
Less absence than prior to injury	149 (31)	156 (33)	REFERENCE	<0.001
Same number of absences	117 (24)	157 (34)		
More absences than prior to injury	222 (45)	153 (33)	1.7 (1.3-2.2)	
- Change in school attendance was calculated as the difference in the number of days absent from school in the academic period of the injury compared to the academic period prior to injury. - Odds ratio compares the odds of an increase in school absence compared to no change or fewer absences in athletes with concussion versus athletes with ankle or leg injuries.				
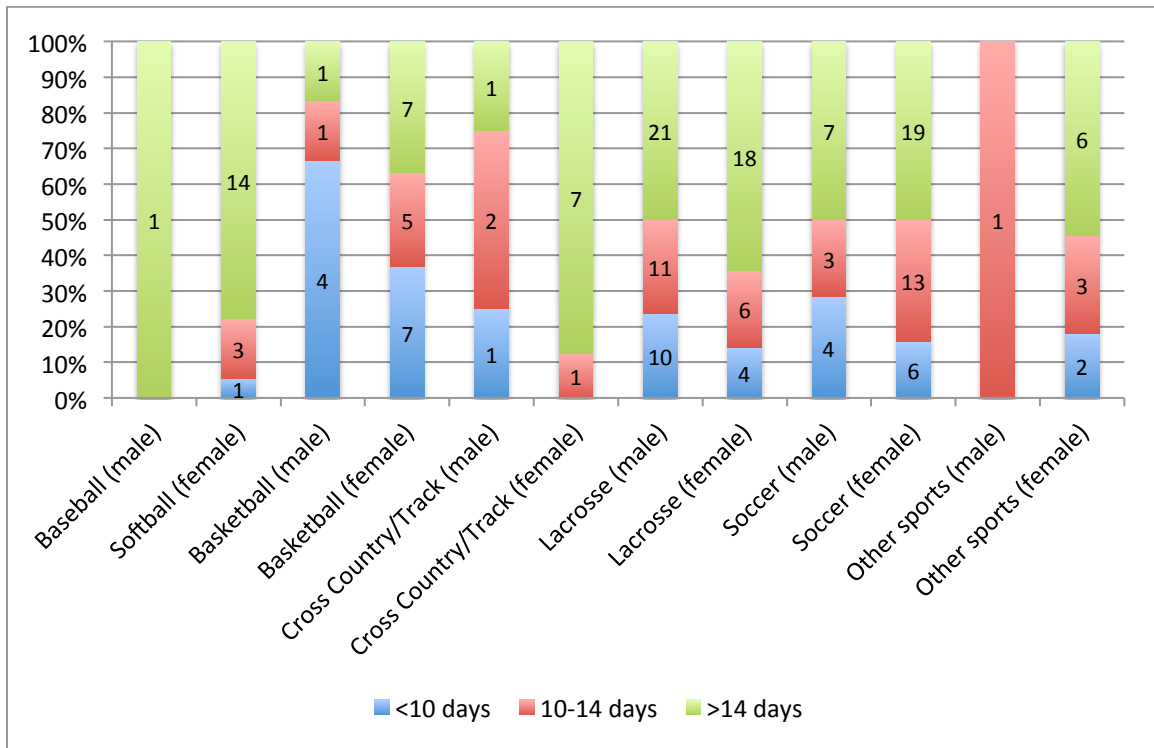
Figure 3.2 Severity of concussion injury by sport and gender.

Note: Stacked bars represent the proportion of days lost from sport in each severity category: less than 10 days, 10-14 days, and more than 14 days.

Table 3.5. Distribution of concussion injuries by gender and sport.

Sport	Male Athletes		Female Athletes		Rate Ratio (95%CI)	p-value
	Average annual athletic exposures	Number of concussion injuries (%)	Average annual athletic exposures	Number of concussion injuries (%)		
Basketball *	74,158	6 (9)	63,158	19 (20)	3.72 (1.43-11.38)	0.0014
Cross Country and Track	293,469	4 (6)	218,043	8 (8)	2.69 (0.72-12.22)	0.054
Lacrosse	93,591	43 (64)	61,591	31 (32)	1.10 (0.67-1.78)	0.35
Soccer *	77,067	14 (21)	69,019	39 (40)	3.11 (1.65-6.20)	0.001
TOTAL		67 (100)		97 (100)		
P-values were calculated from Pearson chi-square comparison of rates of injuries by gender for each sport where gender could be inferred.						

Table 3.6. Odds of injury severity by gender.

Days lost from sport	Male Athletes N (%)	Female Athletes N (%)	Odds Ratio (95% CI)	p-value
Concussion Injury				
Mean (sd)	*21.85(1.55)*	*25.79 (1.81)*		*0.10*
<10 days	67 (27)	20 (16)	REFERENCE	
10-14 days	70 (29)	31 (24)	1.4 (0.77-2.85)	0.24
>14 days	106 (44)	77 (60)	2.4 (1.36-4.34)	0.002
Ankle/Leg Injury				
Mean (sd)	*14.50 (1.48)*	*20.21 (6.08)*		*0.30*
<10 days	141 (57)	101 (55)	REFERENCE	
10-14 days	41 (17)	24 (13)	0.82 (0.46-1.44)	0.48
>14 days	65 (26)	58 (32)	1.25 (0.81-1.93)	0.89
Odds ratios compare female athletes to male athletes and the least severe injuries (<10 days lost from sport) as the reference.				

CHAPTER 4: LONGITUDINAL ANALYSIS OF ACADEMIC PERFORMANCE IN HIGH SCHOOL STUDENTS WITH ATHLETIC INJURIES

Abstract

  Background. Understanding the recovery of adolescent athletes following concussion, including the effects on academic performance, is essential to minimize the consequences for the future health of the athletes. The aim of this study is to use longitudinal statistical methods to characterize the impact of sport-related concussion on academic performance in high school athletes.

  Study Design. A retrospective cohort of athletes participating in school sports in a large suburban school district during the 2009-2010 academic year was analyzed. A group of athletes with sport-related concussion recorded in the electronic medical record and unexposed comparison group who experienced ankle or knee injuries during the study period were included in analyses. Academic grades and absence from school in the two academic periods prior to injury, the academic period of the injury, and the two academic periods following the injury were analyzed. Subgroup analyses were conducted to explore the effects in younger athletes and gender groups.

  Methods. Students t-tests were conducted to test for a change in mean GPA from the academic period prior to injury and the academic period of injury, effect sizes were calculated based on Cohen's method. Repeated measures MANOVA were conducted to test for differences between groups on mean GPA in the academic period prior to injury and the academic period of the injury. Growth curve models were constructed to visualize the mean change in academic

performance over time. Random coefficient models were used to explore and explain average trends in mean GPA and individual differences in mean GPA.

Results. 494 concussion injuries and 473 ankle/leg injuries were recorded during the study period. While there was not an overall main effect noted in this population, there is an indication that younger athletes with more severe injury are at risk for poor academic outcomes following injury. Athletes with both concussion injury and ankle or leg injury show a decline in academic performance in the academic period of injury and those that follow. Both groups also demonstrate an increase in the number of days absent from school in the period of injury compared to the period prior to injury. Analyses of a subgroup of younger athletes (grades 9 and 10) with more severe injuries there was a 16% greater decline in academic performance for the group with concussion injuries compared to those with ankle or leg injury (coeff=-0.18, p=0.017, 95% CI=-0.32 to -0.03).

Conclusions. High school athletes with sport-related concussion are at risk for decline in academic performance following injury. Athletes with both concussion and ankle or leg injury experience an increase in the number of days absent from school, which can negatively impact academic achievement. Research regarding development of targeted instructional interventions that provide opportunities for academic support as well as cognitive rest in an effort to get students back to pre-injury performance levels is warranted.

4.1 Introduction

Sport related injuries have consequences beyond the physical manifestations of the injuries. School-aged athletes with injuries have higher rates of school absence than students without injury(114-116), which has the potential to impact academic performance. Symptoms associated with concussion such as concentration and memory difficulties, may further impact student performance in school.

Compared to adults, adolescents are at increased risk for concussion with greater severity and prolonged recovery from symptoms.(3, 71, 117) While most cognitive detriments associated with concussion are the same in children as in adults, the fact that the adolescent brain is actively maturing may result in significant secondary consequences in children as their ability perform day-to-day tasks impacts their educational and social attainment.(58)

A review of published studies examining cognitive effects 6 to 14 days following concussion in adolescents, provides evidence that adolescent athletes experience a range of neurocognitive symptoms 6 or more days following concussion injury.(118) Athletes in the reviewed studies demonstrated declines in the domains of reaction speed, memory, and total symptom scores at the time of follow up.(118)

These studies support the current understanding of adolescent athlete recovery from concussion injury. While adults generally resolve symptoms within the first week after injury, recent research indicates that young athletes may begin *showing* new cognitive symptoms 7-10 days following injury.(33, 35)

The adolescent brain may be more sensitive to metabolic changes following injury than adult brains, impacting recovery time and partially explaining the delayed recovery trajectory observed in adolescents compared to adults.(33, 50) Adolescents with subsequent concussions demonstrate more severe immediate symptom presentation and may experience longer-term neurological deficits.(33, 36, 51)

Recovery trajectories following concussion injuries are highly individual and difficult to predict. Severity and duration of neurocognitive and other symptoms are influenced by individual characteristics, injury conditions, and return to play progression. Deficits in different cognitive domains may be the result of injury site, as different parts of the brain control different cognitive function. On average, however, evidence is increasing that adolescents will experience symptoms that persist beyond the acute period of the injury.

The aim of this section of the dissertation was to explore the longitudinal trends of academic performance in high school athletes with concussion injury and ankle/leg injury using random effects models to produce effect estimates.

4.2 Methods

4.2.1 Study Subjects.

This retrospective study includes participants that were grade 9 through 12 from one school district consisting of 27 schools. The school district serves a county with approximately one million residents characterized by a higher than average median household income (approximately twice the national median

household income).(106) The school district enrolls over 175,000 students annually and those students perform at a higher level than other students in their state and in the US on standardized tests. The school district employs certified athletic trainers to support all athletic programs. The athletic trainers monitor all athlete participation in sport practice and competition, documenting all injuries in an electronic medical record (EMR).

The study population for this research was restricted to students who were participating in scholastic athletics and had records in the electronic medical records maintained by district employed athletic trainers for injuries documented during the 2009-2010 academic year. Inclusion criteria were students with documented sport-related concussion or ankle/lower leg injury. During this period, concussion assessment and rehabilitation protocols were consistent across all schools in the district. Additional information regarding time lost form sport and academic time lost was collected. The institutional review board of Drexel University and the Research Screening Committee of the study school district approved the study prior to obtaining student records.

4.2.2 Concussion Definition.

Athletes were categorized as exposed for analyses if they had a documented concussion during the study period. For inclusion in the study, athlete records were required to include academic information for the study period and data available on injury recovery and return to play. Sport-related concussions were diagnosed by district employed athletic trainers using a

standardized protocol. The athletic trainers monitor all athlete participation in sports practice and competition, and document all athletic injuries in an electronic medical record (EMR) system for students participating in 27 club and varsity sports. Athletic trainers at official scholastic games and practices diagnose concussion according to a standardized protocol. This assessment tool has been adapted from the Standardized Assessment of Concussion (SAC).(15, 16) The SAC is administered immediately following injury by a certified athletic trainer and assesses orientation, immediate and delayed memory, concentration, exertional maneuvers, and a brief neurological screening. If the injured athlete scores below a previously measured baseline, the athlete is not returned to play and is referred for follow up and rehabilitation with athletic trainers. Injury assessment and rehabilitation information is recorded in the EMR by the athletic trainer on a daily basis. Annual in-service sessions provide ongoing training in concussion recognition and management. The athletic trainers have frequent contact with athletes, increasing recognition of changes in behavior associated with concussion. Athletes with complicated presentation of symptoms are referred to physicians for care. Reevaluation and rehabilitation services are provided at the school's athletic training facility by district trained athletic trainers.

4.2.3 Comparison Group Definition

Athletes without concussion during the study period who had ankle or lower leg injuries were included in analyses as a control group. To be included in the control group, athletes must have a documented ankle or lower leg injury

during the study period, no concussion during the study period, academic

information available for the study period, and data on recovery and return to

play.

4.2.4 Outcome Definition.

Subject specific and overall grades were obtained as measures of academic

performance.   The study school district has a common grading scale across all

schools. Grades for two total quarters are considered in t-test and MANOVA

analyses – the quarter prior to injury and the quarter of the injury. Grades for

five academic periods (two prior to injury, the quarter of the injury, and two

quarters following injury) are analyzed using longitudinal methods.

4.2.5 Variables

Variables used in analyses include time lost from sport, absence from

school, grade level, gender, and sport played at the time of injury.

Absence from school was included in study data as the raw number of days

that a student was not in school during an academic period. For analyses, a

change in school attendance is calculated as the difference in the number of days

a student was not in school during the academic period of injury compared to the

academic period prior to injury. The change in school attendance was

categorized as "less" if the athlete had fewer days absent in the period of injury

compared to the period prior to injury, "same" if the number of days absent was

the same, and "more" if the athlete had more days absent from school in the period of injury compare to the period prior to injury.

Time lost from sport was calculated as the number of days elapsed from the date of the injury to the date the athlete was returned to play. Time lost from sport is used as a measure of injury severity, with more severe injuries requiring a longer period of time before the athlete returns to play. Gender is not reported directly in study data and was inferred in a subset of the study population from the sport played where gender is indicated in the name of the sport. For example, athletes coded as playing "Girls Soccer" are inferred to be female, while those playing "Boys Soccer" are inferred to be male.

In an effort to identify athletes with injuries early in the quarter to allow time for an effect on academic performance, analyses were restricted to athletes with injuries in the first half of the quarter. This restriction on the study population did not change the result.

4.2.6 Statistical Analysis.

Unpaired student's t-tests were conducted to test for a change in mean GPA from the academic period prior to injury and the academic period during which the injury occurred. Data are presented for athletes with concussion and with ankle or leg injuries, further subdivided by severity into varying periods of time lost for sport. Effect sizes were calculated based on Cohen's method, which estimates the magnitude of the effect by describing the mean difference between

groups in terms of standard deviations(119). To calculate Cohen's *d*, the mean difference is divided by the pooled standard deviation for the samples.

Repeated measures MANOVA were conducted to test for differences between groups on mean GPA in the academic period prior to injury and the academic period of the injury. Type I errors were assessed through simulation, due to violations of the normality assumptions for the ANOVA test. Simulations were performed, computing sample sizes and standard deviations, assuming equal means. The simulation produces a p value for 5,000 ANOVA and F-test simulations. If this number deviates from the reported p-value for the study data analyses, type I error is more likely.

Growth curve models were constructed to visual the mean change in academic performance over time. Random coefficient models were used to explore and explain average trends in mean GPA and individual differences in mean GPA by allowing random variation in subject-specific relationships with piecewise splines where both the level of response and the change is allowed to vary between groups after controlling for covariates. Polynomial terms were included to correct for nonlinear trends in the outcome variable. Model fit was assessed using likelihood ratio tests.

Analyses were restricted to younger athletes (academic years 9 and 10) with more severe injuries (time lost from sport greater than or equal to 10 days) for subgroup analyses, to test the a prior hypotheses predicting greater potential for effect in these groups.

All analyses were performed with Stata/IC 11.2 for Mac. Results were considered statistically significant at a *p* value < 0.05. Analyses were restricted to several subpopulations to assess the effects in specific groups. Interactions between exposure, time, and grade level were considered to test a prior hypotheses.

4.3 Results

A total of 494 concussion injuries and 473 ankle and leg injuries were recorded during the study period. Of this population, 275 were in grade 9 at the time of injury, 287 in grade 10, 219 in grade 11, and 186 in grade 12. Table 4.1 provides the distribution of each injury type in the population. Information about injury severity and academic data were not available for all subjects.

4.3.1 Change in Mean GPA with Injury

Table 4. 2 presents results of student's t-test exploring the change in mean GPA from the academic period prior to injury to the academic period of injury in athletes with concussion injury and athletes with ankle or leg injury.
Athletes with concussion injuries had a mean difference in GPA of -0.011 points on a 4.0 point scale (sd=0.45, p=0.62) and athletes with ankle or leg injuries had a mean difference in GPA of -0.035 (sd=0.44, p=0.10). (Table 4.2) A t-test comparing these mean difference indicated no statistical difference (p=0.43).

In both groups, the decline in academic performance was greater and statistically significant when the analyses were restricted to athletes with the

most significant injury (as measured by time lost from sport greater than 14

days). In this subpopulation, athletes with concussion had a mean difference in

GPA of -0.090 (d=0.14, sd=0.46, p=0.004) and athletes with ankle or leg injuries

had a mean difference in GPA of -.095 (d=0.15, sd=0.39, p=0.010).

Similar subanalyses were conducted for English, Math, and Science

grades, comparing grades in these subjects prior to injury to grades in the

academic period of the injury. No statistically significant differences were found

in the change in these grades before and after injury between the two injury

groups.

A repeated measures MANOVA test of the main effects of injury type,

grade level, and injury severity (as measured by time lost from sport) on the

mean GPA in the academic period prior to injury and the academic period of the

injury shows no main or interaction effects for injury type (p=0.20). Results are

presented in Table 4.3. Grade level (p=0.08), injury severity (p=0.03), and

increased absence from school (p<0.001) were significantly associated with

change in mean GPA. Simulations to assess type I error due to violations of the

normality assumption produced p-values that were not significantly different

from the study data, making type I error in these analyses unlikely.

4.3.2 Longitudinal change in mean GPA

Growth curve models were constructed to observe the mean change in

GPA over time. Figure 4.1 illustrates the mean change in GPA over time in

athletes with concussion injury and athletes with ankle or leg injury. Both groups

experienced a decline in mean GPA at the time of injury and in the academic periods following injury.

Random effects analyses showed that GPA and absences vary both within and between subjects (standard deviation both between and within subjects >0). Grade level, injury type, and time lost from sport also varied between subjects (standard deviation >0). Due to this variation, random coefficient models were constructed allowing both the slope and intercept of the model to vary. Likelihood ratio tests indicated that allowing the slope to vary does not improve the regression model. Likelihood ratio tests comparing the model allowing the intercept (individual mean GPA) to vary by subject resulted in a significantly improved model (p<0.001) compared to a fixed effects model, therefore a random intercept model was used for the analyses presented here.

Random intercept models indicated a decline in academic performance as reported by mean GPA following both concussion and ankle/leg injury when the model is controlled for injury severity, absence from school, and grade level.

After controlling for the number of days absent from school and severity of injury, athletes with concussion experienced a 16% (coeff= -0.18, p=0.017, 95% CI= -0.32 to -0.03) greater decline in average grades over the observation period compared to athletes with ankle/leg injuries for injuries occurring in grades 9 and 10.

4.4 Discussion

In the analyses presented here, the academic performance effects of a concussion injury were compared to other athletic injury. Compared to athletes with ankle/leg injuries, high school students with sport-related concussion did not suffer a significant decline in academic performance. Athletes in both injury groups experienced a decline in mean GPA during the quarter of injury compared to the quarter prior to injury. When analyses were restricted to younger athletes (grades 9 or 10) or those with more severe injuries (time lost from sport greater than 10 days), athletes with concussion injury demonstrated a greater decline in average grades over the observation period than athletes with ankle or leg injury.

These analyses were limited by several factors. First, the dependent variable was not measured in a standardized manner. The grade point average in a given quarter was not necessarily based on the same classes as in a different quarter. Variation in coursework and instructors may have an effect on individual learning. Growth patterns in academic achievement are also associated with decreasing cognitive capacity for new knowledge as a child ages.(30, 57, 120) Curriculum and complexity of instruction also increase with succession through academic grades which can affect student achievement.(120) Additionally, the study sample was drawn from a single school district that is not generalizable to other populations. The study school district has high student achievement when compared to other school districts and students have access to resources that may not be available in other districts.

The random coefficient model is limited by several factors. First, analysis was limited by the assumption of a linear trend in the outcome variable. In this case the trend trajectory was not linear, and a polynomial trajectory correction term was included in the model. This complicates interpretation of the model effect estimates, but capture the patterns of change over time and allow for identification of differences in trends between groups.

Second, the random coefficient model is unable to account for measurement error in the outcome variable as would be possible in a structural equation model. This limitation is outweighed, however, by the flexibility of the random coefficient model when modeling time across outcome measurements. For example – each academic period results in a recorded grade that is based on a variable number of graded elements over variable number of instructional days. These data would be problematic for analysis in a structural equation model, but do not violate any assumptions of the random coefficient model.

In the study population analyzed, there does not appear to be a significant negative effect on academic performance following sport-related concussion in older students or in students with mild concussion when compared to athletes with ankle or leg injury. This finding does not rule out the possibility that individual injury may have academic consequences for an athlete. In the school district considered, athletes have access to care from certified athletic trainers to aid in rehabilitation, and the school district as a whole has a greater awareness of concussion injuries than other school districts that do not have access to resources and training regarding concussion injury rehabilitation. This increased

awareness may be associated with increased accommodation and academic support following injuries that mitigates the academic effects that are of concern.

There appears to be a significant decline in academic performance in younger athletes (grades 9 or 10) with severe concussion injuries compared to athletes with similarly severe ankle or leg injury (measured by time lost from sport). This finding is consistent with the understanding that younger adolescents are more susceptible to concussion injury due to the rapid neurocognitive development occurring during puberty. All adolescent athletes should be closely monitored following concussion injury, but particular attention should be paid to the neurocognitive rehabilitation and academic return of younger athletes. Additional cognitive rest or accommodation in the classroom may be necessary to prevent negative effects on academic performance measures in these athletes.

4.5 Tables and Figures

Table 4.1. Distribution of injury in the study population.

	Concussion Injuries N (%)	Ankle/Leg Injuries N(%)	p-value[4]
Grade Level	494	473	
9 (Freshman)	157 (32)	118 (25)	<0.001
10 (Sophomore)	162 (33)	125 (26)	
11 (Junior)	105 (21)	114 (24)	
12 (Senior)	70 (14)	116 (25)	
Gender[1]	371	430	
Male	243 (65)	247 (58)	0.02
Female	128 (35)	183 (42)	
Severity[2]	493	430	
<10 days lost	112 (23)	242 (56)	<0.001
10-14 days lost	114 (23)	65 (15)	
>14 days lost	267 (54)	123 (29)	
Absence[3]	488	466	
Same or fewer days	266 (55)	313 (67)	<0.001
More days	222 (45)	153 (33)	

[1] Gender was inferred from the sport played as it was not directly described in the study data.
[2] Injury severity was by the number of days lost from sport.
[3] Absence from school was calculated as the difference in the number of days the student was not in attendance during the academic period of the injury compared to the academic period prior to injury.
[4] P-values were calculated from Pearson chi-square differences in proportion of each type of injury.

Table 4.2. Comparison of mean GPA prior to injury to academic period of the injury.

	N	Mean difference	Standard Deviation	p-value	Effect Size
Mean GPA for academic period of injury compared to period prior to injury					
Concussion Injury	426	-0.011	0.45	0.62	0.02
<10 days lost	93	-0.034	0.33	0.18	0.06
10-14 days lost	96	0.011	0.47	0.82	0.02
>14 days lost	219	-0.31	0.46	0.004	0.14
Ankle/Leg Injury	408	-0.035	0.44	0.10	0.05
<10 days lost	238	-0.032	0.49	0.43	0.04
10-14 days lost	67	0.045	0.37	0.76	0.02
>14 days lost	120	-0.095	0.39	0.010	0.15
Overall p-value				0.43	
Effect sizes are calculated based on Cohen's d, p-values test the null hypothesis that there is no change in mean GPA, and the overall p-value tests the null hypothesis that the mean difference in GPA is the same in athletes with concussion and athletes with ankle or leg injury.					

Table 4.3. Effects of injury type and severity on mean GPA.

	Wilks' Lambda	df	F	p-value	Effect Size
Model	0.94	8	3.17	<0.001	
Injury type	0.99	1	1.62	0.20	0.08
Grade Level	0.99	3	1.86	0.08	0.06
Severity	0.98	3	3.36	0.03	0.01
Absence	0.98	1	7.6	<0.001	0.11
[1]Injury type - concussion vs ankle/leg injury [2]Grade level in school (9 through 12) [3]Severity - measured by time lost from sport [4]Absence – increase in absence from school compared to academic period prior to injury MANOVA test of the main and interaction effects of injury type, grade level, and injury severity (as measured by time lost from sport) on the repeated measure of mean grade point average in the academic period prior to injury and the academic period of injury.					

Table 4.4. Results of random intercept models assessing the academic impact of concussion based on severity and grade level.

	Coefficient	Coefficient p-value	95% CI Lower	Upper	Model p-value
Concussion injury	-0.068	0.127	-0.15	-0.29	0.008
Model is controlled for injury severity, absence from school, and grade level					
Severity					
<10 days lost	-0.044	0.605	-0.21	0.122	0.21
10-14 days lost	-0.23	0.015	-0.41	-0.05	0.016
>14 days lost	-0.046	0.48	-0.18	0.08	0.50
Models are controlled for injury type, absence from school, and grade level Severity is reflected in the models as a measure of time lost from sport.					
Grade Level					
9 (Freshman)	-0.17	0.049	-0.34	-0.001	0.039
10 (Sophomore)	-0.10	0.215	-0.27	0.06	0.016
11 (Junior)	0.018	0.828	-0.14	0.17	0.54
12 (Senior)	0.032	0.756	-0.17	0.23	0.82
Models are controlled for injury type, absence from school, and injury severity					

Table 4.5. Results from random intercept model restricted to athletes in lower grades (grade 9 or grade 10) assessing the academic impact of concussion based on severity of injury.

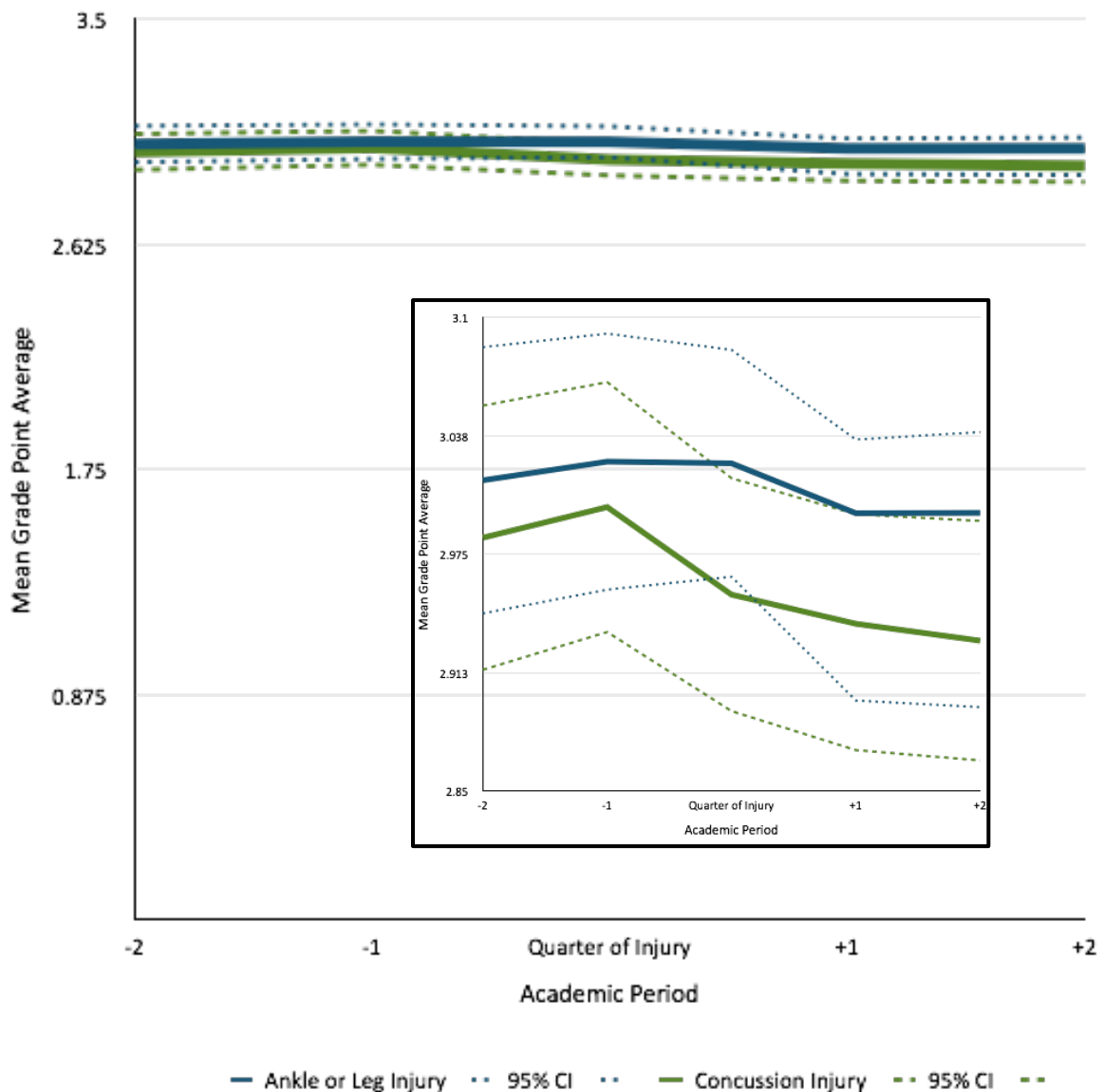|	Coefficient	Coefficient p-value	95% CI Lower	Upper	Model p-value
Severity					
<10 days lost	-0.082	0.484	-0.31	0.14	0.26
>= 10 days lost	-0.18	0.017	-0.32	-0.03	0.012
Model are controlled for absence from school					

Figure 4.1. Growth curve model illustrating change in mean GPA over time.

Note: Academic periods are centered around the quarter of injury. Two quarters prior to injury, the quarter when injury occurred, and two quarters following injury are shown. Dashed and dotted lines show 95% confidence intervals. Inset shows graph with a truncated y-axis to emphasis effects.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

The research presented in this dissertation aims to increase the body of knowledge regarding the post-acute neurocognitive impact of concussion injuries in adolescent athletes. First, a systematic review of current literature addressing the post-acute cognitive effects of concussion in adolescents found that adolescent athletes experience a range of neurocognitive symptom deficits six or more days following their injury. Athletes in the reviewed studies demonstrated significant declines in the domains of reactions speed, memory, and total symptom score during post-acute follow up.

The reviewed studies support the current understanding of adolescent athlete recovery from concussion injury. While adults generally resolve symptoms within the first week after injury, recent research indicates that young athletes may begin *showing* new cognitive symptoms 7-10 days following injury.(33, 35) The adolescent brain may be more sensitive to metabolic changes following injury than adult brains, impacting recovery time and partially explaining the delayed recovery trajectory observed in adolescents compared to adults.(33, 50)

Descriptive analyses confirm that the study data are consistent with other study populations and provide information about subpopulations, injury severity, and comparative results for athletes with concussion injury and athletes with ankle/leg injury. During this study period, 494 concussion injuries and 473 ankle or leg injuries were recorded in the study school district. Many of the results presented here are consistent with other studies examining concussion injuries

and recovery in high school athletes. First, football (36% of concussion injuries, injury rate=5.19/10,000AE, 95%CI 4.42-5.96) and lacrosse (15% of concussion injuries, injury rate= 4.77/10,000AE, 95%CI 3.68-5.89) account for a large proportion of concussion injuries in this population. These result align with results from a 10 year prospective study (between academic years 1997-1998 and 2007-2008) of concussion rates in the same study population that found high rates of concussion in athletes participating in these collision sports (39).This trend is true in other study populations, as well. (9, 45)

Additionally, concussion severity results in this study are consistent with data from other populations.(45, 108, 109) In this study, football, baseball/softball, basketball and wrestling had a higher proportion of concussion injuries that resulted in more than 14 days of time lost from sport than concussion injuries that resulted in less than 10 days of time lost.

Finally, in the subpopulation where gender could be inferred from the sport played, female athletes account for a greater proportion of concussion in each sport except lacrosse. Female athletes were also more likely to have more severe concussion than male athletes participating in equivalent sports. These trends are not evident when comparing athletes with ankle and leg injuries.

In this study population, there was a significantly higher proportion of concussion injuries in younger athletes compared to ankle or leg injuries. Athletes with concussion injuries were twice as likely to be in grade 9 or grade 10 than in grade 12 when compared to athletes with ankle and leg injuries. This result is consistent with younger athletes being more susceptible to concussion

injuries (33, 36), but could also be explained by younger athletes being more willing to openly report injury symptoms than older athletes.

Athletes in this study population with concussion injury had greater odds of a significant increase in the number of days absent from school than athletes with ankle or leg injuries. This result is of particular interest in the context of this dissertation as absence from school is closely tied to academic performance. Students who are absent from the classroom miss instructional time and are more likely to perform poorly on classroom and standardized assessment.(110)

In longitudinal analyses, high school students with sport-related concussion did not suffer a significant decline in academic performance compared to athletes with ankle or leg injury. Athletes in both injury groups experienced a decline in mean GPA during the quarter of injury compared to the quarter prior to injury. When analyses were restricted to younger athletes (grades 9 or 10) or those with more severe injuries (time lost from sport greater than 10 days), athletes with concussion injury demonstrated a greater decline in average grades over the observation period than athletes with ankle or leg injury.

There appears to be a significant decline in academic performance in younger athletes (grades 9 or 10) with severe concussion injuries compared to athletes with similarly severe ankle or leg injury (measured by time lost from sport).

All adolescent athletes should be closely monitored following concussion injury, but particular attention should be paid to the neurocognitive rehabilitation and academic return of younger athletes. Concern over academic

time lost must be balanced with cognitive rest necessary for recovery from concussion injures. Accommodation in the classroom may be necessary to prevent negative effects on academic performance measures in athletes following concussion injury.

5.2 Public Health Implications

An active lifestyle is associated with risk of injury. Physically active individuals are more likely to suffer injuries as a result of their action.(121) Sports and recreational pursuits are an important part of social and cultural activity and also a source of risk. Participation in structured activity during adolescence is associated with positive psychological, social, and educational outcomes.(19-21) Evidence is emerging indicating that concussions are more common and carry a heavier burden of consequences than previously suspected.(11, 81)

There is potential for concussions to have significant impact on academic performance in high school athletes. In adolescent athletes with concussion, attention must be paid to balancing the required cognitive rest with academic demands. Minor attention deficit or impaired information processing can have a significant impact on an adolescent's ability to function academically(58) and evidence suggests that early return to school (before resolution of symptoms) may prolong recovery.(33, 75)

Athletes with injuries miss more school than uninjured students, and athletes with concussion are absent from school more than students with non-

concussion injuries. These absences result in a loss of instructional time that impacts the student's ability to perform academically. (110) This concern for loss of instructional time is in conflict with the current policy of cognitive rest following concussion injury. Return to the classroom must be balanced with the need for cognitive rest when considering individual recovery plans.

Given the far reaching potential impact of adolescent concussion injuries and the increasing public health burden, these injuries warrant the significant attention and research they are receiving. Physical activity and participation in athletics are important for adolescent development and should be encouraged. Minimizing the negative effects of injuries that results from these activities will ensure that adolescents maximize the potential benefits of sports participation.

5.3 Policy Implications

In November 2012, the 4th International Consensus Conference on Concussion in Sport held in Zurich resulted in the publication of an updated consensus statement building on previous statements and presenting an improved understanding of concussion diagnosis and recovery management. The group encourages investigations of the pathophysiologic mechanisms, symptom identification and management, genetic markers, and neuropsychological assessment of concussion injuries.(4) The statement also encourages extending the recovery time for adolescent athletes due to differing physiological responses and increased risk of diffuse cerebral swelling in children.

For any athletes with concussion, cognitive rest may be as important as physical rest for recovery.(80, 81) Poor communication between healthcare providers and school administration make it difficult for adolescent athletes to get the rest they need to heal.(9, 33, 71, 81) Awareness of the impact of concussions on academic outcomes may help with future identification of high-risk athletes and allow educators opportunity for targeted intervention to prevent negative academic consequences. Currently, many athletes are expected to return to school environments that require focused attention over long periods and exposure to loud environments within days of injury.(57, 82, 83) Administrative policies allowing for cognitive recovery periods and individualized academic rehabilitation plans will allow full recovery from injury, minimizing academic consequences. The research presented here was conducted within a school district that allocates significant resources to medical resources in their athletics programs. This may have resulted in a shift on effects tested toward the null, as district personnel may have been better educated about appropriate accommodations for athletes following concussion injury.

As further research emerges outreach efforts should be made to educate athletes, referees, parents, coaches, school administrators, and health care providers on the prevention, detection, management, and potential consequences of concussion injury. Young athletes and those with post-acute symptom presentation should receive recovery care that is coordinated with academic programs that includes cognitive therapy and academic support services.

Finding a balance between allowing for appropriate recovery and rehabilitation that includes adequate attention to cognitive rest, maintenance of social connections, and academic support is likely to be a challenging and highly individual endeavor, but may result in better long term outcomes for high school athletes with sport-related concussion injuries.

5.4 Limitations of Current Research

The research presented in this dissertation is an exploratory examination of academic performance in high school athletes with concussion. This research was limited by several factors that could be overcome in future research projects. First, participation data for the study period was not available. Therefore, injury rates presented in Chapter 3 are based on average participation numbers for the two academic years following the study period. As participation numbers are fairly stable over time in the study district, it is anticipated that the numbers presented are an adequate estimate of injury rates. These rates align with other study data.

Second, data on variables that may have been identifiers were restricted by the school district. Access to calendar age, gender, history of concussion, and other injury or medical history were not available for these analyses. Completion of these data would make the results of analyses more meaningful. Some medical conditions and learning disabilities impact concussion assessment and recovery.

In particular, history of concussion is a predictor of concussion recovery and would have added to the value of the analyses presented.

The current research should be duplicated in other populations. The study population was drawn from a large suburban school district that is has access to resources that many smaller or less well funded schools may not have access to. The study school district places substantial resources into athletics and athletic injury management, accompanied by professional development for district administration and staff about injury management and recovery requirements. This awareness and level of support is not available in most school districts in the country. Attention in this district to injury management and recovery may have resulted in diminishing the effects being studied for this dissertation. Students in this district may receive academic accommodations following injury that would not be available to injured students in other school districts.

Additional studies would benefit from a prospective design with a common assessment of academic performance to reduce the amount of error due to the variability of outcome measurements noted in this study.

5.5 Future Research Considerations.

The research presented in this dissertation could be expanded on by duplication in another study population, examination of additional variables measuring academic outcomes such as standardized academic assessments, or by implementing a prospective longitudinal study.

Concussion research, particularly in adolescent populations, is of great current interest. Policy and administrative support for research should be leveraged to launch additional studies while interest is high. While biological, imaging, and genetic studies are of value in concussion research, population based research studies have the greatest potential for actually informing how concussion injuries are managed and minimizing the long term impact of these injuries.

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2. Stringer GA, Mieja A, Rui H, Mitchell E, Michael YL, Hyslop T. Serum 25-Hydroxyvitamin D and Breast Cancer Risk: a meta-analysis. (in review by Journal of Clinical Oncology)

Peer-reviewed Abstracts

1. Peck AR, Witkiewicz AK, Chengbao L, Stringer GA, Klimowicz AC, Pequignot E, Freydin B, Tran TH, Yang N, Rosenberg AL, Hooke JA, Kovatich AJ, Nevalainen MT, Shriver CD, Hyslop T, Sauter G, Rimm DL, Magliocco AM, Rui H. Loss of Nuclear Localized and Tyrosine Phosphorylated Stat5: A Predictor of Poor Clinical Outcome and Increased Risk of Antiestrogen Therapy Failure in Breast Cancer. Abstract (accepted), American Association of Cancer Research Annual Conference, 2010 in Orlando, Florida

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