UNMASKING THE IMPACT: ANALYZING THE ROLE OF ATHLETIC IDENTITY ON CONCUSSION OUTCOMES IN COLLEGIATE ATHLETES

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PUBLIC ABSTRACT

Background: A concussion is a concerning injury because of the potential long-term effects to the brain. Typical concussion evaluation and management tools include tests that ensure an athlete is physically ready to return to play (e.g., clinical evaluation, symptom reports, balance assessment). However, psychological factors are often overlooked from these protocols, despite increasing evidence that it may prolong recovery. One psychological factor to consider is athletic identity, which is defined as the exclusivity and strength with which an individual identifies with the athletic role and looks to others for confirmation of that role.

Purpose: The purpose of this study was to examine athletic identity in collegiate athletes to predict outcomes following concussion, including concussion symptom scores, days to symptom resolution, and days to full medical clearance (FMC).

Methods: Participants diagnosed with a concussion were included in the study and completed demographics, injury/recovery information, symptom report of the Sport Concussion Assessment Tool and the Athletic Identity Measurement Scale (AIMS) within 5 days of their injury, and (2) at the time of FMC (within 3 days). The AIMS is a 7-item questionnaire that assesses the extent to which the athlete role is a stable and central part of one's self-identity and includes three subscales: social identity, exclusivity, and negative affectivity. Total and subscale scores for the AIMS can be calculated and interpreted, in which higher scores indicate a stronger athletic identity.

Results: A total of 92 collegiate athletes (mean age: 20.8±1.6; 39 female, 53 male) completed the study. The negative affectivity subscale was positively associated with total number of symptoms, symptom severity score, and days to FMC. The negative affectivity subscale also significantly predicted an increase in total number of symptoms and an increase in symptom severity scores, while controlling for known variables that impact concussion recovery outcomes. The AIMS total score, the social identity subscale and the exclusivity subscale did not predict any concussion recovery outcomes.

Conclusion: Among collegiate athletes, stronger negative affectivity was associated with worse outcomes following concussion. These findings further expand our knowledge and understanding about athletic identity and its relationship to concussion outcomes in a collegiate athletic population. The information gleaned from this study gives clinicians a starting point for addressing collegiate athletes who are stronger in negative affectivity following a concussion, but further research is warranted.

ABSTRACT

Background: A concussion is a concerning injury because of the potential long-term effects to the brain. Typical concussion evaluation and management tools include tests that ensure an athlete is physically ready to return to play (e.g., clinical evaluation, symptom reports, balance assessment). However, psychological factors are often overlooked from these protocols, despite increasing evidence that it may prolong recovery. One psychological factor to consider is athletic identity, which is defined as the exclusivity and strength with which an individual identifies with the athletic role and looks to others for confirmation of that role.

Purpose: The purpose of this dissertation was to examine athletic identity in collegiate athletes to predict outcomes following concussion, including concussion symptom scores, days to symptom resolution, and days to full medical clearance (FMC).

Methods: This was a prospective, repeated measures design study performed in a university laboratory setting. Participants diagnosed with a concussion were included in the study and asked to complete two testing sessions: (1) within 5 days of their injury (the acute visit), and (2) at the time of FMC (within 3 days; FMC visit). During the acute visit, participants provided informed consent, as well as information regarding demographics (e.g., age, sex), injury characteristics (e.g., mechanism of injury), and medical history questions (e.g., concussion history, diagnosis of depression/anxiety). Additionally, participants completed two surveys, the Athletic Identity Measurement Scale (AIMS) and the symptom checklist of the Sport Concussion Assessment Tool (SCAT5/SCAT6). The AIMS is a 7-item questionnaire that assesses the extent to which the athlete role is a stable and central part of one’s self-identity and includes three subscales: social identity, exclusivity, and negative affectivity. At the FMC visit, participants completed recovery information (i.e., days to symptom resolution and days to FMC) and the same surveys completed at the acute visit. A series of hierarchical multiple regression analyses were conducted in a stepwise fashion to assess the extent to which athletic identity predicted total number of symptoms, symptom severity score, days to symptom recovery and days to FMC. These analyses were evaluated based on an a-priori alpha level <0.05.

Results: A total of 92 collegiate athletes (mean age: 20.8±1.6; 39 female, 53 male) completed the study. There was a statistically significant weak and positive relationship between the negative affectivity subscale and total number of symptoms ($p < 0.01$), symptom severity score ($p < 0.01$), and days to FMC ($p < 0.01$). The negative affectivity subscale significantly predicted an increase in total number of symptoms ($F_{(1, 87)} = 5.827$, $p = 0.018$, $R^2 = 0.055$) and an increase in symptom severity scores ($F_{(1, 87)} = 4.002$, $p = 0.049$, $R^2 = 0.038$), while controlling for sex, history of learning disorder or dyslexia, history of depression/anxiety which are known variables that impact concussion recovery outcomes. The AIMS total score, the social identity subscale and the exclusivity subscale did not predict any concussion recovery outcomes.

Conclusion: Among collegiate athletes following concussion, the negative affectivity subscale was positively associated with total number of symptoms, symptom severity score, and days to FMC. Additionally, the negative affectivity subscale predicted more total number of concussion symptoms and higher symptom severity score reported at the acute visit over and above known variables that impact concussion symptom scores. These findings further expand our knowledge and understanding about a specific psychosocial factor (i.e., athletic identity) and its relationship to concussion outcomes. The information gleaned from this study gives clinicians a starting point for addressing collegiate athletes who are stronger in negative affectivity following a concussion, but further research on the psychometric properties of the AIMS in a concussion population is warranted.

This dissertation is dedicated to my friend, Jordy Fleming.

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CHAPTER 1: INTRODUCTION

1.1 Overview of the Problem

Over the past few decades, concussion has emerged as an injury of concern in healthcare because of increasing rates of injury, the potential severity of symptoms, and the long-term consequences on the brain.[1] The most basic definition of a concussion is "the immediate and transient symptoms of a traumatic brain injury induced by biomechanical forces".[2,3] The actual incidence of this injury has been difficult to delineate but current rates indicate 9,542 concussions per 22,870,364 athlete exposures (AEs) for an overall rate of 4.17 per 10,000 AEs for high school students;[4] while collegiate athletes rates have been reported as 3,497 concussions per 8,474,400 AEs indicating 4.13 per 10,000 AEs.[5,6] This injury results in a variety of clinical signs and symptoms, classified into the following domains: somatic (e.g., headache), cognitive (e.g., feeling like in a fog), emotional (e.g., sadness), and sleep-related disturbances (e.g., drowsiness).[3] It also represents a functional disturbance rather than a structural injury, making it unique from musculoskeletal injuries where signs and symptoms may outwardly present.[7] Most individuals who sustain a concussion recover within 1-3 weeks; however, recovery can extend for much longer where individuals may experience persistent symptoms and other potential short-term and long-term consequences.[3]

Standard concussion assessment and management typically includes clinical evaluation, symptom reports, balance assessment, vestibular and ocular assessment, and neurocognitive testing where physical readiness is prioritized.[7] What is often overlooked from these assessment and management protocols are psychosocial factors, despite increasing evidence that psychological factors may complicate recovery and lead to poor outcomes after concussion.[8] Altered mood states are psychological responses that have received the most empirical attention as several studies have found an increase in depressive[9-11] and/or anxiety[12-14] symptoms in athletes following concussion that contributed to prolonged recovery. Additionally, qualitative studies have indicated that athletes' perception of internal and external pressures to return to sport influenced injured athletes to return to sport prior to actually feeling ready to return.[8] Other psychological responses, such as fear of reinjury[15] or amotivation,[16] have been associated with increased symptoms after concussion. Clinicians are likely not aware of or know how to mitigate the impact of these factors and as a result, athletes can be at risk of poor outcomes associated with these psychological responses to injury. These poor outcomes may include increased social isolation, minimization of symptoms to return to sport sooner, and prolonged symptom duration, which have all been observed in athletes after sustaining a concussion.[17] One psychological factor with minimal exploration thus far concerning its influence on concussion recovery is athletic identity.

1.2 Significance of the Problem

Athletic identity is defined as the exclusivity and strength with which an individual identifies with the athletic role, and looks to others for confirmation of that role.[18] This concept is largely derived from identity research within social psychology,[19] and should be viewed within the framework of a multidimensional self-concept.[20] Brewer and colleagues, who coined the term athletic identity, indicated that it serves as a cognitive structure that directs and arranges the processing of self-related information, but also highlighted its role as a social construct, suggesting that the identification of this role is derived from the feedback of important others (e.g., parents, coaches, teammates, spectators).[20] To assess this psychological factor, Brewer and colleagues developed the Athletic Identity Measurement Scale (AIMS). This is a multidimensional measure that includes three subscales: social identity, exclusivity, and negative affectivity.[21] Social identity is how much an individual identifies with the athletic role, exclusivity is considered solely identifying with the athletic role, and finally, negative affectivity is negative emotions in response to failure to fulfill this athletic role.[21]

Most research has focused on the implications of a stronger athletic identity as it indicates someone who places high value and prioritizes sport in their life.[20] When defining athletic identity, Brewer and colleagues proposed a stronger athletic identity can act as either a "Hercules' muscle" or an "Achilles' heel" indicating both the positive and negative consequences of such an identity.[20] A stronger athletic identity acting as a "Hercules' muscle" has been associated with a number of positive outcomes including greater commitment toward sport participation,[22,23] increased sport motivation,[24] greater performance across the season when winning,[25] and positive well-being.[26] Alternatively, a stronger athletic identity acting as an "Achilles' heel" may have negative consequences within the sport domain.[20] Research has suggested that athletes with a stronger athletic identity may neglect other identities to maintain the athletic role.[27] Furthermore, as per Hughes and Coakley,[28] individuals who identify themselves strongly and exclusively as athletes are more inclined to adopt the sociocultural "sport ethic" value system, which prioritizes athletes making sacrifices for their sport, embracing risks, and continuing to play despite pain and injuries. These athletes may be more likely to put themselves in situations that cause an injury such as concussion.

This becomes troubling because the negative consequences of a stronger athletic identity can be amplified if an athlete becomes injured. An athlete may feel that their sense of self is shaken and have difficulty adjusting given the threat to their self-concept.[16,27] Following an injury, athletes with stronger athletic identity have demonstrated increased depressive symptoms.[18,29] Past studies have shown that a stronger athletic identity significantly predicted positive athlete attitudes towards playing through an injury,[30] over adherence to rehabilitation protocols,[31] and attempts to expedite the rehabilitation process.[32] More specifically, Weinberg et al.[30] found that recreational basketball players who almost exclusively identify with the athletic role and experience negative affect when unable to perform well exhibit more positive attitudes toward playing through pain and injury. Furthermore, Hilliard et al.[31] found that injured college athletes who experienced negative affect made more attempts to expedite rehabilitation after injury. Additionally, research has found athletes with a stronger athletic identity who viewed concussion as a threat to their athletic status were less likely to report a concussion,[33] and had less intention to report symptoms of an concussion during a game or 24 hours after a game.[34]

Specific to concussion recovery, much of the current literature has used qualitative methodology to explore athletic identity, as studies indicated former athletes expressed difficulties transitioning into other careers or identities after sport termination due to concussion.[35-37] To date, only one study has used athletic identity to predict recovery in concussion and found stronger athletic identity predicted more intense symptoms and slower recovery.[16] However, this study was conducted with youth athletes from a hospital based clinic which may have captured athletes with more severe concussion symptoms and is not representative of collegiate athletic populations. Additionally, this study only reported the AIMS total score, and not subscales of athletic identity. Collegiate athletes with stronger athletic identity may engage in risk-taking behaviors such as nondisclosure or minimization of symptoms to return to sport sooner. This is concerning because delayed reporting has been associated with acutely high symptom burden and longer symptom recovery between 2 and 5 days,[38,39] and it puts an athlete at risk for subsequent injury.[8,40]

This dissertation was designed to examine the role of a specific psychological factor, athletic identity, on concussion recovery outcomes in collegiate athletes within an existing theoretical and empirically supported framework.[41] One such framework that was considered was the integrated model of response to sport injury.[42] While not directly tested in this dissertation, this model was recognized as valuable in suggesting that athletic identity could be a psychological factor that may predict recovery outcomes post-concussion.[41] This model posits that personal and situational factors influence a psychological response that dynamically changes over time to impact recovery.[42] This dynamic process occurs through primary (e.g., "Is this injury harmful to me?") and secondary (e.g., "Will I be able to deal with this injury, and if so, how?") cognitive appraisals of the injury. These cognitive appraisals then determine emotional and behavioral responses that could influence recovery outcomes.[43]

Applying the model to the population of interest, a collegiate athlete who has a stronger athletic identity sustains an concussion that they may appraise the injury as a direct threat to their self-concept (**see Figure 1**).[16] This may cause emotional responses such as fear, helplessness, frustration, sadness, apathy, and irritability.[35] In addition, it may cause a variety of behavioral responses such as an athlete choosing to over or under adhere to rehabilitation, minimizing symptoms, hyper focusing on symptom expression, or isolating themselves from important social support networks.[16,31] These emotional and behavioral responses could then influence recovery outcomes like returning to sport too soon, increased symptom expression, prolonged recovery, and subsequent reinjury.[8,16] This theoretical framework may help guide stakeholders (i.e., researchers, clinicians, athletes) to understand why athletic identity may influence psychological responses following concussion and highlight the need to further explore this construct in a population of individuals with a concussion.

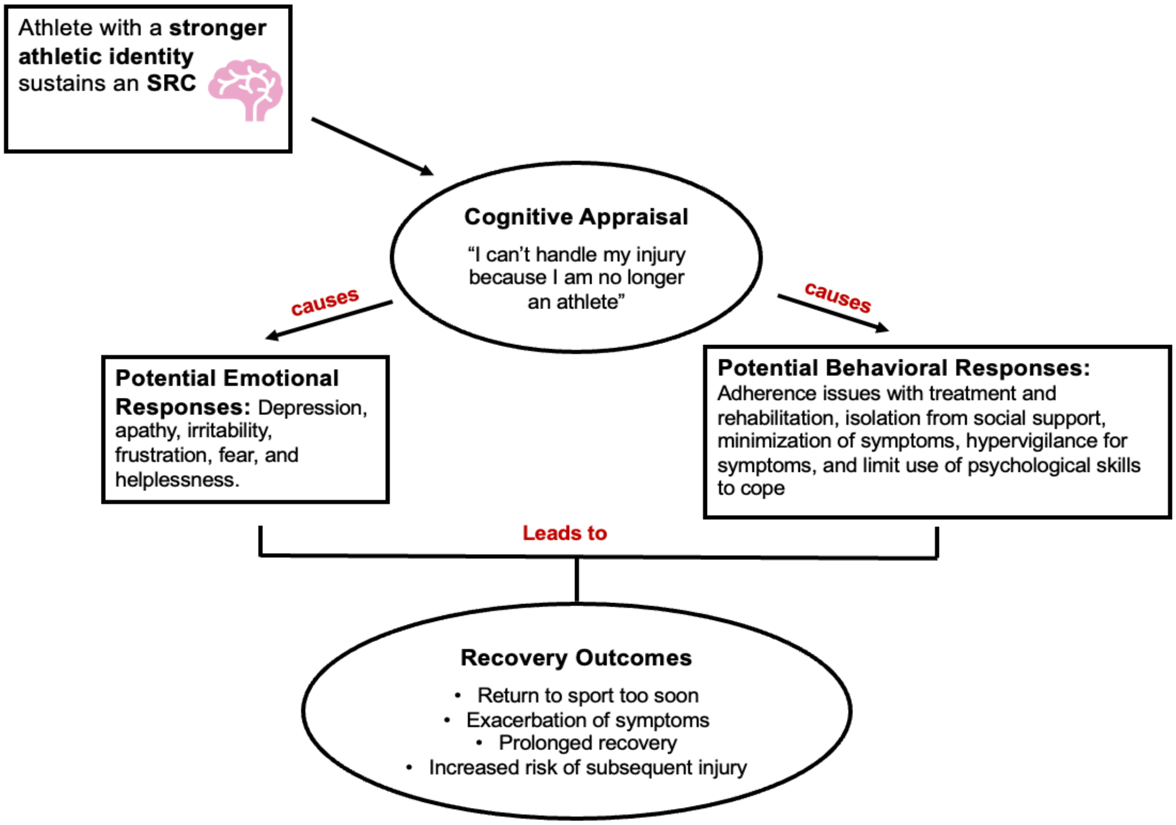

Figure 1. Application of the integrated model of response to sport injury for an athlete with a stronger athletic identity following concussion.

The dissertation aims to provide a better understanding of the influence of a psychological factor impacting concussion recovery outcomes guided by theory. Understanding the implications of athletic identity can guide clinicians' decisions about treatment and rehabilitation, including helping athletes develop other important identity roles, engage in psychological skills training, keeping an athlete embedded in their sport during the recovery process, or making referrals to mental health professionals. Additionally, this information may be important to athletes making decisions about returning to sport, as it highlights the unintended consequences of a stronger athletic identity, a factor we might consider to be necessary for successful participation in sport. The outcomes will also fill a crucial gap in the literature, as most evidence focuses on physical readiness, despite increasing evidence that suggests psychosocial factors also influence concussion recovery. Additionally, it provides knowledge on the influence of athletic identity and its subscales on concussion recovery outcomes in collegiate athletes, which has yet to be assessed. Information gleaned from this study will be useful to the concussion field along with the sports medicine field as athletic identity can be easily assessed and applies to other sport injuries (e.g., ACL tears).

1.3 Purpose of the Study

The overall purpose of this dissertation was to examine athletic identity in collegiate athletes to predict outcomes following concussion, including concussion symptom scores, days to symptom resolution, and days to full medical clearance (FMC). The central hypothesis of this study was that collegiate athletes with a stronger athletic identity would report higher concussion symptom scores and longer recovery time following concussion. More specifically, a stronger athletic identity would be associated with more total number of symptoms and higher symptom severity scores during the acute visit. Additionally, a stronger athletic identity at the acute visit would be associated with more days to symptom resolution and days to FMC. I tested these hypotheses and accomplished this objective through two specific aims.

1.4 Specific Aims and Hypotheses

Specific Aim 1: To examine whether athletic identity was related to the total number of symptoms, and symptom severity scores in collegiate athletes with a concussion during the acute visit.

Hypothesis 1a: Collegiate athletes with concussion who reported a stronger athletic identity would report more total number of symptoms during the acute visit.

Hypothesis 1b: Collegiate athletes with concussion who reported a stronger athletic identity would report higher symptom severity scores during the acute visit.

Specific Aim 2: To examine whether athletic identity was related to days to symptom resolution and days to FMC in collegiate athletes with a concussion.

Hypothesis 2a: Collegiate athletes with concussion who reported a stronger athletic identity during the acute visit would report more days to symptom resolution.

Hypothesis 2b: Collegiate athletes with concussion who reported a stronger athletic identity during the acute visit would report more days to FMC.

1.5 Operational Definition of Terms

Athletic Identity: Athletic identity is defined as the exclusivity and strength with which an individual identifies with the athletic role, and looks to others for confirmation of that role.[18]

Clinical Recovery: Clinical recovery marks the point at which an individual resumes their regular activities after sustaining a concussion.[3]

Collegiate Student-Athlete: An athlete meeting the criteria who is simultaneously a full-time student in an academic program and participates in NCAA Division I, II, or III sports or club sports including baseball, basketball, bowling, cheerleading, cross country, dance, fencing, women's field hockey, football, golf, gymnastics, ice hockey, lacrosse, rifle, women's rowing, rugby, skiing, soccer, softball, swimming and diving, tennis, track and field, volleyball, water polo, or wrestling.

Complete Symptom Resolution: The resolution of symptoms linked to the current concussion while at rest, without the reappearance of symptoms during or after maximal physical and cognitive exertion.[3]

Full Medical Clearance (FMC): FMC is the time the individual received medical clearance for full unrestricted activity by a physician. Individuals with concussion were required to report the resolution of their symptoms, undergo a vestibular/ocular motor assessment to reach baseline levels, progress through all five stages of the Concussion in Sport Return to Play (RTP) stepwise protocol, and receive clearance from a physician.[3] Typically, individuals followed the protocol for five days, unless symptoms recurred, in which case they remained in their current state until symptom resolution.

Concussion: A concussion is defined as a direct or indirect blow to the head, face, neck, or body that results in an altered mental status and various clinical signs and symptoms.[3] Physicians evaluated all concussions using the following criteria: a) the observation of at least one on-field sign (e.g., lying motionless on playing surface, falling unprotected to the surface, disorientation/confusion, balance issues), b) the presence of symptoms (e.g., headache, neck pain, dizziness, nausea), and/or c) any impairment detected during sideline assessment (e.g., SCAT5/SCAT6).

CHAPTER 2: REVIEW OF THE LITERATURE

This review of the literature investigates the previous research in areas related to the current study, including concussion, athletic identity, and the integrated model of response to sport injury. The extensive concussion overview encompasses information on the definition, pathophysiology, epidemiology, clinical profiles, diagnosis, management, return to play process, and risk factors associated with concussive injuries. The next section focuses on psychosocial factors that have been assessed related to concussion including altered mood states, social dynamics, coping strategies/behaviors and fear. The psychosocial factors section ends with an extensive discussion on athletic identity which focuses on defining this psychosocial factor and investigating how it has previously been studied in sport and in injured populations with a focus on concussion. The remaining section is on the integrated model of response to sport injury and explains how athletic identity can be highlighted in the integrated model of response to sport injury to understand the impact of this factor following concussion. The overall purpose of this literature review is to provide a thorough discussion on concussion and how athletic identity and the integrated model of response to sport injury have been previously studied in concussion literature and the relevant gaps in the existing literature that need to be addressed in future research.

2.1 Concussion Definition

The most basic definition of a concussion is the immediate and transient symptoms of a mild traumatic brain injury (TBI)[2] in which a TBI is defined as an alteration in brain function, or some other evidence of brain pathology that is produced by an external force.[44] In the literature, a concussion has been defined as a subset of a TBI or mTBI or used interchangeably with mTBI.

There is much debate over the definition of this injury and its definition has evolved over the years in conjunction with our understanding of a concussion.

The first published consensus statement from the Congress of Neurological Surgeons[45] defined a concussion as a clinical syndrome characterized by the immediate and transient post-traumatic impairment of neural function such as alternation of consciousness, disturbance of vision or equilibrium due to mechanical forces. Various organizations in the last 30 years have also published operational definitions for concussion, including the Team Physician Consensus statements,[46,47] the American Academy of Neurology,[48,49] the National Athletic Trainers' Association,[50,51] the American Medical Society for Sports Medicine,[52] and the Concussion in Sports Group (CISG).[3,7,53-56] The terminology of a concussion has come a long way as our understanding of this injury has progressed. Previous evidence has used descriptors such as "bellringer", "ding", "banged up", and "clearing the cobwebs", that should no longer be accepted today.

The CISG is an international group that first convened in the early 2000's to develop a consensus statement for concussion in sport and has met 5 times since this original meeting to provide updates and modifications. The most recent operational definition of a concussion came about from the 2022 Amsterdam Consensus Conference as a modification to the sport-related concussion (SRC) definition from the 2016 CISG meeting held in Berlin. The CISG conceptual definition of SRC is "a TBI caused by a direct blow to the head, neck, or body resulting in an impulsive force being transmitted to the brain that occurs in sports and exercise-related activities."[3] This direct blow then initiates a neurotransmitter and metabolic cascade, that may also result in possible axonal injury, blood flow change and inflammation that affects that brain. In the research setting, abnormalities may be present on functional, blood flow or metabolic imaging studies, but no abnormality will be seen on standard structural neuroimaging studies like computer tomography or magnetic resonance imaging T1- and T2—weighted images. The signs and symptoms of SRC may present immediately, or evolve over time (i.e., minutes or hours). Additionally, these signs and symptoms are likely to resolve within days but may be prolonged. Furthermore, SRC may result in a range of clinical symptoms and signs that may or may not involve in loss of consciousness (LOC). These clinical symptoms and signs cannot be explained solely by drug, alcohol, or medication use, but may occur alongside these things. Additionally, these clinical symptoms and signs cannot be explained solely by other injuries (e.g., cervical injuries, peripheral vestibular dysfunction) or other comorbidities (e.g., psychological factors or coexisting medical conditions).[3] This conceptual definition has been accepted as a majority decision (78.6%) (though not an 80% consensus) by the CISG[3] and as such the definition and terminology "concussion" or "SRC" will be used throughout this dissertation.

2.2 Pathophysiology of Concussion

The work of Giza and Hovda[57] laid the foundation for our understanding of the acute pathophysiology of concussion. Following a biomechanical force to the brain (i.e., concussive event), a neurometabolic cascade of events happens concurrently, leading to potential changes in mental status, symptoms, neurocognitive function and/or motor control.[58] It is proposed that a complex set of processes are responsible for this myriad of changes and are likely a result of ionic shifts, neuronal depolarization, glucose metabolism changes, impaired neurotransmission, altered cerebral blood flow, and disrupted axonal function that occur at different stages after the functional injury.[57,58]

The initial event includes an influx of ions and neuronal depolarization that triggers the opening of voltage-gated ion channels, that continues through a positive feedback loop.[57]

Additionally, excitatory amino acids, particularly glutamate, binds to N-methyl-D-aspartate (NMDA) receptors, causing even further neuronal depolarization that opens potassium/calcium ion channels, leading to the buildup of calcium in the cell.[57,59] This buildup of calcium triggers changes in the cellular physiology, such as cell damage and mitochondrial impairment. These initial events create a ‘depression-like’ state that spread throughout the cell that we may recognize as the very acute post-concussive symptoms.[57]

To combat this sudden influx of ions and restore cellular homeostasis, membrane ionic pumps work intensely to increase adenosine triphosphate (ATP) production.[57,59,60] This causes a massive increase in cerebral glucose metabolism, or hyperglycoloysis, in which there is a depletion of intracellular energy reserves and an increase in adenosine diphosphate (ADP). This creates an energy crisis as there is a high demand for energy to reestablish homeostasis combined with the coinciding decreased capability to transport energy from altered cerebral blood flow.[58] Following this period of hyperglycoloysis, there is a longer period, typically 7 to 10 days, of glucose metabolic depression. The energy crisis followed by metabolic decline are responsible for the detected cognitive deficits and synaptic plasticity, but it is expected that these biochemical changes are fully reversible for a concussion.[61]

Cerebral blood flow alterations play a significant role in the evolution of injury sequelae as it signifies one of the most lasting markers of a concussion in animal models of TBI.[62] Concussed football players demonstrated a significant decrease in cerebral blood flow at 8 days compared to within 24 hours post-injury and a significant decrease in cerebral blood flow at both time points compared to healthy controls.[62] Another study assessed the recovery of cerebral blood flow and compared this recovery with cognitive and behavioral symptoms.[63] Results of this study found cognitive and behavioral symptoms resolved at 1-week and 1-month while cerebral blood flow in the dorsal midinsular cortex was decreased at 1-month post-concussion and inversely related to psychiatric symptoms in collegiate athletes.[63] Yet another study examined cerebral blood flow alterations after SRC though this study examined these variables in children aged 11-15 years old.[64] While improvements across recovery resolved in 14 days for total symptom score and 30 days for reaction time, respectively, this was not seen in cerebral blood flow.[64] Compared to control values, only 27% of concussed individuals had similar values at 14 days and 64% had similar values at 30 days after SRC.[64] Additionally, one other study demonstrated changes in cerebral blood flow, yet these individuals persisted up to 40 days post-concussion.[65] It seems evident from the research that there are cerebral blood flow alterations following injury, however, it is not clear at which point those levels return to baseline.[62-65] Additionally, these recent studies have used arterial spin labeling (ASL), an advanced magnetic resonance imaging (MRI) technique, as it is capable of assessing cerebral blood flow measurements non-invasively and may be a suitable option for assessing alterations across recovery to aid in management of concussion.[62]

In addition to the ionic influx, glutamate release and energy crisis that occurs from a concussion, axonal dysfunction and disconnection has been documented.[57,58] Axonal dysfunction occurs because of damage to the neurofilaments and microtubules following the biomechanical stretch from a concussion.[57] This may be especially problematic for pediatric populations given the ongoing myelination that occurs during brain development.[58] Researchers have found white matter damage and accompanying cognitive impairments in the immature brain after repeat mTBI.[66] Currently, we are limited in our understanding of disrupted axonal structure, but advances in neuroimaging approaches such as diffusion tensor imaging will provide more insight.[58]

Although limited research exists in the mTBI realm, another pathophysiologic process that occurs after a concussive injury is increased neuroinflammation. Rodent models have demonstrated an upregulation in inflammatory genes as well as acute neuroinflammatory responses such as the presence of macrophage and greater microglia. Increased concentrations of inflammatory markers in the brain may reduce behavioral responses. To detect subtle abnormalities and deficits and help with diagnosis of a concussion, magnetic resonance spectroscopy can be used.[58,67,68]

2.3 Epidemiology of Concussion in Sport

There are approximately 1.6 to 3.8 million TBIs that occur annually in the United States, according to estimates from the Center for Disease Control and Prevention (CDC).[69] It is suspected that about 300,000 of those approximated TBIs would be considered SRCs, which account for approximately five to nine percent of all sport injuries.[70,71] Of note, these statistics do not take into account the number of concussions that go undiagnosed, and these approximations are likely lower than the actual occurrence of head injuries.[72-74] Researchers have made a significant effort to utilize sport-related injury surveillance systems to provide more accurate estimation of SRC incidence.

Gessel and colleagues investigated the epidemiology of concussions of high school athletes using the High School Reporting Information Online (RIO) and compared these rates to collegiate athletes using the National Collegiate Athletic Association Injury Surveillance System (NCAA ISP).[70] A total of 396 concussions from 4,431 injuries were reported over the course of 2005-2006 from 9 high school sports which accounted for 8.9% of total injuries. Over the course of the year, there were a total of 1,730,764 athletic exposures (AEs), resulting in a concussion injury rate of 0.23 concussions per 1000 AEs.[70] The authors also broke this down into AEs from practice and competition exposures. There were 1,246,499 practice exposures, and 484,265 competition exposures resulting in a practice rate of 0.11 concussions per 1000 AEs and a competition rate of 0.53 concussions per 1000 AEs indicating more concussions occurred during competition.[70] When this data was weighted, the national estimate for the number of concussions sustained in all 9 sports was 135,901. Furthermore, using the national estimate, most concussions result from participation in football (40.5%, n = 55,007), then girls' soccer (21.5%, n = 29,167), boys' soccer (15.4%, n = 20,929), and girls' basketball (9.5%, n = 12,923). The remaining estimates from the other 5 sports include boys' basketball (2.8%, n = 3,823), volleyball (1.9%, n = 2,568), wrestling (4.4%, n = 5,935), baseball (1.5%, n = 1,991), and softball (2.6%, n = 3,558).

When compared to the 9 college sports using the NCAA ISS during the 2005-2006 school year, there were a total of 8,293 injuries which included 482 (5.8%) concussions. The overall rate of concussion was higher in college sports than in high school sports, however, concussions compromised a greater proportion of total injuries sustained by high school athletes compared to college athletes.[70] Finally, this study also showed differences among sex in which girls had higher rates of concussion in both high school and college compared to boy in sports that both sexes played.[70] This was one of the first studies to evaluate concussions rates for multiple sports among high school and collegiate athletes using nationally representative data.

A handful of studies have provided updates on concussion incidence and trends at the high school level using nationally representative data.[4,75-78] To provide the most recent epidemiological study, a report from Kerr and colleagues[4] provided data from 20 high school sports using the High School RIO during the 2013-2014 to 2017-2018 school years. A total of 9,542 concussions were reported which occurred during 22,870,364 AEs for an overall concussion rate of 4.17 per 10,000 AEs.[4] Most SRCs were reported to occur during competition settings (63.7%) compared to practice settings (36.3%).[4] When breaking down the incidence of SRC by sports, boys' football had the highest overall concussion rate with 10.40 per 10,000 AEs, then girls' soccer with 8.19 per 10,000 AEs, followed by boys' ice hockey with 7.69 per 10,000 AEs.[4] Looking more specifically at boys' football, the incidence rate during competition increased overtime whereas the practice rate decreased (1.56 vs. -0.28 per 10,000 AEs).[4] Additionally, when comparing sex-comparable sports, the overall concussion rate was higher in girls' sports (3.35 per 10,000 AEs) than in boys sports (1.51 per 10,000 AEs).[4]

Injury mechanism distributions indicated 62.3% of concussions were due to contact with another person, 17.5% occurred from contact with the surface, and 15.8% of SRCs were from contact with equipment or an apparatus.[4] This study also reported on recurrent SRCs which found 8.3% of the overall sample were recurrent with boys' ice hockey representing the largest proportions (14.4%), followed by boys' lacrosse and girls' field hockey (12.1%).[4] Furthermore, the proportion of concussions that were recurrent was higher in girls than in boys among sex-comparable sports (9.3% vs. 6.4%).[4] It was found that linear trend tests indicated decreases in the recurrent concussion rate across the study period. Overall, this study found that concussion rates were generally higher than previous reports from similar surveillance-based studies with decreasing rates of recurrent concussions.[76-78] This likely occurred because previous studies reported on data when mandatory concussion legislation for high school sports across all 50 states and the District of Columbia did not exist.[4] In the time since, increased reporting and better concussion management has occurred because of legislation.[75]

More recent efforts to provide epidemiological data of the incidence of concussion at the collegiate level have also been published.[5,6] First, SRC data from the NCAA ISP during the 2009-2010 to 2013-2014 academic years were analyzed to provide concussion injury rates, national estimates, rate ratios and injury proportion ratios.[6] A total of 1,670 SRCs were reported which represented 10,560 SRCs annually during the study period and accounted for 6.2% of all injuries reported in the NCAA ISP.[6] The overall concussion rate was 4.47 per 10,000 AEs from a total of 3,638,885 AEs among the 25 sports that were assessed. Comparing competition and practice reports, a higher number occurred during competition (n = 888, 53.2%) than in practice (n = 782, 48.8%) and the competition rate was 12.81 per 10,000 AEs while the practice rate was 2.57 per 10,000 AEs.

Football contributed the most to the total number of SRCs with 603 reported or an annual national estimate of 3,417 which represents 36.1% of all SRCs. This was followed by men's ice hockey (n = 224, 13.4%) and women's soccer (n = 136, 8.1%). Interestingly, men's wrestling had the highest overall concussion rate with 10.92 per 10,000 AEs but the authors also noted that the concussion rate in the 2013-2014 academic year (5.45 per 10,000 AEs) was lower than what had been reported during the previous four years (12.38 per 10,000 AEs). About 1 in 11 (9.0%) of all the reported SRCs were recurrent with men's ice hockey (20.1%) representing the largest proportion of recurrent concussions. This study also reported on common injury mechanisms and found the most SRCs occurred from player contact (68.0%), although the injury mechanism-activity combination varied by sport.[6] Additionally, Zuckerman and colleagues[6] discussed the national estimates found in this study compared to previous estimates and suggested the incidence of concussion has not increased, though increases were seen in specific sports including men's football, women's ice hockey, and men's lacrosse compared to previous national estimates.[79] They suggest these increases may represent increased reporting, increased clinical sensitivity to diagnose SRC, and likely other factors.[6]

A very recent update from Chandran and colleagues[5] has provided the epidemiology of SRCs in 23 NCAA sports during the 2014-2015 to 2018-2019 academic years using the NCAA ISP. A total of 3,497 SRCs from 8,474,400 AEs indicating 4.13 per 10,000 AEs were reported during the study period.[5] Comparing competition and practice, more SRCs occurred during competition (51.4%, n = 1,797) with a rate of 10.39 per 10,000 AEs than practice (48.6%, n = 1,700) with a rate of 2.52 per 10,000 AEs. Additionally, the highest SRC rates were observed in men's ice hockey (7.35 per 10,000 AEs) followed by women's soccer (7.15 per 10,000 AEs), men's football (6.99 per 10,000 AEs), women's ice hockey (6.98 per 10,000 AEs), and gymnastics (6.68 per 10,000 AEs).[5] The authors highlighted increased rates of SRC for women's soccer and volleyball from 2015-2016 to 2018-2019.[5]

This study also noted a difference in injury mechanism distribution between men's and women's sports with player contact accounting for the largest proportion of all reported SRCs in men's sports (77.0%) and equipment/apparatus contact accounted for the largest proportion of SRCs in women's sports (39.2%).[5] When examining injury history, most SRCs reported during the study period were reported as new injuries; however, the greatest prevalence of recurrent SRCs were observed for men's ice hockey (10.6%) and women's ice hockey (8.3%).[5] Overall, the updated incidence of SRCs at the collegiate level was in alignment with previous epidemiologic data, but did indicate increased rates in women's sports, specifically soccer and volleyball, as well as equipment/apparatus contact as a mechanism of injury for women's sports that may warrant attention.[5]

2.4 Clinical Profiles of Concussion

Concussion is distinct among other sport-related injuries because it is heterogeneous, meaning that different people will experience different signs and symptoms. To address this issue, researchers have proposed clinical profile-based approaches to conceptualize concussion.[80-83] These approaches are designed to inform both assessment and more targeted and effective therapies for athletes with SRC based on the athlete's clinical profile.[80] The model was first conceptualized in 2014 to include six different clinical profiles that included cognitive/fatigue, vestibular, ocular, posttraumatic migraine, anxiety/mood, and cervical.[83] However, since the introduction of this model, cervical and sleep-related problems have transitioned to represent modifiers and thus the model has been updated.[80] The updated clinical profiles include: (1) cognitive/fatigue, (2) affective (anxiety/mood), (3) posttraumatic migraine, (4) vestibular, and (5) ocular.[52,80] Athletes with SRC may present with symptoms of one clinical profile or, more likely, with symptoms and impairments of multiple profiles.[52,80,81,83] Additionally, when determining an athlete's clinical profile, clinicians must recognize that profiles may overlap and share some clinical characteristics, which has implications for determining best treatment options.[80,81] Below, an overview of the clinical profiles will be provided including a discussion on the overlapping nature of these profiles.

2.4.1 Clinical Profile: Cognitive/Fatigue

The cognitive/fatigue profile is defined by prevailing accounts of difficulty with cognitive or thinking skills and noticeable fatigue when partaking in mental acitvities.[80] The most common symptoms of this profile include difficulty concentrating, confusion, feeling slowed down, difficulty remembering, feeling like "in a fog," and low levels of energy.[52,80] Kontos et al.[80] found that the cognitive/fatigue profile was the least common primary profile accounting for 26 out of 236 participants (11%). However, it has been well established in the literature that many athletes experience transient cognitive decline after a concussive event.[9,84-86] For example, in a sample of high school athletes with a concussion, impairments on reaction time, verbal memory and motor processing speed were all noted with verbal memory and motor processing speed returning to baseline levels by 14 days postinjury and reaction time returning to baseline levels up to 21 days later.[86]

The heterogeneity of this injury may make it difficult for athletes to recognize cognitive deficits or notice changes in mental capacity, but objective neurocognitive testing evaluations are often used to detect discrepancies in attention and memory processes.[87-89] Fazio and colleagues[87] found that athletes with a concussion (both high school and college) may not recognize or report cognitive impairments even though they may be detected using neurocognitive testing. Thus, clinicians should always compare subjective symptom reports with objective neurocognitive testing of multiple cognitive domains, including memory, attention, executive functioning, and processing speed.[80] Additionally, due to declines in cognitive efficiency and an inability to maintain productivity in certain environments, functional impairments associated with this profile may include trouble upholding academic and/or professional duties.[90,91]

2.4.2 Clinical Profile: Affective (Anxiety/Mood)

The affective clinical profile is associated with emotional and behavioral changes after injury. The most common symptoms of this profile include sadness, more emotional, irritability, depression, anxiety, and moodiness.[52,80] This profile was the second most prevalent primary profile for 24% of the population assessed in in a concussion specialty clinic.[80] Furthermore, research has suggested that upwards of 20% of collegiate athletes display an increase in depressive symptoms following SRC.[92] Some athletes may not express emotional changes outwardly, but they may exhibit behavioral responses that are signs of an underlying psychological disturbance (e.g., avoidant coping, ruminative thinking, hypervigilance).[93,94] Comparisons of individuals with a concussion, those with orthopedic injuries and healthy controls showed that individuals with a concussion may not engage in coping skills such as active, planning, acceptance, religion, self-distraction, and venting to the same extent as athletes with orthopedic injuries or no injury at all.[93] Following SRC, the use of unhealthy coping strategies, such as a maladaptive passive coping style, might lead to emotional and persisting post-concussive symptoms and emotional sequalae.[93] For example, the use of passive coping would be an athlete delaying a return to academics because of fear associated with experiencing unpleasant SRC symptoms.[14] Furthermore, indicators of an underlying emotional disturbance may include inconsistent symptoms reporting and a worsening of symptoms over time.[14,80]

2.4.3 Clinical Profile: Posttraumatic Migraine

According to the *Headache Classification Committee of the International Headache Society*,[95] a posttraumatic migraine is defined as a moderate-to-severe, pulsating headache after head trauma that is accompanied by symptoms of nausea and/or sensitivity to light and noise. The most common symptoms of this profile include headache, pressure in head, neck pain, sensitivity to light, and sensitivity to noise.[52,80] In fact, the most commonly reported symptom of SRC is headache with a mean score of 2.21 ± 1.70 on the Post-Concussion Symptom Scale, and most athletes will report symptoms consistent with migraine in the first week following injury.[96] This is not true for all athletes as some may experience a persistent, intermittent headache beyond this one-week timeframe.[97,98] Kontos and colleagues reported that the posttraumatic migraine profile as the most common primary profile with 26% of participants.[80]

Athletes are at an increased risk for prolonged recovery and may have difficulty tolerating functional activities when they experience migraine symptoms.[97,98] One study of high school football players with posttraumatic migraine performed worse on visual memory and reaction time and reported more symptoms compared to football players with just headache or no headache across recovery time points.[98] The posttraumatic migraine group was also 2.6 times more likely to have a prolonged recovery greater than 20 days compared to the headache group and 7.3 times more likely than the no headache group.[98] Furthermore, risk factors that may predispose an athlete to display this clinical profile after SRC include a personal or family history of migraine.[99,100] A recent systematic review of pre-injury migraines as a vulnerability factor for worse outcomes following SRC indicated there is some evidence to support this relationship.[101] The authors noted that some of the larger, better designed studies suggested pre-injury migraines may be a risk factor for worse concussion outcome.[101]

2.4.4 Clinical Profile: Vestibular

The vestibular system is a complex sensorimotor system that is responsible for a variety of functions, including detection of motion and position of the head and body, motor responses, multisensory integration, and higher-level cognitive-perceptual functions.[102] This tells us that the vestibular system is incredibly important for maintaining postural stability and is involved in vestibular-oculomotor response which occurs through central vestibular pathways that integrate sensory input from several sources, such as peripheral vestibular organs, visual pathways, and proprioception.[103] Signs and symptoms such as dizziness, vertigo, nausea, postural instability, visual distortion, balance problems, and fogginess are most commonly associated with a disruption of vestibular function.[52,80,102] Kontos et al.[80] indicated that a primary vestibular profile accounted for 19% of all 236 participants. Furthermore, research indicates that vestibular dysfunction occurs in 50-84% of athletes who report dizziness following SRC.[96,104,105] Additionally, the vestibular clinical profile may not present itself when athletes are engaged in activities at rest, but may experience a provocation of symptoms when engaged in dynamic movements like sport participation, motion related activities like riding in a car, and/or when in a crowded environment.[80]

The vestibular clinical profile also has implications for SRC recovery as it may be associated with longer recovery time.[106] A positive vestibular/ocular motor screening on all domains except near point convergence and accommodation was associated with increased recovery time following SRC in a sample of youth and adolescent athletes.[106] Another study found that dizziness reported at the time of injury was associated with a 6-fold increase in protracted recovery for high school football players.[104] Additionally, adolescents assigned to persistent vestibular-ocular groups reported higher symptoms at 11-21 days post-injury and also took longer to recover compared to the no vestibular-ocular impairment group.[107] Collegiate athletes with abnormal scores on smooth pursuits, horizontal saccades, vertical saccades, and convergence were associated with increased time-to-clearance for return to sport.[108] More specifically, any score ≥ 2 on the vestibular/ocular motor screening predicted significantly greater days to clearance for return to play of 13.1 days compared with athletes with no abnormal test scores in which clearance occurred on average 9.6 days from the SRC event.[108] Finally, high susceptibility toward motion sickness has been identified as a potential risk factor for the development of the vestibular clinical profile as high school athletes with a history of motion sickness susceptibility exhibited higher baseline vestibular ocular-motor scores than those without this history.[109]

2.4.5 Clinical Profile: Ocular

The ocular profile is characterized by impairment in vision and related symptoms.[80] The most common symptoms of this profile include blurred or double vision, sensitivity to light, trouble focusing, frontal headache or pressure, nausea or vomiting, and fatigue with activities like reading or computer work.[52,80] Of the 236 participants, Kontos and colleagues[80] found that 38 participants (16%) with a concussion were considered to have ocular issues as their primary profile. Oculomotor dysfunction in athletes with SRC can include deficiencies in convergence and accommodative functions, which help to maintain near vision.[110-114] Athletes may also express difficulties with academics as there is a demand on vision in this environment that may be affected when there is an oculomotor deficit.[115]

Currently, ocular function represents a domain that has not been studied extensively in the context of SRC.[116] However, of the available evidence, this clinical profile has implications for SRC recovery as athletes diagnosed with a vision disorder after SRC are at risk for prolonged recovery time.[117,118] Vision disorders may also be quite prevalent in children and adolescents with prolonged symptoms after concussion with 69% of children from a tertiary referral center had at least one associated vision disorder[112] and 62.5% of children with SRC who reported persisting symptoms had vestibulo-ocular dysfunction in another study.[119] Additionally, athletes with SRC who had a convergence insufficiency exhibited lower performance on neurocognitive testing and reported higher symptoms on questionnaires of visual function.[112,114] In another study, using objective visual tracking methods in adolescents after SRC, right eye skew was altered compared to health controls.[120] Finally, with limited research, there are no known risk factors associated with the ocular profile,[80] though researchers have conjectured that a preinjury history of an oculomotor abnormality may lead to a higher predisposition to display the ocular profile after SRC.[81]

2.4.6 Modifiers of Concussion: Cervical and Sleep

On the current model of concussion clinical profiles, cervical has evolved into a modifier, but should still be evaluated due to the role of the neck in stabilizing the head. Cervical symptoms may be reported as neck stiffness or pain, limited range of motion or strength in the neck, a headache that likely originates toward the back of the head, and numbness or tingling.[80]

Sleep is another modifier of concussion. Sleep problems represent one of the most common complaints following SRC as 30% to 70% of patients report this[121] and may be another indicator of prolonged recovery.[122] Individuals with a concussion who report sleep problems indicate complaints of drowsiness, excessive daytime sleepiness, nighttime sleep disruption, difficulty falling asleep, or sleeping too much/too little.[123] Furthermore, sleep difficulties may change throughout the course of recovery and some athletes, especially adolescents, may engage in modifiable behaviors such as socializing, using electronics late at night and staying up to complete homework that could directly affect sleep.[80] Research has shown associations between sleep problems and a greater symptom burden and longer symptom duration in pediatric patients with concussion[124,125] and collegiate athletes.[126,127]

2.4.7 Overlapping Clinical Profiles

As previously mentioned, athletes may present with one clearly defined clinical profile, but it is much more likely that athletes will present with multiple profiles that overlap with one another.[80] More specifically, significant associations were supported among all primary concussion clinical profiles and at least one secondary profile, with the exception of the cognitive/fatigue primary profile.[80] For example, athletes whose primary clinical profile was ocular were more likely to have a secondary cognitive/fatigue profile. Furthermore, the study found that two secondary profiles are particularly common among those with primary vestibular profile and primary posttraumatic migraine profile. Participants with a primary vestibular profile were more likely to have a secondary posttraumatic migraine and ocular profile while participants with posttraumatic migraine profile were more likely to have a secondary vestibular and anxiety/mood profile.[80] This also highlights the reciprocal association between the vestibular and posttraumatic migraine profiles. This has previously been supported in concussion literature as posttraumatic migraine was associated with higher symptom provocation on vestibular/oculomotor screening.[128]

Research has supported the overlapping nature of these clinical profiles. Outside of the typical symptoms of a posttraumatic migraine, other potential symptoms associated with this profile include sleep dysregulation and anxiety/mood disturbances.[52,129,130] Overlaps with the affective clinical profile might occur as associations between the vestibular system and mood changes have been found.[131-133] For example, the sensation of dizziness has been seen as both a symptom and a cause of anxiety[134,135] and anxiety is often triggered by a vestibular event.[136] An example of this is presented by Sandel and colleagues[14] in which an athlete with a vestibular disturbance may experience both dizziness and anxiety when running sprints at practice so they may avoid any physical activity or movement of their head to avoid experiencing dizziness again. This would cause challenges for the recovery of the athletes, but it should also be noted that if clinicians are not appropriately detecting and addressing anxiety, it may impede the efficacy of treatment.[14,137] Additionally, symptoms of the vestibular and ocular profiles often overlap suggesting that these two common profiles may co-occur in athletes and pose challenges for treatment.[80] Research has found that dizziness can occur with reading in individuals with a concussion with only oculomotor dysfunction in children.[138] Although the cognitive/fatigue profile was not significantly associated a secondary clinical profile, athletes may also endorse a nonspecific headache, fatigue toward the end of the day, and a disruption to their sleep schedule.[139] Finally, it must be noted that despite this preliminary research, there is still a need to explore the associations among the different clinical profiles and the underlying mechanisms for these relationships.

2.5 Diagnosis and Assessment of Concussion

Diagnosing concussion can be a challenging task for healthcare providers as there is no biomarker or one single assessment measure that can be used; however, significant progress on this front has been made over the past two decades. A beneficial, though not required, first step in the assessment of concussion is the use of baseline testing by healthcare providers. This can and should be conducted to aid healthcare providers in establishing a 'normal' level of functioning and establish the degree of change after an impact to the head and/or to facilitate injury management.[51] Baseline testing should occur on an annual basis and would typically occur prior to the start of an individual's athletic season or the start of the academic year.[51] In fact, many sport organizations and athletic associations (e.g., NCAA) require baseline testing. A baseline assessment battery should involve clinical evaluation, self-reported symptoms, motor control and balance assessment, identification of comorbidities like learning disability, mental health history, family history of neurological conditions, and neurocognitive function.[51,52] Researchers and clinicians alike should keep in mind that pre-existing factors such as psychiatric condition and treatment for headaches/migraines and "sandbagging" by individuals may occur and limit the utility of some tests.[140-143] Despite this, baseline assessments should be performed as they are an integral part of concussion assessment.

Once a concussion is suspected, a multifaceted approach is employed for diagnostic criteria which relies on immediate clinical presentation and its evolution over the first 24-48 hours, followed by a series of clinical assessments and self-reported symptoms.[52] The diagnosis can be complicated for clinicians as no one injury is the same as each individual and injury can present itself with a unique set of clinical signs and symptoms.[52] Typically, an individual with concussion may present with one or more of the following: symptoms (e.g., headache), physical signs (e.g., LOC), balance problems, behavioral changes (e.g., irritability), cognitive impairment (e.g., decreased reaction time), and/or sleep disturbance (e.g., trouble falling asleep).[3] In general, concussion diagnosis involves an assessment battery that includes clinical evaluation (e.g., physical signs like loss of consciousness, neurobehavioral changes), symptom reports, balance assessment, and neurocognitive testing.[3] Approximately half (47.4%) of recent CISG attendees identified detection of concussion as 6th in terms of priority for future research and medical organizations have advocated for identifying the best and most accurate battery of concussion assessments.[3,144] Diagnostic assessments typically used to supplement the information found in a clinical examination will be discussed below and includes symptoms, the Sport Concussion Assessment Tool-6 (SCAT6), the Balance Error Scoring System (BESS), the Vestibular Ocular Motor Screening (VOMS), Immediate Post-Concussion Assessment and Cognitive Testing (IMPACT), and King-Devick.[3,51,52,145]

2.5.1 Assessment of Symptoms

A major component of concussion diagnosis comprises the assessment of signs and symptoms. Unfortunately, the signs and symptoms of concussion are not always specific to the injury itself and may be confused with other sport-related conditions (e.g., dehydration), especially when mechanism of symptom onset is ambiguous.[146,147] A symptom checklist is often utilized for assessment of signs and symptoms that allows for a depiction of how the participant is feeling in a variety of areas, along with the severity and duration of each symptom. The evaluation of symptoms should occur at a variety of timepoints including at baseline, during the sideline assessment, and at the time of clinical examination following injury to better understand the trajectory of symptoms throughout recovery. There are a number of symptom checklist available that include the Post-Concussion Symptom Scale (PCSS),[148-150] Post-Concussion Symptom Inventory (PCSI),[7,151] Graded Symptom Checklist (GSC),[50,152,153] Head Injury Scale (HIS),[154] Rivermead Post Concussion Symptom Questionnaire (RPQ),[155-157] and the SCAT.[3,145,158,159]

The symptom checklists from the SCAT6 and the Child SCAT6 are commonly used and recommended by the CISG.[145,158,159] The symptom checklist of the SCAT6 consists of 22 symptoms, that include headache, “pressure in head”, neck pain, nausea or vomiting, vertigo, blurry vision, balance problems, sensitivity to light and noise, feeling slowed down, feeling as if they are “in a fog”, “don’t feel right”, difficulty remembering and concentrating, fatigue, confusion, drowsiness, more emotional, irritability, sadness, nervous or anxiousness, and difficulty falling asleep. These symptoms are graded on a Likert-scale of 0-6 with 0 representing no symptoms and 6 representing a severe symptom.[158] The sum of how many symptoms reported provides the total number of symptoms (out of 22) and the sum of graded scores of each symptoms provides that severity of symptoms (out of 132). The Child SCAT6 is similar but consists of 21 symptoms that are adapted to be easily understood by a child (ages 8 to 12 years). For instance, nausea was changed to “I feel sick to my stomach”.[159] This symptom checklist is graded on a Likert-scale of 0-3 with 0 representing “not at all/never” and 3 representing “a lot/often”.[159] For this checklist, the total number of symptoms is out of 21 and the severity of symptoms is calculated out of 63. The Child SCAT6 also provides a parent symptom checklist to allow the parent of the child to report their perception of their child’s symptoms side by side. Another commonly used and well-validated symptom report is the PCSS which also includes 22 symptoms graded on a 7-point Likert-scale.[149] The PCSS differs from the symptom checklist of the SCAT6 as it only captures a total score and includes different symptoms descriptions, including "excessive sleep", "numbness or tingling" and "visual problems".

Baseline symptoms scores from the various tools described above have been reported in multiple studies in a variety of populations. It may be expected that no symptoms are reported at baseline, but this is not always the case due to medical history and comorbidities. Data presented by Valovich McLeod et al.[160] and Mailer et al.[161] indicate anywhere from 50-85% of athletes experience one or more symptoms during their baseline assessment with adolescents in particular showing a higher percentage of baseline symptoms compared to adults. Females represent another vulnerable population as another study found they are more likely to report more symptoms at baseline compared to males.[162] Other research has demonstrated that high school and college athletes reporting baseline symptoms are more likely to report a higher number and severity of those same symptoms following SRC, which emphasizes the importance of capturing this data preinjury at baseline.[163] Utilizing previous iterations of the SCAT, studies have shown that the most commonly reported symptoms at baseline are headache, fatigue, difficulty concentrating, drowsiness, trouble falling asleep, and nervous/anxiousness.[162,164] Furthermore, Kontos and colleagues[96] grouped related symptoms, known as symptoms factors, and found higher levels of cognitive-sensory symptoms and vestibular-somatic symptoms at baseline when using the PCSS.

Due to 99% of concussions resulting in symptoms, researchers have focused on understanding what symptoms are more frequently reported at initial presentation. The available evidence seems to suggest that headache is the most commonly endorsed symptom as 87.5% - 94.7% of adolescent and collegiate athletes reported experiencing headache after a concussion.[76,77,165-168] Additionally, dizziness has been reported by 61.3%-73.8% of individuals,[76,77,165,167,168] 54.8% - 61% of individuals report difficulty concentrating,[76,165,167,168] 46.6% - 52.6% of individuals report sensitivity to light,[77,167] and 39.3% of individuals report sensitivity to noise.[77] Research has also indicated fatigue, feeling slowed down, drowsiness, and feeling mentally foggy as commonly reported symptoms.[76,149,165,166] Initial research focused on LOC as a requirement for positive concussion diagnosis; however, this is no longer the case as LOC only occurs in about 6.4% - 10% of all concussive injuries.[165,167,168]

Literature has also focused its attention on identifying symptoms that take longer to resolve as they relate to prolonged recovery. Symptoms of sleep disturbance, frustration, forgetfulness, and fatigue were the most likely to be reported at a follow-up visit in children with concussion.[169] Another study observed excessive sleep in up to 38% of patients as the most frequent symptom and trouble falling asleep as the most severe symptom at 2-3 weeks after a concussion.[170] Relatedly, 20% of children reported fatigue one month after concussion.[169] Headache is also a frequently reported symptom well after the concussive event.[169-171] Research has found more than 25% of patients were still endorsing headache one month after concussion and another study found 43% of patients still reported headache 3 months after injury.[169,171] Additionally, other commonly reported symptoms that take longer to recover include irritability, sleep disturbance, frustration, poor concentration, and fogginess.[166,169] Symptoms that seem to recover more quickly after concussion include double vision, nausea, dizziness, and depression.[169] Knowing which symptoms are quicker to recover and which ones are slower can provide clinicians with more information for more targeted treatment options.

Furthermore, post-concussion symptom report is an important marker of recovery. Research on concussion recovery has focused on detailing the time to symptom resolution, though more research is considerably needed. Early studies proposed that symptoms resolved within 5-10 days of the concussion.[84,87,172-176] More specifically, collegiate football players reported symptom resolution occurred on average 3.5 days after SRC and about 88% reported no symptoms within one week of injury.[173] This was also supported in another study of collegiate football players in which 91% of these individuals' symptoms returned to baseline after 7 days.[84] NCAA ISP data indicated most concussions (60.1%) had symptoms resolve within 1 week and a little over a third of concussions resolved in ≤ 3 days after injury.[177]

The literature shows no consensus on when symptom resolution occurs as other research indicates that symptom resolution can take longer.[169,175,177-181] Only a small subset of collegiate athletes (6.2%) took over 4 weeks for symptoms to completely subside[177] and another study found 10-15% of patients had symptom recoveries greater than 10 days.[175] A more recent study characterized SRC recovery at 1-week postinjury time intervals on symptom reports.[181] In line with much of the previous research, symptoms improved significantly in the first two weeks after SRC.[181] This study also found that after the first two weeks, improvement slows as approximately 45% of athletes were asymptomatic by 3 weeks and 56% of athletes were asymptomatic by 4 weeks.[181] Timing of symptom report, including delayed reporting and delayed onset of symptoms also matters and represents an important factor for estimating recovery. For example, delayed symptom onset in a large sample of concussed military academy cadets and intercollegiate athletes had higher symptom burdens 24 to 48 hours after injury and took a median difference of 2 days longer to become asymptomatic, and 3 days longer to return to activity compared to a those who had immediate onset of symptoms.[38]

Relatedly, delayed reporting and removal from athletic activity after SRC led to 4.9 more days missed which was defined as the number of days between the concussion-causing event and clearance for return to contact.[39] An important takeaway from that study and many others is that the discrepancies in symptom resolution may stem from the definition of symptom recovery. Studies may define symptom recovery as zero reported symptoms on symptom checklists, deemed asymptomatic, [173,175,177,179,180,182] while others have defined symptom resolution as returning to baseline, comparing symptoms to a control group, normative baseline levels, or some other definition.[84,169,172,174,176,178,183,184] Consistent definitions and methodology of symptom resolution moving forward will better clarify when symptom resolution actually occurs.

We must also acknowledge some of the various limitations to the utilization of symptom reports. Research on prior medical history seems to suggest that history of concussion, ADD/ADHD, learning disorders, and psychiatric disorders impact symptom reporting.[185-187] These comorbidities often share symptoms of concussion and make it difficult to delineate between the symptoms of concussion or the other condition.[144] Another major limitation is the reliance on the athlete to report subjective symptom information.[3] Athletes may be reluctant to report symptoms of a concussion for a variety of reasons and/or may not be knowledgeable about common symptoms of a concussion to report it.[3] Some evidence has indicated about 40% of high school and collegiates athletes did not report an SRC to an authority figure (e.g., athletic trainer, coach).[73,188,189] Nondisclosure of symptoms puts an individual at risk for neurologic consequences if they were to sustain another head impact before they properly recovered.[3,190] Considerable research has been done to understand why an athlete may not report symptoms of concussion.[33,73,74,188,189,191-197] One avenue for this research has been related to lack of knowledge about concussion. Underreporting may exist because athletes do not associate the symptoms they are experiencing to a potential concussion given the unique presentation and symptom profile of each concussion.[196] Relatedly, athletes have indicated they did not think it was a serious injury or felt they could continue to play with little danger to themselves.[73,188,189,191,198] Research supports this potential explanation as an association between athletes' symptom knowledge and symptom reporting behaviors exists.[173,192]

Efforts have been made to reduce underreporting by educating athletes about concussions [199-202] including policy mandates from states that require concussion education for athletes, parents, and coaches.[203-205] Concussion education does improve intentions to report and concussion reporting behaviors.[199,202,206] In a sample of high school football players, all athletes exhibited improved intent to report concussions, increased concussion knowledge, better concussion attitudes, and more perceived behavioral control immediately following an education program and at a one-month follow-up.[206] There has been an inconclusive debate about the benefit of increased concussion knowledge. Evidence has also indicated that participants with a higher concussion knowledge (e.g., what is a concussion) also endorsed more reasons that athletes may hide symptoms.[207] This would indicate that a lack of concussion knowledge is not the only factor that explains why athletes may not report SRC and its symptoms.

There may be psychosocial and sociocultural factors that contribute to concussion reporting behaviors.[196] Research has indicated athletes may not report a concussion because they do not want to stop playing, they do not want to look weak amongst their peers, and they do not want to let their teammates down.[73,208,209] One study found that collegiate athletes reported a fear of repercussions from coaching staff or loss of standing on the team if they were to sustain a diagnosed SRC.[191] Other studies of NCAA student athletes have suggested various social pressures (e.g., coaches, teammates, and parents) influence disclosure behaviors.[194,207,210,211] For example, student athletes indicated they believe symptom reporting was less likely to occur in high stakes situations (e.g., important competition) versus low stakes situations.[207] Furthermore, these athletes identified their teammates as holding attitudes that support underreporting.[207]

These narratives speak to the sport ethos that exists in which playing through pain and injury is rewarded.[39,212,213]

2.5.2 Sport Concussion Assessment Tool-6 (SCAT6)

The Sport Concussion Assessment Tool Sixth Edition (SCAT6) is a commonly administered, standardized tool for healthcare professionals to use during clinical assessment if a concussion is suspected.[145,158] The SCAT6 can be performed in approximately 10 to 15 minutes and is considered to be the most well-established instrument specifically for sideline assessment.[145,158] The first section of the SCAT6 is the Immediate On-Field Assessment, which includes observable signs, the Glascow Come Scale, red flags, a cervical-spine assessment, coordination and ocular/motor screen, and the Memory Assessment Maddocks Questions.[158] This first section is not required at baseline and is designed to rule out any serious etiologies like possible cervical fracture or other "red flags" after a suspected concussion.[158]

The remaining SCAT6 is focused on several clinical assessments, starting with questions regarding the patient's pertinent medical history.[158] This is followed by the symptom checklist (see *Assessment of Symptoms* section). A clinician will then conduct a cognitive screening which includes the Standardized Assessment of Concussion,[145] which starts with orientation, followed by immediate memory, and concentration.[158] More specifically, the orientation component asks a series of 5 questions (e.g., "what month is it?") and each response is given a 0 or 1 depending on the correct response for an orientation score out of 5. The immediate memory component includes a list of 10-words per trial in which a clinician will read a list of words to the patient and the patient will repeat as many of those words in any order back to the clinician, and this will be completed three times.[158] An immediate memory score out of 30 is provided and the clinician should record the time of the last trial completed. Previous iterations of the SCAT included a 5-

word list that was excluded following the release of the SCAT6.[145,158,214] The concentration component includes a digit backwards section in which the clinician will read a string of numbers and the patient will repeat those numbers back, but in reverse order (e.g., if 7-1-9 is said then 9-1-7 is repeated back) followed by the patient stating the months of the year in reverse order starting with December.[158] The SCAT6 updates now indicate clinicians should record the amount of time it takes to complete the months in reverse order and the number of errors. A score of 1 is given if there are no errors and the participants completes this task in under 30 seconds. The score for the digit and months section is combined for a concentration score out of 5.[158]

Following the brief cognitive assessment, the patient will be asked to complete the Modified Balance Error Scoring System (mBESS)[215] to assess balance and coordination, which will be reported on more in-depth elsewhere (see *Balance Error Scoring System* section). Clinicians are then directed to proceed to the Tandem Gait/Dual Task Tandem Gait, which is another new addition to the SCAT6.[158] The final testing section is delayed recall in which a patient is asked to recite the list of words that were utilized during the immediate memory component. This final component should be performed at least 5 minutes after the completion of the immediate memory section.[158] Ideally, baseline and post-injury assessments of the SCAT6 should be conducted in the same setting, and this test should not be used to diagnose concussions, assess recovery, or measure a patient's readiness to return to activities after a concussion, but rather, in conjunction with other assessment tools.[145,158]

2.5.3 Balance Error Scoring System (BESS)

To assess the clinical domain pertaining to postural stability, clinicians often use the BESS or mBESS.[215] Other assessment measures may include force plates or the Sensory

Organization Test (SOT)[216] that provide accurate balance measurements in a controlled environment, but are not be suitable for all situations given the inaccessibility (e.g., financial cost, inability to use on the sideline). The BESS is frequently employed as a balance assessment in the clinical sports medicine setting because it is convenient (e.g., portable and easy to administer), cost friendly, and has moderate to good reliability.[84,172,217]

To administer the BESS a patient would stand in three different stances on both a firm surface (e.g., hard floor) and unstable surface (e.g., foam pad of medium density).[215] The three different stances include a double-leg stance (i.e., the feet are together), a single-leg stance (i.e., the patient stands on their non-dominant foot) and a tandem stance (i.e., the non-dominant foot is placed directly behind the dominant foot).[215] The patient is asked to balance in each of these three stances for 20-seconds with the eyes closed and hands on hips on both the firm and unstable surfaces.[215] Performance on the BESS is objectively measured based on the number of errors that occurred during each 20-second stance. Each stance is scored out of 10 for a total score of 30 with more errors (i.e., higher score) indicating worse performance. The errors for the BESS include moving the hands off the iliac crests, opening the eyes, stepping/stumbling/falling, abduction or flexing of the hip beyond 30 degrees in single leg stance, lifting the forefoot or heel off of the testing surface, or remaining out of the proper testing position for greater than five seconds.[215] The mBESS would include the same three stances, but only performed on the firm surface.

Previous research employing the BESS in concussed populations have found balance and postural stability deficits.[218-220] Multiple studies have found that performance on the BESS typically worsens by 3-6 errors compared to baseline performance when individuals are assessed within 24 hours after injury.[84,172,221,222] Other research has also shown that errors will typically return to baseline values within 2-5 days after concussion and with repeated administration errors will continue to improve.[84,172] In a pediatric concussed sample, 45.5% of patients had abnormal BESS scores ($\geq$ 25) at the initial visit.[218] Additionally, Covassin and colleagues[219] assessed BESS scores at 1, 2, and 3 days post-injury and results indicated that high school male athletes (mean = 18.8) scored worse than college male athletes (mean = 13.0), while college female athletes (mean = 21.1) scored worse than high school female athletes (mean = 16.9). Another study demonstrated 65.0% of patients showed improvement on BESS scores from diagnosis to return to play.[223] These studies would indicate it is important to assess balance and postural stability following concussion and throughout recovery.[3,7,51]

Despite the positive evidence for utilizing the BESS within the acute stage of concussion (~3 days), its utility beyond that has been questioned. For example, there are reliability concerns for clinical interpretation as only moderate ICC values (~0.57) have been found for the total BESS score.[215,224] Additionally, previous research has found that following concussion, scores on the BESS return to baseline despite other tests indicating deficits remain (e.g., continued symptomology and cognitive deficits).[84] Furthermore, there has been evidence to indicate significant learning effects for the BESS have been found with serial testing. In a study of 50 healthy young athletes, those in the practice group who received serial administration of the BESS had significantly lower error scores than baseline at multiple time points.[225] The authors note this learning effect was especially prominent during tandem conditions.[225] Previous research has also indicated a variety of other factors may also limit BESS performance including prior functional ankle instability and injury,[226] fatigue and dehydration,[227] and the sideline environment.[228]

2.5.4 Vestibular/Ocular Motor Screening (VOMS)

Vestibular dysfunction is a commonly reported issue for individuals following concussion and may cause delayed recovery[102] making it a vital piece as part of standard concussion assessment and management.[3] Clinicians have begun using the VOMS to determine changes in vestibulo-ocular control and identify impairments and symptoms of concussion in the vestibular and ocular systems. The administration of the VOMS takes about five to 10 minutes per individual and includes a series of seven tasks: smooth pursuits (H-test, eye movement with stationary head), horizontal and vertical saccades (rapid lateral eye movement with stationary head and rapid up and down eye movement with stationary head), near point convergence (NPC), horizontal and vertical vestibular ocular reflex (VOR) (head rotation with eyes focused on a stationary target and head nodding with eyes focused on a stationary target), and visual motion sensitivity (VMS) (standing head/trunk rotation with eyes focused on thumb held out in front of the nose).[229] Before the first task patients are asked to rate their headache, dizziness, nausea, and fogginess symptoms on a scale of 0-10 and then asked to rate their changes in these symptoms after completing each task.[229] NPC uses both the symptom report and an objective measurement in millimeters of the point of convergence.

There are two common scoring methods used for the VOMS.[229-231] Traditionally, the total scoring method added up all of the self-reported symptom severity across headache, dizziness, nausea, and fogginess for a maximum of 40 points for each VOMS assessment.[229] A recent study by Kontos et al.[230] have provided a total score for VOMS by summing each VOMS assessment score for a maximum score of 280. The other more comment scoring method calculates a change score by subtracting the difference between the pretest total symptom score and the total symptom score for each VOMS assessment.[231] Studies have been conducted on the use of these different scoring methods. A prospective study documented changes in vestibular and ocular motor impairments and symptoms in concussed high school athletes using total and change scoring methods and found both scoring systems on the VOMS were useful for identifying impairments following concussion.[232] Petit and colleagues demonstrated total provocation scores for each VOMS task were associated with recovery time and only horizontal saccades, vertical saccades, and NPC change scores were associated with recovery time in college aged individuals.[233] More research is needed to assess the utility of VOMS change scores,[232,233] but thus far the VOMS may be a useful tool for monitoring the changes of the vestibular and ocular motor systems during concussion management.[229]

Additionally, VOMS has demonstrated high sensitivity as a diagnostic tool as well as internal consistency in a preliminary investigation.[229] More specifically, this study compared VOMS and PCSS scores from adolescents with a concussion and healthy adolescents and found all VOMS tasks had a positive correlation with the PCSS total symptom score and the VOR and VMS tasks were the most predictive of concussion.[229] Additionally, an NPC distance of ≥ 5cm had a 38% increased likelihood of identifying a concussion correctly, while any VOMS task with a symptom report of ≥2 resulted in a 50% likelihood of detection.[229] Another study also demonstrated that VOMS items measure unique aspects of vestibular function that other assessments measures do not assess and had good reliability.[234] Additionally, a positive VOMS, excluding NPC and accommodation was associated with increased recovery time following concussion in youth and adolescent athletes.[106]

The VOMS has become a commonly used and valid tool as part of the multifaceted concussion approach, yet limitations to its use still exist. There is a subjective nature to the VOMS as it used subjective reporting in which participants indicate their own perceived rating of the 4 symptoms. This introduces bias as participants may not want to report symptoms to prevent suspicion of a concussion[234] or may not understand what the symptoms are (e.g., differentiating "pressure in head" from headache). Additionally, Elbin et al.[232] reported symptom improvement (i.e., fewer symptoms) post-test on the VOMS compared to baseline levels, making it more difficult to utilize as a comparison tool.

2.5.5 Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)

Neurocognitive testing has progressed from more traditional paper and pencil methods to computer-based neurocognitive examinations to make it more convenient for sports medicine use.[51,235,236] Computerized neurocognitive testing (CNT) is one tool that has been widely used for concussion assessment and management and provides an objective complement to athlete symptom reports. There are several different CNTs available for concussion assessment including: Automated Neuropsychological Assessment Metric (ANAM), Central Nervous System Vital Signs (CNS-VS), Axon/CogState/CogSport, and the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).[51] It has been reported that 60% of athletic trainers utilize some form of CNT with the ImPACT battery being the most commonly used.[237] The ImPACT battery is a neuropsychological assessment tool that measures concentration, attention, memory, visual motor speed, and reaction time that has been used in a variety of populations including high school, collegiate, and professional athletes. The ImPACT battery provides 5 composite scores including verbal memory, visual memory, processing speed, reaction time, impulse control, and total symptoms.[238]

Efforts by researchers have been made to ensure the ImPACT battery is a reliable CNT intended to evaluate concussion and can be administered in a serial fashion, as recommended, to track recovery in athletes. Researchers have examined the test-retest reliability of ImPACT by employing the battery at multiple timepoints, starting with 1 hour (Intraclass Correlation Coefficients – ICCs = 0.51 – 0.85),[239] followed by intervals of 1 week (Pearson correlation coefficient = 0.67 – 0.79),[240] 1 month (ICCs = 0.60 – 0.88),[241] 45 days (ICC = 0.70 – 0.87),[238] 50 days (ICCs = 0.74 – 0.91),[238] 1 year (0.62 – 0.82)[242], and 2 years (0.46 – 0.74).[243] Furthermore, researchers have also examined validity measures of ImPACT[147,244-247] with results suggesting the ImPACT had acceptable construct, convergent, and divergent validity.[245,246] Additionally, the ImPACT reported high levels of sensitivity (91.7%) and specificity (89.4%) in Division I collegiate athletes.[147]

Neurocognitive impairment has been well documented in the literature for athletes following concussion, both at the high school and collegiate level.[84,86,178,183,219,240,248-257] Some studies indicate that neurocognitive impairment resolves relatively quickly as one study found impairment typically resolved within 5 days of concussion and fully resolved by 10 days,[248] while a study of collegiate athletes found neurocognitive performance returned to baseline levels within 5 to 7 days following injury.[84] Other studies have suggested neurocognitive performance may take longer as two studies suggested neurocognitive impairment may take up to 14 days to resolve in high school and collegiate athletes.[86,258] While Henry et al.[181] found that neurocognitive impairment lingered in high school athletes across several domains up to 28 days after SRC. More specifically, visual memory, processing speed, and reaction time demonstrated a linear recovery trajectory, significantly improving over time up until 3 weeks after injury and verbal memory did not demonstrate significant improvement until 4 weeks after SRC.[181]

There are several other factors that may contribute to worse neurocognitive function post-concussion. Specifically, researchers have indicated that younger athletes demonstrate significantly worse neurocognitive performance compared to older athletes,[219,248,249,253] suggesting that when assessing neurocognitive performance following SRC, clinicians should take age into account. Additionally, research seems to suggest there are sex differences in neurocognitive performance in concussion,[219,251,259-261] although research is mixed.[181,262,263] Continued research on the existence of sex differences in neurocognitive performance after concussion is warranted and clinicians should evaluate post-injury neurocognitive performance in relation to baseline performance of the athlete or normative values for athletes of the same sex.[264] Finally, an emerging yet necessary effort by Wallace and colleagues has been made to understand racial differences on neurocognitive performance.[254-256] In one study, the relationship between race and SES on baseline concussion assessment of neurocognitive performance and oculomotor function was explored in high school athletes given the high participation of Black/African American individuals at this level, primarily participating in high-risk sports that might lead to concussion.[255] Race was defined as either White/non-Hispanic or Black/African American and SES status was determined by whether the individual's participating high school was a Title I or non–Title I school. Regarding neurocognitive performance at baseline, White/non-Hispanic athletes performed significantly better than Black/African American individuals on all measures of the ImPACT battery while individuals from non-Title I school performed better on visual memory and reaction time than individuals from Title I schools.[255] The results of this study suggest race and SES influence neurocognitive performance in high school athletes which highlight the need for individualized concussion baseline measurements or race-specific normative reference values.[255]

2.5.6 King-Devick (KD)

Another tool that can be used as a sideline assessment to assess the visual system after concussion is the King-Devick (KD). The KD test was originally intended as a reading tool to assess ocular motor function and identify learning disabilities as it is a rapid number naming test that requires attention, language, and concentration.[265] Currently though, this test is being used as an efficient sideline screening tool as part of the multifaceted approach after suspected concussion. The KD test was initially administered using a physical, spiral bound booklet with 3 test cards but there is now a more recent version designed for a tablet. When completing the KD test, individuals are instructed to read single digit numbers as fast as they can without making errors from left to right on three test cards that increase in difficulty while the clinician keeps time. The test is completed twice and takes less than two minutes to administer. The number of errors and the fastest total time it takes to read all three cards constitutes the summary scores for this evaluative tool.[266] Previous research suggests the KD test is reliable with high test-retest reliability ICCs ranging from 0.60 to 0.97.[267-272] However, mixed results on the clinical utility of the KD test have been found indicating sensitivity and specificity may be low.[271,273-275] A recent study found the KD test had the greatest diagnostic accuracy at 0-6 and 24-48 hours after SRC but declined across subsequent post-injury time points.[275] At the 0-6 and 24-48 hours timepoints there was an 80% sensitivity, but 46% and 41% specificity, respectively.[275] Additionally, the authors reported the KD test had significantly better area under the curve when administered on an iPad compared to the spiral card system.[275] These results would indicate it may be best to use the KD test as a sideline screening tool and not a concussion diagnosis tool.[265]

Research with the KD test has suggested significantly slower times, indicating worse performance, has been found in concussed athletes when compared to baseline assessments and/or healthy participants.[269,276,277] NCAA collegiate athletes had slower post-concussion KD performance scores in the first two days after injury and this was associated with longer recovery times, when adjusting for covariates.[278] Though the authors note that change in KD score from baseline to post-injury was not associated with time to return to play, just the actual post-injury KD score.[278] A majority of adolescent athletes performed worse on the KD test by taking 14.1 seconds longer to complete the test after concussion.[276] Other studies have also demonstrated worse performance on the KD test albeit with a smaller change in baseline to post-injury performance with times ranging between 4.7 seconds to 7.4 seconds.[266,273,279,280] Additionally, two studies have shown an increase in performance on the KD test in which 38% of concussed athletes performed faster on the KD test in one study[273] and another indicated 28% of concussed athletes demonstrated faster KD performance.[276] It is possible that faster performance on the KD test was indicative of athletes' desire to return to play sooner.[273] However, a major limitation of many of these studies is a small sample size indicating a need for future research with a more robust sample.[266,269-271,277,279,280]

2.6 Management of Concussion

Considering the heterogeneity of concussion, management of concussion can be complicated, and a one-size fits all approach will not be effective and may even harm some athletes.[281] There has been a shift in the approach to assessing and managing this injury that emphasizes active and targeted treatment based on specific concussion symptoms and impairments that would include considerations for the characteristics of the injury and athlete alike.[128,139,282] When researchers proposed clinical profile-based approaches, assessment and more targeted and effective therapies for athletes with concussion were included in the design.[80-83] This is a far cry from early consensus statements that described the basis of concussion management as strict physical and cognitive rest, known as "cocoon therapy."[283,284]

2.6.1 Management of Concussion: Cognitive/Fatigue Profile

Starting with the cognitive and fatigue profile, an assessment of symptoms and cognitive functioning is warranted. The clinical interview should be targeted at evaluating academic and work performance while symptom inventories can evaluate the presence and severity of perceived cognitive complaints.[80] For example, one question on the SCAT6 asks, "do your symptoms get worse with mental activity?"[158] An athlete presenting with the cognitive clinical profile might present with confusion, disorientation, and/or poor performance on CNT.[52] An athlete presenting with the fatigue clinical profile might present with tired or subdued appearance, decreased arousal, and/or drowsiness.[52] Additionally, subjective symptom reports should always be compared with objective neurocognitive testing, like the ImPACT battery.[80,90,260] The assessment of this profile will then inform the management of this injury.

Targeted treatment strategies for the cognitive/fatigue profile can include brief academic/work accommodations, behavioral regulation, and/or medication with stimulant properties.[80] More specifically, to address the cognitive symptoms, a clinician may include targeted treatments of academic accommodations and formal neurocognitive evaluation/rehabilitation.[52] A four-step graduated Return to Learn (RTL) protocol was established to help students safely return to full academic activity[7] as a concussion can make learning difficult.[285] School personnel should be informed of the injury and implement an initial school support plan without delay and schools should be prepared to provide additional support if recovery is prolonged.[52,286] Academic accommodations for student-athletes may include breaks during the school day, increased time to complete assignments and tests, extended due dates for major projects, allow use of headphones or sunglasses to reduce noise and light sensitivity, and limit the use of electronic screens.[52] Additionally, clinicians should provide individualized accommodations based on patient-specific symptoms, symptom severity, academic demands, as well as pre-existing conditions, such as mood disorder, learning disability or attention deficit/hyperactivity disorder.[52,285,287]

Focusing on symptoms related to fatigue, targeted treatments of cognitive behavioral therapy and graded exertional tolerance training may be necessary.[52] One objective physiological sign of acute concussion is exercise intolerance that appears to reflect diminished autonomic function and control of cerebral blood flow.[288,289] Exercise may help restore some of the initial pathophysiological deficits that occur with emerging evidence that sub-symptom threshold exercise may improve recovery in acute concussion and appears to be safe.[290-292] For those with persisting symptoms after concussion, a formal symptom-limited aerobic exercise program has been shown to be both safe and improve resolution of persistent symptoms compared with controls.[293-295] One example of this is the Buffalo Concussion Exercise Treatment Protocol that uses the Buffalo Concussion Treadmill Test.[296] This test is an incremental treadmill test that starts with the participant walking on a treadmill set at 3.6mph at a 0% incline for one minute with a 1% increase in include after each minute at the same speed.[297] During every minute of the test, ratings of perceived exertion and symptoms are assessed while heart rate and blood pressure are recorded every two minutes.[297] When the participant reports an exacerbation of post-concussion symptoms, defined as three or more points compared to the participant's pre-exercise test symptom score, the test is stopped.[297] An exercise prescription is then made based on identifying the intensity of aerobic exercise that aggravated post-concussion symptoms so that athletes can perform 20 minutes per day of aerobic exercise at an intensity of 80% - 90% of the sub-symptom threshold heart rate.[296,297] The athlete will perform this once per day for 6 – 7 days of the week.[296,297]

2.6.2 Management of Concussion: Affective (Anxiety/Mood) Profile

To evaluate the affective profile, an appreciation for both the physiological and psychological components of the injury and a thorough knowledge of the typical signs and symptoms of concussion is required.[80] A clinical interview and symptom questionnaires of emotional functioning may help to elucidate the level and nature of emotional distress after the injury.[80] It is necessary for clinicians to consider the role that mental health may be playing in the presentation of physical symptoms and it is not enough to simply ask athletes as they may not understand how psychological processes may influence perception and reporting of somatic symptoms and/or they may not want to accept a psychological explanation for physical complaints.[80] Additionally, to develop an appropriate treatment plan for those presenting with the affective clinical profile, it is important to determine if there is a presence or overlap with secondary clinical profile(s).[14] It may be important to address another clinical profile first or concurrently (e.g., vestibular clinical profile) with the affective clinical profile.[14]

Targeted treatments may include psychoeducation, behavioral regulation strategies, addressing sleep disturbance, physical activity, desensitization to environmental stimuli, ensuring the athlete with a concussion maintains social engagement, use of mental health counseling, and cognitive behavioral therapy (CBT).[14,52] For example, psychoeducation might include the clinician setting a realistic, yet positive, expectation for recovery, a description of the pathophysiology of the injury, commonly experienced symptoms, and effective strategies for symptom reduction.[298] This can occur in a variety of formats such as individual feedback, group sessions, or handouts.[298] Additionally, behavioral regulation strategies may be useful in alleviating symptoms and include a focus on maintaining healthy lifestyle factors such as a regular sleep schedule, proper nutrition and hydration, daily movement (i.e., non-contact physical activity), and management of stress.[299]

Another option for treatment may include the use of psychotherapy such as CBT.[300] This therapy is a standardized, skills-based treatment that aims to change maladaptive beliefs and coping behaviors to improve health outcomes.[301] A recent study evaluated the feasibility and benefits of a standardized, brief CBT intervention program for children and adolescents with persistent postconcussive symptoms.[302] Patients between the ages of 8 to 17 years old who sustained a concussion in the last month to 12 months and reported ongoing PCS and functional impairment were enrolled in this multi-site study. Patients completed the Concussion Symptoms Treatment and Education Program (C-STEP) that comprised of 6 sessions that included (1) diagnostic intake and introduction to the treatment approach, (2) psychoeducation and sleep hygiene, (3) activity scheduling and diaphragmatic breathing, (4) relaxation training, (5) cognitive errors and restructuring, and (6) wrap-up/review. Each session was 45-60 minutes long and typically completed weekly. Patients also completed assessments related to their symptoms, health-related quality of life, depression and anxiety, and functional outcomes. Results indicated an improvement in symptoms over the course of treatment with the biggest improvement noted between sessions 2 and 3.[302] Patients also reported reductions in depression and anxiety and improvements in functional outcomes.[302] Overall, the CBT intervention program was feasibly implemented and beneficial for the patients enrolled in the study.[302]

2.6.3 Management of Concussion: Posttraumatic Migraine Profile

To evaluate the migraine profile, a comprehensive evaluation of headache characteristics should be conducted as part of the clinical interview as it can offer valuable knowledge about the nature and classification of the headache.[80] Headache characteristics include onset, severity, frequency, duration, triggers, location, quality/sensation (*e.g.,* pulsating, throbbing, sharp pain), accompanying symptoms (*e.g.,* nausea), and presence/absence of an aura.[80] A clinician may also notice during the physical exam that an athlete has an avoidance reaction to bright light, occipital and neck tenderness, and tight neck muscles.[52] It may also be necessary to perform CNT as athletes exhibiting the migraine profile have demonstrated decline across memory and speed composites.[303] Potential targeted treatments for this profile may include manual therapy and treatment of headache disorder.[52] Additionally, sleep hygiene may be beneficial which includes limiting caffeine intake, daily exercise, reducing nighttime stress through mindfulness mediation, keeping a consistent bedtime and wake up time, limiting naps to less than 30 minutes, and eliminating noise in the sleep environment as much as possible.[304,305]

2.6.4 Management of Concussion: Vestibular Profile

Evaluation of the vestibular profile includes an assessment of symptoms during the clinical interview and screening for vestibular-oculomotor function. Questions related to what activities provoke symptoms (e.g., when you engage in dynamic head movements during physical activity, do you notice an increase in symptoms?") and activities that might be avoided due to symptom provocation (e.g., athletes avoid running during sprints because it causes them to feel dizzy) should be asked during the clinical interview.[80] Symptom reports should also be verified using comprehensive vestibular-oculomotor tools, such as the VOMS.[229] Balance testing, such as the BESS, are also recommended in the acute phase of injury.[221] Clinicians may notice during the physical exam that athletes present with impaired balance and gait, and have abnormal vestibular-ocular reflex or other abnormal vestibular testing.[52]

The vestibular profile should include targeted treatments such as graded exposure to stimuli and vestibular rehabilitation.[52] Vestibular therapy is a promising treatment option for patients presenting with vestibular dysfunction.[306-309] A comparison of a 4-week precision vestibular rehabilitation intervention compared with a behavioral management control intervention was conducted for adolescents with vestibular symptoms and impairments within 21 days of SRC.[310] Study results indicated the vestibular intervention group significantly improved in horizontal and vertical VOR, but not VMS on the VOMS compared to controls and experienced greater clinical improvements in vestibular symptoms/impairments than those in the behavioral management control group across the 4-week intervention.[310] Furthermore, in a sample of active duty service members, a comparison of clinical outcomes between military personnel receiving generalized and individualized vestibular rehabilitation treatments for persistent vestibular-related symptoms following mTBI was completed.[311] Both groups demonstrated significant improvements from pre-to-post treatment on self-reported dizziness-related impairment and balance performance with and without head movement with no differences between groups on treatment effects on any of the outcome measures.[311] This study provided evidence for the use of vestibular rehabilitation as well as the use of different forms of vestibular therapy that may be necessary in different clinical settings.[311]

2.6.5 Management of Concussion: Ocular Profile

Similar to the vestibular clinical profile, assessment of the ocular profile following concussion requires symptom assessment and oculomotor functions, including the VOMS, with specific assessment of smooth pursuits, saccades, NPC, and accommodation.[80,229] CNT may also be used during evaluation for the ocular profile as athletes with convergence insufficiency demonstrated lower performance on neurocognitive testing and reported higher symptoms on visual function questionnaires.[112,114] During the physical examination, athletes may present with abnormal NPC, pursuits, and saccades, impaired accommodation, and symptom provocation on oculomotor tests.[52]

Targeted treatment approaches for this profile may include ocular rehabilitation, lens change, and visual-training exercises.[52,80] Visual training exercises generally occur through neurovestibular therapy and behavioral optometry with notable improvements after concussion.[312-314] A success rate of vision therapy for those with convergence insufficiency and accommodative insufficiency was assessed in a sample of patients referred for post-concussion vision problems in two private practice setting.[315] Vision therapy was recommended for 80% of the patients and of the 54% who completed therapy, 85% of patients with convergence insufficiency had a successful outcome and 15% were improved, while 33% of patients with accommodative insufficiency had a successful outcome and 67% improved.[315] Additionally, research also suggests combining office-based and home-based vision therapy training will maximize visual improvement and functional results following injury.[314]

2.7 Return to Play after Concussion

The Return to Play (RTP) gradual, stepwise progression provides a framework for clinicians to follow to ensure a patient who suffers a concussion can return to sport and activity safely.[52] This progression should include an increase in physical demands and sport-specific activities without return of symptoms before the final introduction of exposure of contact, as well as a demonstration by the athlete of psychological readiness for returning to sport.[52] Additionally, considerations are made for the athlete's age, prior history of concussion, level of play, and the ability to provide close supervision to ensure the RTP progression is individualized and a function of the athlete's injury.[52] An individual should not return to participation until cleared by a physician or a trained medical professional.[3,7] The RTP progression and clinical management of concussion has evolved immensely over time as knowledge and understanding of this injury has progressed, with updates provided from the CISG.[3,7]

The initial guidelines for RTP were based on concussion grades (I-III) and the number of subsequent concussions.[316] The RTP protocol was adopted by the CISG in 2001 to introduce a stepwise progression and how to progress a patient through the protocol.[56] This update removed the concussion grading scale from clinical management and the RTP protocol did not specify any management adjustments based on concussion severity.[56] The first stage indicated complete rest until asymptomatic for the concussed individual and light aerobic exercise such as cycling or walking for stage two.[56] This was followed by the introduction of sport-specific training that progressed to non-contact training drills for stages three and four.[56] Once medical clearance was obtained, the fifth step advised full contact training and the sixth, and final, stage included full, unrestricted game play.[56] Progression of a patient from one stage to the next occurred if they remained asymptomatic for 24 hours and if symptoms arose, a patient was recommended to drop back to the preceding asymptomatic stage and attempt to advance again following another 24-hour timeframe.[56]

Additional updates and progressions were made to the RTP protocol during the 2005, 2008, and 2013 CISG meetings.[53-55] A progressive addition of resistance training beginning at stage three was included to the RTP protocol during the 2005 CISG.[55] The 2008 CISG included objectives and specific functional exercises to consider at each stage of the 6-step RTP protocol based on suggestions from expert panelists.[53] For example, a major recommendation for stage three provided clarification that patients should not engage in activities that might cause head impacts to further safeguard the individual from a delayed recovery if exposed too soon.[53] By the fourth CISG meeting in 2012, it was becoming evident that changes were needed at the first stage to include symptom limited physical and cognitive rest rather than complete rest until asymptomatic.[54] Expert panelists proposed these updates based on emerging evidence that complete cognitive and physical rest may actually prolong symptom duration and severity which would ultimately delay recovery.[175,317]

The most recent updates to the RTP protocol were provided by the 2022 CISG.[3] As with previous RTP protocols there are still six steps with specific clinical aims and activity suggestions for clinicians to consider during each stage of the protocol.[3,7] Each step should occur under the supervision of a qualified healthcare professional. Initiation of the RTP protocol may begin with 24 hours of the injury with symptom-limited activity, and advancement through each subsequent step usually requires at least 24 hours.[3] The individual's progression through steps typically depends on symptoms, cognitive function, examination findings and clinical judgement.[3] Exacerbation of symptoms is defined as an increase of more than 2 points on a 0-10 point scale. If an individual experiences symptoms during Steps 1-3, they are instructed to stop and attempt the exercise the next day.[3] If exacerbation of symptoms occurs during Steps 4-6, they should return to Step 3 to establish full symptom resolution with exertion before engaging in those later steps.[3] Typical duration of the RTP protocol is a minimum of 7 days if the patient can withstand each stage after 24 hours of activity, however, unrestricted RTP can take up to 1 month following injury.[3] Repeat of steps may indicate a more prolonged recovery or severe symptom burden for individuals. Other major sports medicine groups support this version of the RTP protocol including the American Academy of Neurology (AAN) and the American Medical Society for Sports Medicine.[48,52]

Clinical recovery from a concussion is defined by the patient's functionality in their ability to resume to daily activities such as work, school, and sport without a recurrence of concussion-associated symptoms.[7] This would include post-concussion symptom resolution and clinically “normal” cognitive function and balance.[7] Thus far, there are currently no objective clinical recovery measures to determine without certainty when an athlete may safely return to sport following a concussion.[7] Previous literature has suggested that most athletes recover from a concussion in approximately 7 – 14 days,[3,7,48,318,319] but a recent systematic review indicated that the estimated pooled mean time for RTP in children, adolescents, and adults was 19.8 days (95% CI: 18.8 to 20.7 days, n=57 studies, I-squared=99.3%, Q-statistic <0.01).[320] Another recent systematic review that included 65 studies and a total of 21,966 patients found that the median time to RTP after concussion is within 21 days in 80% of published studies.[321]

We must also consider that a subset of athletes will experience longer recovery times with research indicating about 20% of athletes with concussion experience protracted recovery of greater than 21 days.[248,322] However, we must consider that advances made in concussion management may also reflect longer recovery times, as well as limitations of selection bias in studies that draw from large concussion clinics that may include athletes with more complicated recoveries.[3,7] Finally, research suggests that if symptoms persist, worsen or do not show progressive improvement 2-4 weeks after injury, it is advisable to undergo a multimodal evaluation and consider a referral for rehabilitation.[3,323]

2.8 Risk Factors for Concussion

There are subsets of individuals who are more at risk for sustaining concussion and may experience a protracted recovery. These individuals may have pre-injury risk factors or post-injury clinical factors that increase the likelihood and susceptibility of sustaining a concussion and/or predispose them to longer recovery times. Pre-injury risk factors may include age, gender, sex, previous concussion history, psychiatric disorders, and learning disabilities/attention deficient disorders,[2,3,10,219,324-328] while post-injury clinical factors may include continuing to play with concussion, initial symptom burden, and posttraumatic migraine.[3,329] For the purposes of this dissertation, age, sex, and previous concussion history will be described in more detail below while psychiatric disorders will be described elsewhere (See **Psychosocial Factors that Influence Concussion**).

2.8.1 Age

Numerous studies have investigated the relationship between age and concussion with these studies demonstrating that the incidence of concussion varies by age.[330] Adolescents and young adults, particularly those in high school and college sports, tend to have a higher incidence of concussions compared to young children (<9 years) or older adults.[331,332] Research suggests that the age range 9-22 years old has the highest risk of sustaining a concussion which coincides with the period when team sports are most popular.[332] Furthermore, many epidemiology studies have shown that the incidence of SRC is greater among high school athletes in comparison to their collegiate counterparts across multiple sports,[333] with many of these studies focusing on football.[334-336] Guskiewicz et al.[336] observed a higher incidence of concussions in a prospective cohort of high school football players when compared to their college football counterparts. Another study, which compared college football data from the NCAA-ISS to high school data from the National Athletic Treatment, Injury, and Outcomes Network (NATION), identified high school football players as having the highest risk of SRCs over a single season.[335] An epidemiological study encompassing high school football players within the HS-RIO system and college football players from the NCAA-ISS revealed a greater proportion of SRCs among high school athletes, even though the overall injury rate was higher in college athletes.[334]

Some available evidence suggests there is still debate on this topic. Looking specifically at the 2005-2006 school year, Gessel et al.[70] compared 9 college sports to those studied in the HS-RIO. In general, the concussion rate was greater in collegiate sports compared to high school sports during both competition and practice settings, excluding baseball and softball. Notably, the authors also found that concussions constituted a larger proportion of total injuries sustained by high school athletes in all sports except for football and men's basketball, in contrast to college athletes. However, this study was before Youth Concussion laws were enacted, updates to the definition and increased awareness due to increase in concussion knowledge and media. More recent data from both Chandran et al.[5] and Pierpoint et al.[337] corroborates the findings corroborates the findings of Gessel et al.[70] as data from the NATION and NCAA-ISS indicate a greater incidence of SRC among collegiate athletes.[77]

In addition to comparisons among incidence of concussion, research has also focused its attention on comparing recovery duration among high school and collegiate athletes. Similarly, evidence suggests high school athletes typically take longer to recover.[168,184,319] One systematic review found high school athletes differed on symptom recovery compared to collegiate athletes (15 days vs 6 days), while neurocognitive recovery rates were similar (7 days vs 5 days).[319] In high school football, the mean (SD) number of reported symptoms was the highest at 5.60 (3.16), followed by college football at 5.56 (3.03), and youth football at 4.76 (2.58).[168] Kerr et al.[168] also found RTP time distributions differed across levels of competition. Among the groups, high school athletes had the highest percentage of concussions resulting in an RTP period of at least 30 days (19.5%), followed by youth athletes (16.3%) and college athletes (7.0%).

Other evidence appears to suggest a contrast to these findings. For example, Covassin et al.[219] studied 150 high school and 72 collegiate athletes who had suffered concussions and discovered no disparities in the total number of reported symptoms or the proportion of athletes who returned to baseline symptom scores by day 14 post-injury. Additionally, a retrospective analysis of clinical medical records for 184 high school and college athletes also showed no variations in symptom presence, symptom severity, or return to baseline symptom scores when utilizing reliable change index methods.[338] However, in contrast, Cantu et al.[339] examined a sample from a specialty clinic and observed that athletes aged 18 years and older, compared to those younger than 18 years, experienced a greater number of symptoms and longer symptom duration following concussions.

There are several explanations for why incidence and recovery of concussion differs among that of high school and collegiate athletes. Some authors have suggested that the higher likelihood of increased playing time, less effective protective gear, and lower skill levels has been proposed as factors that could contribute to a higher concussion rate among high school athletes.[70,336] Additionally, high school athletes may face an increased risk of concussion and prolonged recovery due to their developing and susceptible brains and thus more easily disrupted, requiring less force to trigger the neurobiological processes that follow an concussion.[168,335] Changes in brain development, characterized by a structural reorganization where white matter increases and gray matter reaches its peak, may result in increases in reported cognitive deficiencies.[168] This hypothesis has been disputed though as evidence suggests brain development still continues into the mid-20's which would encompass the age range of collegiate athletes.[335]

It has also been suggested that collegiate athletes compete at a more intense and competitive level (i.e., greater intensity of play), often being larger and stronger compared to their high school counterparts.[340] This has led to suggestions that such factors could potentially elevate the risk of concussions among college athletes. This disparity in incidence and recovery among high school and collegiate athletes might stem from unequal healthcare access at the high school level, potentially leading to less recognition and guidance when a concussion occurs compared to the collegiate level, where resources (e.g., healthcare professionals, neurologists, educators/tutors, and time-management consultants) are more readily available.[77,168] Finally, high school students experience lengthier class durations without breaks, which can extend the duration of symptom recovery.[168]

2.8.2 Sex

Being female is another recognized risk factor for concussion, a finding that has been substantiated by numerous studies in sports involving both sexes.[5,70,76,341-344] Utilizing epidemiological databases, Gessel et al.[70] revealed sex-based disparities, with girls experiencing higher concussion rates than boys in sports that are played by both sexes, both in high school and college settings. Additionally, Covassin et al.,[341] using the NCAA-ISS, found that females were more likely to sustain an SRC than males. More specifically, female basketball and soccer players had a 1.4 times greater SRC incidence, while female softball players had a two-fold greater incidence compared to their male counterparts.[341] In a comparison of high school sex-comparable sports, it was observed from the HS-RIO that the concussion rate was greater in girls' sports (3.35 per 10,000 athlete exposures) compared to boys' sports (1.51 per 10,000 athlete exposures).[4] The most recent data on collegiate athletes, as presented by Chandran et al.[5] showed higher SRC rates in women's soccer, basketball, and softball compared to men's sports. Additionally, a previous systematic review of prospective studies discovered that out of 10 studies, nine reported elevated concussion rates among females.[343] A meta-analysis and systematic review comprising 38 studies identified significantly higher concussion incidence rates specifically in women's soccer and basketball compared to males.[342] Furthermore, another systematic review revealed that 10 studies indicated a higher concussion risk among women.[324] Interestingly, four studies suggested men had a higher risk of concussion, but these were primarily focused on high-collision sports like football and may introduce a bias.[324] The observed heightened risk of concussion among female athletes is noteworthy, especially given the substantial underrepresentation of female athletes in consensus and position statements pertaining to concussion research.[345]

The disparities in concussion incidence between sexes can be attributed to various factors. One biological difference is that females often exhibit reduced head-neck strength, higher peak angular acceleration, and increased angular displacement when compared to males.[346] Furthermore, the mechanisms of injury may vary between male and female soccer players; females are more prone to head injuries resulting from contact with the playing surface or equipment while males incur their concussions due to player-to-player contact.[347] Additionally, gendered behavior might also explain these differences. For example, in a survey of college athletes, Kroshus et al.[210] found greater symptom reporting intentions among females compared to males, while another study found female athletes were more inclined to report their symptoms to coaches and parents.[198] Females may be more likely to engage in these behaviors because it is socially acceptable to express vulnerability, whereas the same perception may not apply to men who engage in the contemporary sport ethos.[210]

2.8.3 History of Concussion

A prior history of concussion increases the likelihood of experiencing another concussive injury in the future which has been confirmed in numerous studies of high quality evidence over the years.[173,324,348,349] Many early studies on this topic assessed the relationship between a history of concussions and an increased risk of sustaining a subsequent concussion primarily with football players. Guskiewicz et al.[173] assessed a prospective cohort of NCAA college football players across 25 colleges and universities and found that players who reported a history of 3 or more previous concussions were 3 times more likely to have another concussion than players with no concussion history. While another study found that high school and collegiate football players with a history of concussion within the last five years were at a 5.8 greater risk for sustaining a second concussion.[349] Recently, a synthesis study of 12,320 student athletes spanning middle school, high school, and collegiate athletes found that a prior history of concussion emerged as the strongest predictor of SRC risk. Those with a history of concussion had an odds ratio of 9.14, signifying a significant association with the likelihood of experiencing a subsequent SRC.[348] The cause for the increased risk of concussion for those with a concussion history may be related to the biological vulnerability due to the ongoing energy crisis that occurs after injury.[57]

There seems to be mixed evidence when it comes to a history of concussion and its association to a longer recovery time. A prospective, longitudinal investigation among collegiate student-athletes found a median of 14 days of total RTP duration for athletes with a self-reported history of three or more concussions compared to 12.7 days for athletes with two or less self-reported concussions.[350] In a matched case-control study of younger athletes (aged 9-18 years old), prior concussions were associated with post-concussion syndrome.[351] Additionally, in a racially diverse sample of adolescents prior concussions predicted protracted recovery.[327] While other research has noted a lack of association between concussions history and longer recovery times, suggesting continued research is needed.[352,353]

2.9 Psychosocial Factors that Influence Concussion

The existing consensus guidelines for managing concussions place significant emphasis on an athlete's physical readiness as the primary determinant of medical clearance for RTP following a concussion.[3,8] This determination hinges upon a clinician's assessment, the resolution of concussion symptoms, and the presence of clinically normal measures of balance and cognitive function. Moreover, these guidelines advocate for a gradual, symptom-guided progression of cognitive and physical demands to enable the athlete to rebuild confidence during their recovery with the intention of fostering psychological readiness to return.[3] Implicit in this approach is the assumption that both physical and psychosocial recovery progress concurrently and that achieving physical recovery alone is adequate to reduce the risk of recurrent concussion.[8] Furthermore, healthcare professionals have received limited guidance in evaluating or mitigating the influence of psychosocial factors when making medical clearance decisions following concussion.[354] This concern is gaining prominence as emerging evidence suggests that a multitude of psychosocial factors are linked to concussion recovery. While this dissertation focuses on one specific psychosocial factor, athletic identity, other research on psychosocial factors will also be explored below.

2.9.1 Altered Mood States

Altered mood states, such as depression and anxiety, have received the most attention as it relates to recovery from a concussion. Kontos and colleagues[9] conducted a prospective study examining depression and neurocognitive performance after concussion among male and female high school and collegiate athletes. The authors assessed 75 athletes diagnosed with concussion using the Beck Depression Inventory-II and ImPACT at baseline and at 2-, 7-, and 14-days post-injury. The findings of this study indicated that athletes exhibited higher levels of depression at each timepoint following injury. Notably, there were significant correlations between depression, neurocognitive performance, and concussion symptoms. Somatic depression was related to slower reaction time and lower visual memory scores, while total depression at 14 days was related to higher symptoms scores at 14 days. Additional research focusing on depression has yielded similar findings in young athletes. Morgan et al.[351] conducted a retrospective case-control study using the Vanderbilt Sports Concussion Clinic database. They compared 40 patients with prolonged concussive symptoms exceeding three months to age- and sex-matched controls. The results revealed that athletes with prolonged symptoms were more likely to have a history of premorbid mood disorders and psychiatric illness compared to their matched controls. Furthermore, a logistic regression analysis indicated a 17.9% increase in the odds (95% CI 2.9-113.0) of developing prolonged symptoms for athletes with a history of mood disorders.[351]

Data has also been collected to prospectively assess both anxiety and depression in NCAA athletes at baseline and one week following a concussion.[10] The results from the 71 enrolled athletes showed that baseline depression was the strongest predictor of post-concussion depression and also predicted post-concussion anxiety. Specifically, athletes with a concussion who were positive for depressive symptoms at baseline were 4.59 and 3.40 times more likely to experience depressive symptoms and state anxiety respectively following a concussion. This study also found that co-occurring depression and anxiety were common post-concussion, but the associations between baseline anxiety and post-concussion anxiety were not statistically significant.[10] Yet another study of collegiate athletes found that those with affective symptoms (e.g., feeling more emotional, sadness) and nervous-anxious symptoms exhibited delayed clinical recovery, both in time to symptom resolution and time to RTP.[355]

Numerous studies have also directed their attention specifically to anxiety and its implications for symptom exacerbation and prolonged recovery. One study involving 129 youth aged 10-18 years old following concussion found that 18 individuals (22%) reported clinical levels of pre-injury anxiety, and 17 (13%) reported clinical levels of post-injury anxiety.[356] Another study in a similar age group found that higher anxiety symptoms after concussion were associated with prolonged recovery, defined as recovery beyond 28 days.[357] Martin et al.[358] found that anxiety was significantly associated with delayed symptom recovery, return to school, and return to physical activity in a sample of children and adolescents who presented to tertiary concussion clinics. After adjusting for age and sex, patients with anxiety reported an additional 2.64 concussion symptoms and 7.45 higher vision symptom severity scores compared to those without anxiety.[358] Furthermore, collegiate athletes have also exhibited elevated levels of anxiety at the beginning of the stepwise concussion progression[359] and upon RTP.[359,360] A common recommendation emerging from these studies that focus on altered mood states is the need for evaluating these psychosocial factors post-injury. This evaluation serves the purpose of monitoring and improving the recovery process, especially for individuals who may be at a higher risk of developing prolonged symptoms.

2.9.2 Social Dynamics

In addition to altered mood states, there has been a growing interest in examining social dynamics, primarily assessed through pressure and social support, in the context of recovery and RTP after a concussion. Pressure has been predominantly explored in qualitative studies, where athletes have expressed experiencing both internal and external pressures to resume sport participation following a concussion before feeling ready to return. For instance, in separate qualitative studies, female athletes participating in contact sports expressed feeling pressure from teammates, coaches, and parents to expedite their return to sport to minimize the adverse impact on the team.[361,362] Other qualitative research has revealed that athletes sometimes place internal pressure on themselves to return to sport prematurely, driven by personal goals, the desire to not let their team down, and to avoid being sidelined.[362-364]

The influence of social support on RTP following concussion has also been investigated. Williams et al.[365] studied peer relationships among high school athletes after a concussion and found that this significantly improved between 3 days post-injury and return to sport, but this was not associated with time to return or a history of concussion. In a qualitative study, youth hockey players reported perceiving positive social support from coaches, teammates, and parents which they internalized as concern for their well-being after injury.[361] Nevertheless, other qualitative research has found disparities in perceived social support between what an athlete recovering from concussion wanted and what teammates felt was necessary.[362] Specifically, teammates of one athlete described offering tangible support, such as practical assistance, and informational support, like advice and guidance, to better facilitate the athlete's RTP while the athlete with a concussion described a need for emotional support from their teammates.[362]

2.9.3 Coping Strategies/Behaviors

When individuals face an injury, such as a concussion, they rely on various coping mechanisms to navigate their recovery and the time away from their sport. Kontos et al.[93] conducted a study to compare coping resources among high school and college athletes who had experienced a concussion, those with orthopedic injuries, and healthy controls. Approximately one week after injury, 68 athletes completed the Brief COPE Inventory. The results revealed differences in coping resources among these groups. Athletes with a concussion reported lower levels of active coping, planning, acceptance, reliance on religion, self-distraction, venting, and self-blame compared to the orthopedic injury group. The authors suggested that athletes with concussions might not engage in coping to the same extent as those with other injuries, possibly due to the passive nature of recovery, a lower perception of threat, a shorter recovery period, and fewer visible signs of injury.[93]

In another study, researchers explored the relationship between neurocognitive performance and coping resources in high school and collegiate athletes at 3 and 8 days post-SRC.[366] Similar to the previous study,[93] athletes completed the Brief COPE Inventory. The findings indicated that athletes who exhibited decreased scores in visual memory and increased total symptom scores tended to use avoidance coping strategies such as self-distraction, behavioral disengagement, and self-blame at 8 days post-injury. The authors noted that while avoidance coping is typically considered maladaptive, in this context, it may be beneficial for athletes due to the uncertainty surrounding their recovery and return to play, potentially preventing frustration and other negative emotional responses.[366]

2.9.4 Fear

Fear has been explored in various ways including fear of recurrent concussion, fear of movement, and fear related to returning to play in the context of concussion outcomes with diverse findings. In a prospective cohort study, the Tampa Scale of Kinesiophobia (TSK) was employed to assess fear of movement amongst adolescent athletes with a concussion and a control group.[367] This study also examined correlations between kinesiophobia, concussion symptoms and reaction time.[367] This investigation found that at the acute visit (within 14 days of injury), the concussion group reported higher kinesiophobia scores, with a greater proportion reporting high scores ($\geq$37) compared to the control group. At the RTP visit, there was no significant difference in fear of movement between groups, but 28% of the concussion group still reported elevated kinesiophobia. Furthermore, there was a significant and moderate correlation between kinesiophobia and reaction time ($r = 0.50$; $p = 0.01$) among adolescents with a concussion.[367]

Anderson and colleagues[15] investigated changes in fear of re-injury during the recovery process and compared changes in clinical outcomes between high school athletes with a concussion who report high and low levels of fear of re-injury.[15] A total of 41 athletes were enrolled in the study and the results demonstrated a significant difference in TSK scores between the initial visit and RTP visit, with a significant decrease in scores over time. Additionally, athletes with higher TSK scores exhibited significantly more concussion symptoms, particularly in the cognitive-migraine-fatigue and affective symptom factors at the initial visit. They were also more likely to exhibit vestibular/ocular motor symptoms beyond clinical cutoffs at RTP compared to athletes with lower TSK scores. However, there were no differences in neurocognitive outcomes or recovery time between the high and low fear groups.[15]

In another study, fear of returning to play and fear of re-injury were compared among Division I collegiate athletes who had sustained a concussion or orthopedic injury[368] The results showed that athletes with a concussion scored significantly lower for both fear of re-injury and fear of RTP compared to the orthopedic injury group, indicating that the orthopedic injury group exhibited greater fear after injury. The authors suggested that these findings could be attributed to the longer recovery time for orthopedic injuries and the perception that concussions may be less severe because their symptoms and the physical nature of the injury are less apparent.[368] However, some collegiate athletes have also reported experiencing a fear of reinjury following a concussion.[362]

2.9.5 Athletic Identity

The psychological factor of interest of this dissertation is athletic identity, which refers to the exclusivity and strength with which an individual identifies with the athletic role, and looks to others for confirmation of that role.[18] This concept is largely derived from identity research within social psychology, which has primarily concentrated on group affiliation and social roles, with two main theories, identity theory and social identity theory, showing significant similarities.[19] These theories suggest that identities are formed through the categorization of the self within social roles and through identification with social categories or groups. While identity theory emphasizes the role-based nature of identities,[369] social identity theory focuses on the processes of self-categorization and social comparison in forming social identities.[19] Both theories underscore the importance of social context in shaping individual identities. Brewer and colleagues proposed that athletic identity should be viewed within the framework of a multidimensional self-concept and indicated that it serves as a cognitive structure that directs and arranges the processing of self-related information.[20] Additionally, they highlighted its role as a social construct, suggesting that the identification of this role is derived from the feedback of important others (e.g., parents, coaches, teammates, spectators).[20]

To assess this psychological factor, Brewer and colleagues developed the Athletic Identity Measurement Scale (AIMS). In its first iteration, it was a 10-tem questionnaire and conceptualized as an unidimensional construct.[20] However, further research indicated that the AIMS was multidimensional and measured three factors in athletic identity including social identity (the extent to which the individuals identifies with the athletic role), negative affectivity (negative emotions in response to failure to fulfill this role), and exclusivity (solely identifying with the athletic role).[21] The AIMS became a 7-item questionnaire as three statements were removed. Most research that has used the AIMS to assess athletic identity reports just the total score with a recent systematic review and meta-analysis indicating limited subscale reporting in the included studies.[370]

Furthermore, most research has focused on the implications of a stronger athletic identity as this signifies a deep connection to and prioritization of sport in one's life.[20] When defining athletic identity, Brewer et al.[20] proposed that a stronger athletic identity can serve as either a "Hercules' muscle" or an "Achilles' heel," symbolizing the positive and negative implications of such an identity. A stronger athletic identity acting as a "Hercules' muscle" has been linked to several favorable outcomes including increased commitment to sports participation,[22,23] increased sport motivation,[24] improved in-season performance, especially when winning,[25] and positive overall well-being.[26] Conversely, a stronger athletic identity acting as an "Achilles' heel" can lead to adverse consequences within the sport domain.[20] Research suggests that athletes with a strong athletic identity may neglect other identities to uphold their athletic role.[27] The negative ramifications of a stronger athletic identity can become more pronounced when an athlete sustains an injury. Such an injury may disrupt an athlete's sense of self and present challenges in adapting to this identity threat.[16,27]

Early research exploring the link between athletic identity and injuries primarily focused on the relationship with depression. Most studies have found that athletes with stronger athletic identities tend to exhibit heightened depressive symptoms.[18,29] To investigate this association, Brewer[18] conducted a series of studies examining the relationship between athletic identity and depressed mood in injured athletes, and in football players, who were injured and uninjured, as a control group. These studies revealed that athletic identity was a significant predictor of depressed mood in a sample of injured athletes and in football players.[18] These findings were further supported by studies involving adolescent athletes[371] and Australian athletes,[29] where individuals with a stronger athletic identity were more prone to experiencing severe depressive symptoms following injury. A recent systematic review indicated that a strong athletic identity is a risk factor for more depressive symptoms after injury.[372] It is worth noting that not all studies have found a relationship between athletic identity and depressive mood. Some research, including a study involving recreational participants with a range of musculoskeletal injuries[373] and another study assessing athletes recovering from ACL reconstruction,[374] indicated athletes with a stronger athletic identity experienced greater improvements in their mood following their injuries.

Furthermore, research has focused on athletic identity in relations to behavioral and injury-related outcomes. Brewer and colleagues[21] conducted a study that examined relationships among psychological factors, including athletic identity with rehabilitation adherence and outcomes after anterior cruciate ligament (ACL) reconstruction. The results included a positive and significant association between AIMS scores and motivation, suggesting that athletes with stronger athletic identities were more motivated to adhere to their rehabilitation regimens. At the 6-month mark following ACL reconstructive surgery, there was a moderate, positive, and significant association between AIMS score and joint stability. Additionally, there was a small yet positive and significant association between AIMS score and rehabilitation outcomes, such as one leg hop distance and knee function. Notably, AIMS scores significantly predicted joint stability, indicating that athletes with stronger athletic identity were more likely to have similar knee joint stability between the affected and unaffected leg. In this case, a stronger athletic identity appeared to be associated with improved functional outcomes which could be beneficial for individuals recovering from ACL surgery.[21] Moreover, a follow-up study found a significant interaction between age and AIMS score in predicting home exercise adherence and cryotherapy use.[375] More specifically, it was noted that younger athletes with a stronger athletic identity were more inclined to complete at-home exercises and to use cryotherapy.[375] While these findings were largely consistent with results in a sample of athletes,[376] one study found that AIMS score did not predict adherence to home rehabilitation exercises after ACL surgery.[377]

Conversely, additional studies have reported that AIMS scores significantly predicted attempts to accelerate the rehabilitation process and rehabilitation behaviors. Specifically, athletes with a stronger athletic identity were significantly more likely to think and behave in a way that would expedite rehabilitation and ignore clinician recommendations[31,32] as well as overadhere to rehabilitation protocols.[31] Researchers speculate that individuals with stronger athletic identities might engage in overadherence to prescribed rehabilitative protocols as a means of maintaining an "ego syntonic state."[378] In essence, they act in a way that aligns with their self-concept as athletes and the associated role responsibilities, such as participating in competitions and training with teammates. As a result, these individuals may feel compelled to expedite the rehabilitation process.[41] It is important to note that this behavior may be perceived as beneficial, particularly considering the evidence support improved functional outcomes among stronger athletic identities.[21] These findings offer valuable insights into the complex interplay between athletic identity and psychological outcomes following sports-related injuries, with implications for understanding and potentially enhancing the recovery processes.

In the wake of injury, there is some indication that athletes may seek to attenuate their athletic identity as a protective response to the potential threat it poses to their sense of self. This thought draws from previous observations of athletes who diminished their identity after they terminated competitive sport involvement,[379] invested in a career outside of sport, [380] experienced team deselection,[381] a poor season,[25] and the notion that although athletic identity is generally regarded as a relatively stable trait,[20] the self is also a flexible entity influenced by developmental and situational factors.[27] In light of this, a study encompassing 108 individuals scheduled for ACL surgery were enrolled to examine the potential for self-protective adjustments in athletic identity following a severe injury.[27] Utilizing a repeated-measures ANCOVA, with age and gender as control variables, the investigation revealed a significant decline in athletic identity over the 24-month study period, particularly in the period spanning 6 to 12 months post-surgery. More specifically, participants who experienced a slower rehabilitation process during this interval had significantly greater decreases in athletic identity. This underscores the dynamic nature of the self, particularly in the context of the need to adapt or reduce one's identity in response to the threat posed by an injury to their positive self-image.[27]

Furthermore, efforts have been undertaken to explore athlete's attitudes and behavioral intentions with regards to playing through pain and injury as a function of their athletic identity. Evidence derived from a study involving 130 collegiate recreational basketball players revealed that athletic identity was a significant factor in shaping attitudes and behavioral tendencies related to injuries.[30] More specifically, individuals with a stronger athletic identity reported more favorable attitudes and behavioral tendencies toward continuing to play, despite pain and injury compared to those in the moderate and low athletic identity groups. Moreover, athletes who scored higher on the exclusivity and negative affect subscales of the AIMS were more likely to endorse toughness and exhibit a greater willingness to play through an injury. Interestingly, these findings suggested that self-identifying as an athlete (as indicated by high scores on the social identity subscale of AIMS) did not significantly influence or predict attitudes and behaviors related to injuries. Instead, it appeared that having an exclusive or negative affect played a more prominent role in shaping these attitudes and behaviors.[30]

Specific to concussion reporting intentions and behaviors, there was a small but significant interaction between perceived concussion reporting norms and AIMS scores. This interaction revealed that stronger athletic identity was associated with non-reporting behaviors, as observed in Division I male ice hockey players.[33] Similarly, in a sample of collegiate football players, athletic identity was associated with a lower likelihood to report symptoms during a game or within 24 hours of a game.[34] However, in a recent study conducted by Martin et al.,[382] the significance of athletic identity as a predictor for an athlete's willingness to report a concussion was not observed in a sample of high school athletes. The authors proposed that this non-significant result could be attributed to the inclusion of the assessment of obsessive passion, which did yield significance in this study. They further noted a strong correlation between these two variables as a possible explanation for this outcome.[382]

Qualitative research has been used abundantly in concussion research, shedding light on the personal experiences of those affected by this unique and often isolating injury. A concussion cannot be seen by the naked eye, it is invisible or hidden,[383] thus juxtaposing itself from other commonly researched injuries such as ACL tears. Caron and colleagues[35] provided the first qualitative account of former national hockey league players' perceptions of their experience with multiple concussions. These athletes described a loss of athletic identity, which hindered their recovery process as they continued to experience symptoms long after the event that resulted in frustration and depression about their situation. Additionally, these retired athletes experienced difficulty transitioning into and embracing another career.[35] These findings were echoed in another study involving former ice hockey players who had retired due to SRC.[36] An autoethnography from Dean[384] provided a personal account of his own experiences with SRC, particularly highlighting the change in athletic identity that occurred due to this injury. The author described this shift in athletic identity as a "(re)negotiation of identity" as he sought to persuade his doctor to allow him to return to play and to convince himself he was still a normal, healthy athlete. The hidden nature of SRC presented a unique challenge, as others might not perceive the individual as injured, causing a disconnect in how they constructed their injury, making it more difficult to align with reality.[384]

Similar to the results seen by Brewer et al.,[35] qualitative research has explored the reconfiguration of athletic identity following a concussion in athletes who return to their sport. These studies have described the change in identity that occurs both during the period of the injury and upon the athlete's reintegration into the team.[362,385] For instance, in a qualitative exploration of the experiences of a female university athlete enduring persistent concussion symptoms for 12 months, one theme emerged, focusing on the construction and negotiation of athletic identity. This theme encompassed the athlete's struggle to reconcile her past self with the person she was becoming in light of her injury.[385] Similarly, in another qualitative study, a female athlete shared her journey of transitioning from a star athlete to adopting the dual roles of student assistant and team manager during her two-season hiatus due to a series of concussions.[362] Upon returning to the team, this athlete described a drastic shift in her status, from an important player on the team to being a reserve player who, at times, did not travel with the team. This transition proved disorienting and strained her relationships with some teammates.[362] The authors of these studies emphasized the need for individually tailored support strategies to assist athletes in navigating the disruption to their identity that may accompany protracted concussion recovery. They recognized that while assuming alternative roles on the team can be beneficial for some athletes, it may not suit everyone, reinforcing the importance of personalized approaches.[362,385]

To date, only a single study has used athletic identity to predict recovery in concussion. This particular study compared personal (e.g., athletic identity) and situational factors (e.g., quality of social support) to concussion symptoms experienced by youth athletes.[16] Conducted by O'Rourke and colleagues, this study revealed a significant association between stronger athletic identity and more intense symptoms, as well as a slower recovery after concussion. The authors postulated that athletes with stronger athletic identities tended to interpret their concussions more catastrophically and had difficulty adjusting to their injury and recovery given the threat to their identity. This negative appraisal of their injury adversely affected these athlete's ability to use psychological skills to cope with their injury and heightened their vigilance regarding ongoing concussion symptoms. The potential emotional and behavioral responses stemming from this adverse cognitive appraisal in youth athletes with a stronger athletic identity may have exacerbated the expression of symptoms and contributed to delayed recovery. O'Rourke et al.[16] also suggested that a slower recovery occurred as athletes may have distanced themselves from sport as a coping mechanism following injury. However, it is also worth noting that this study was conducted with youth athletes from a hospital-based clinic which may have captured athletes with more severe concussion symptoms and may not be representative of collegiate athletic populations. Additionally, this study only used the AIMS total score and did not examine the subscales of the AIMS. No current studies have assessed athletic identity and its subscales to predict concussion outcomes in collegiate athletes.

2.10 The Integrated Model of Response to Sport Injury

This dissertation was designed to examine the role of a specific psychological factor, athletic identity, on concussion recovery outcomes in collegiate athletes within an existing theoretical and empirically supported framework.[41] One such framework that was considered was the integrated model of response to sport injury.[42] While not directly tested in this dissertation, this model was recognized as valuable in suggesting that athletic identity could be a psychological factor that may predict recovery outcomes post-concussion.[41] This model, derived from existing conceptual models rooted in various coping and stress theories, elucidates the dynamic process of psychological responses following a sports injury.[42,386] More specifically, this model suggests that personal and situational factors influence a psychological response that can dynamically change over time to impact recovery. Personal factors may include psychological, demographic, injury-related, and biological differences, while situational factors may include sport characteristics and social and environmental influences.[42]

These factors can influence an athlete's psychological response based on the athlete's cognitive appraisal of the injury, which takes two forms: primary (e.g., "Is this injury harmful to me?") and secondary (e.g., "Will I be able to deal with this injury, and if so, how?") appraisals. These cognitive appraisals determine the level of perceived stress and subsequently shape emotional (e.g., frustration, sadness, relief) and behavioral (e.g., treatment adherence, use of psychological skills) responses that influence recovery outcomes. Therefore, there is a dynamic process in which an athlete's injury appraisal plays a central role in determining their cognitive, emotional, and behavioral responses.[43] This should be viewed as a three-dimensional spiral, where a positive appraisal of the injury tends to lead to a positive recovery experience, while a negative cognitive appraisal places the athlete at risk of a negative recovery outcome, such as prolonged recovery after concussion.[387]

This is a valuable tool to help guide stakeholders (i.e., researchers, clinicians, athletes) understanding of why athletic identity may influence psychological responses following concussion and highlight the need to further explore this construct in a population of individuals with a concussion. By doing so, the results of this study may inform future research that would allow for predictive modeling to help understand the psychological responses to concussion that an athlete may have as they cognitively appraise their injury.

2.11 Summary

The current consensus guidelines for concussion management primarily focus on an athlete's physical readiness as the key factor for medical clearance to RTP and may fail to acknowledge that psychosocial factors play a role in the recovery process. One such psychological factor of interest is athletic identity. While a strong athletic identity is often seen as essential for success in sports, it is associated with negative consequences that can become amplified when an athlete experiences an injury.[20] An athlete may feel that their sense of self is shaken and have difficulty adjusting given the threat to their self-concept,[16,27] leading to increased depressive symptoms.[18,29] Previous studies have indicated that a stronger athletic identity can predict athlete attitudes towards playing through an injury,[30] overadherence to rehabilitation protocols,[31] and attempts to expedite the rehabilitation process.[32] Additionally, research has shown that athletes with a strong athletic identity, perceiving SRC as a threat to their athletic status, are less likely to report such injuries,[33] and are less likely report symptoms of a SRC during or after a game.[34] Specific to concussion recovery, much of the existing literature employs qualitative methodologies to explore athletic identity. Studies have indicated that former athletes often struggle when transitioning to alternative careers or identities following sport termination due to SRC.[35-37] To date, only one study has examined athletic identity to predict recovery outcomes in concussion, finding that a strong athletic identity is linked to more severe symptoms and slower recovery in youth athletes.[16] No current studies have investigated the predictive role of athletic identity and its subscales in concussion outcomes among collegiate athletes. This underscores a significant gap in our knowledge.

CHAPTER 3: METHODS

3.1 Research Design

This was a prospective, repeated measures design to examine athletic identity in collegiate athletes to predict outcomes following concussion and was completed with two specific aims. The purpose of specific aim 1 was to examine whether athletic identity was related to the total number of symptoms, and symptom severity scores in collegiate athletes with a concussion during the acute visit. The independent variables were the total score for AIMS and its subscales, including social identity, exclusivity, and negative affectivity. The dependent variables were the total number of symptoms and symptom severity score. The purpose of specific aim 2 was to examine whether athletic identity was related to days to symptom resolution and days to FMC in collegiate athletes with a concussion. The independent variables were the total score for AIMS and its subscales, including social identity, exclusivity, and negative affectivity. The dependent variables were days to symptom resolution and days to FMC. This study received approval by the Michigan State University (MSU) Institutional Review Board for Human Subjects Research prior to the start of data collection. All participants provided informed consent before participating in the study.

3.2 Participants

Participants diagnosed with a concussion were included in the study. Inclusion criteria encompassed individuals aged 18-30 years old, who received a concussion diagnosis within 5 days of the injury from a licensed healthcare provider following regulations in the state of Michigan (MD, DO, PA, NP). Exclusion criteria pertained to participants with a pre-existing neurological brain condition or those who experienced loss of consciousness equal to or exceeding 20 minutes from the concussive event, as they may have sustained a more serious injury, such as a moderate traumatic brain injury.

Participants were recruited from MSU and other local institutions through a recruitment network established by the primary advisor of this study. Medical staff (i.e., athletic trainers and team physicians) of the varsity and club teams at MSU and other local institutions were asked to contact the study team when they encountered an athlete who had received a concussion diagnosis.

3.3 Operational Definitions

Concussion: A concussion is defined as a direct or indirect blow to the head, face, neck, or body that results in an altered mental status and various clinical signs and symptoms.[3] Physicians evaluated all concussions using the following criteria: a) the observation of at least one on-field sign (e.g., lying motionless on playing surface, falling unprotected to the surface, disorientation/confusion, balance issues), b) the presence of symptoms (e.g., headache, neck pain, dizziness, nausea), and/or c) any impairment detected during sideline assessment (e.g., SCAT5/SCAT6).

Days to Symptom Resolution: Days to symptom resolution was determined by a healthcare provider (MD, DO, PA, NP), and refers to the number of days between the date of concussion to the date the participant no longer had symptoms.

Full Medical Clearance: FMC indicates that a qualified healthcare professional (MD, DO, PA, NP) has cleared the athlete to return for full unrestricted activity. Each healthcare provider used the following criteria for FMC: (1) full symptom resolution, 2) if participants had a baseline assessment, they must have returned to baseline measures, and 3) completed the Concussion in Sport return to play step-wise protocol.[3]

3.4 Procedures

Participants diagnosed with a concussion completed two testing sessions: (1) within 5 days of their concussion (the acute visit), and (2) once the athlete had been cleared to return for full unrestricted activity (+3 days; FMC visit). The acute visit, occurring within 5 days, was chosen to enable the study team ample time to gather data on injuries sustained during weekend sporting events. It is also worth noting that, while the term “acute” in concussion literature typically refers to a 72-hour timeframe,[388] it is important to acknowledge that the acute pathophysiology of a concussion can extend for as long as 10 days.[57]

During the acute visit, participants were asked to provide informed consent, as well as information regarding demographics (e.g., age, sex), injury characteristics (e.g., mechanism of injury), and medical history questions (e.g., concussion history, diagnosis of depression/anxiety). Additionally, participants completed two surveys, the AIMS[22] and the symptom checklist of the Sport Concussion Assessment Tool[158,214] to accomplish Aim 1. At the FMC visit, participants completed recovery information and again, the surveys stated above to accomplish Aim 2. More specifically, participants reported the number of days from the concussion to the days of when their symptoms fully resolved and when they received FMC. This was used to determine the days to symptom resolution and days to FMC (see **Operational Definitions**).

3.5 Measures

3.5.1 Sport-Concussion Assessment Tool-5 and -6 (SCAT5/ SCAT6)

The SCAT5 is a widely used clinical tool for postconcussion assessment. It measures orientation, immediate and delayed memory, concentration, balance, and concussion symptoms.[7] For the purposes of this study, only the symptom evaluation will be used. This includes a self-report measure of 22 concussion symptoms on a 7-point Likert scale of 0 (none) to 6 (severe).

Athletes obtain a total symptom score out of 22 along with a symptom severity score out of 132. The symptoms scale has a high test-retest reliability (r = 0.85).[389] Following the 2022 CISG Consensus Conference held in Amsterdam, the SCAT5 was updated to the SCAT6.[158] There were no changes made to the symptom checklist from the 5th edition to the 6th edition.

3.5.2 Athletic Identity Measurement Scale (AIMS):

The AIMS is a 7-item questionnaire that assesses the extent to which the athlete role is a stable and central part of one's self-identity (see **Appendix A**).[22] Individuals are asked to rate each statement (e.g., "I consider myself an athlete") on a scale from strongly disagree (1) to strongly agree (7). It is comprised of a three-factor model: (1) social identity – the extent to which individuals view themselves as occupying the athlete role (3 items); (2) exclusivity – the extent to which an individual's self-worth is determined only by performance in the corresponding athlete role (2 items); and (3) negative affectivity – the extent to which an individual experiences negative affect in response to undesirable outcomes in athletic domains (2 items). Total and subscale scores for the AIMS can be calculated and interpreted, in which higher scores indicate a stronger athletic identity. In studies of injured athletes, internal consistencies of the AIMS have been acceptable (α = .72 - .78),[31,32] as well as in a population with concussed individuals (α = .71).[16] Furthermore, the AIMS had acceptable internal consistency for exclusivity (α = .84), but unacceptable low internal consistencies for social identity (α = .37) and negative affectivity (α = .41) in a sample of injured athletes.[31] In the current study, the internal consistency was acceptable for exclusivity (α = .78), but not for AIMS total score (α = .68), social identity (α = .47), nor negative affectivity (α = .42).

3.6 Sample Size Estimation

An a priori power analysis was conducted using G*Power version 3.1[390] for sample size estimation, based on data from a previous study assessing athletic identity in a concussed population in youth athletes (*N* = 51).[16] The effect size in this study was 0.10, considered to be small to medium using Cohen's f^2 criteria.[391] Using an acceptable power of (1-β) of 0.80 and a-priori alpha level of 0.05, we estimated that 81 participants were required to identify significant differences based on the analysis plan.

3.7 Statistical Analysis

Descriptive statistics, including mean and standard deviation for continuous variables and frequencies and percentages for categorical variables, were calculated to summarize demographic information, medical history, injury characteristics, total concussion symptom score and concussion symptom severity score from the SCAT5/SCAT6 at the acute visit, AIMS total score and subscales, and recovery data (i.e., days to symptom resolution and days to FMC), for participants with concussion. Reliability (Cronbach's *alpha*) was calculated for the AIMS total score and each of its subscales. Spearman's rank-order correlations were run (based on non-normality of data) to assess the relationships between athletic identity at the acute visit (AIMS total score, social identity, exclusivity, and negative affectivity), concussion symptom scores at the acute visit (total number of symptoms and concussion severity score), and recovery outcomes (days to symptom resolution and days to FMC). The interpretations for these correlation coefficients (positive or negative) are as follows: <0.20 are very weak, 0.20-0.39 are weak, 0.40-0.59 moderate, 0.60-0.79 are strong, and >0.80 are very strong.[392]

To assess Aim 1, a total of eight separate stepwise hierarchical regression analyses were conducted. More specifically, a series of four separate in a stepwise fashion hierarchical regression analyses were completed with athletic identity (AIMS total score, social identity, exclusivity, and negative affectivity) as the independent variable and total number of symptoms at the acute visit as the outcome variable. Covariates were determined by separate univariate linear regressions with known variables that affect concussion recovery,[16,329] and those with a significance level of $p < 0.05$ were entered into the regression models at Step 1. The AIMS total score was entered at Step 2 for the first hierarchical regression analysis. Then it was removed, and the social identity subscale was entered at Step 2 for the second hierarchical regression analysis. These steps were repeated for the exclusivity and negative affectivity subscales. Additionally, another series of four separate stepwise hierarchical regression analyses were completed with athletic identity (AIMS total score, social identity, exclusivity, and negative affectivity) as the independent variable and symptom severity score at the acute visit as the outcome variable. Similar steps were followed as described above in which covariates were added at Step 1, while the AIMS total score and its subscale was added separately at Step 2 for each regression. Participants did not report any symptoms at the second testing session based on FMC being achieved, therefore, we only analyzed symptoms from the acute visit.

Similar to Aim 1, a total of eight separate stepwise hierarchical regression analyses were applied. More specifically, a series of four separate stepwise hierarchical regression analyses were completed with athletic identity (AIMS total score, social identity, exclusivity, and negative affectivity) as the independent variable and days to symptom resolution as the outcome variable, with covariates added at Step 1 and the AIMS total score and its subscale was added separately at Step 2 for each regression. Finally, another series of four separate stepwise hierarchical regression analyses were completed with athletic identity (AIMS total score, social identity, exclusivity, and negative affectivity) as the independent variable and days to FMC as the outcome variable, with covariates added at Step 1 and the AIMS total score and its subscale was added separately at Step 2 for each regression. We also tested for the assumptions of hierarchical multiple regressions which included independence of residuals, linearity, homoscedasticity of residuals, no multicollinearity, no significant outliers, high leverage points or highly influential points, and normality.[393] For all regression models, the unstandardized regression coefficient (*B*), the standardized coefficient (β), the coefficient of determination (R^2), adjusted R^2 (ΔR^2), and p-values were calculated. Statistical significance was set a-priori at $p < 0.05$. All statistical analyses were performed using SPSS software (version 28.0; SPSS, Inc, Chicago, IL).

CHAPTER 4: RESULTS

4.1 Demographic Information

A total of 99 collegiate athletes following concussion were enrolled in the study. Of those, seven were excluded from the study as they were lost to follow-up and did not complete the FMC visit. Thus, a total of 92 collegiate athletes (mean age: 20.8$\pm$1.6; 39 female, 53 male) completed the study. **Table 1** provides a breakdown of demographic variables as the sample was predominantly White (n=61,66.3%), non-Hispanic (n=85, 92.4%), a 4th year Senior (n=26, 28.3%), football player (n=32, 34.8%), and played at the Division I level (n=73, 79.3%). Additionally, **Table 2** and **Table 3** present additional information on medical history and injury information.

Table 1. Descriptive Statistics for Demographic Variables of Collegiate Athletes with a Concussion

Variable	Mean (SD) / N (%)
Age (years)	20.7 (1.6)
Sex	
Female	39 (42.4%)
Male	53 (57.6%)
Race	
Asian	1 (1.1%)
Black	24 (26.1%)
Other	6 (6.5%)
White	61 (66.3%)
Ethnicity[a]	
Hispanic	5 (5.4%)
Non-Hispanic	85 (92.4%)
Other	1 (1.1%)
Year in School	
College Freshman	18 (19.6%)
College Sophomore	15 (16.3%)
College Junior	21 (22.8%)
College Senior (4th Year)	26 (28.3%)
College Senior (5th Year)	7 (7.6%)
Graduate Student	5 (5.4%)

Table 1 (cont'd)

Sport	
Baseball	3 (3.3%)
Basketball	3 (3.3%)
Cheerleading	6 (6.5%)
Dance	1 (1.1%)
Field Hockey	2 (2.2%)
Football	32 (34.8%)
Gymnastics	2 (2.2%)
Ice Hockey	2 (2.2%)
Lacrosse	2 (2.2%)
Rowing	3 (3.3%)
Rugby	8 (8.7%)
Soccer	12 (13.0%)
Softball	3 (3.3%)
Tennis	1 (1.1%)
Track & Field	1 (1.1%)
Volleyball	6 (6.5%)
Wrestling	5 (5.4%)
Level of Play	
Division I	73 (79.3%)
Division II	4 (4.3%)
Division III	5 (5.4%)
Club	10 (10.9%)

[a]One participant was missing data

Continuous data are presented as mean (SD) and categorical data are presented as n (%).

Table 2. Descriptive Statistics for Medical History of Collegiate Athletes with Concussion

Variable	Mean (SD) / N (%)
Previous History of Concussion	
No	47 (51.1%)
Yes	45 (48.9%)
Number of Previous Concussions	1.67 (1.3)
Headache/Migraine Disorder	
No	87 (94.6%)
Yes	5 (5.4%)
Learning Disorder/Dyslexia	
No	88 (95.7%)
Yes	4 (4.3%)
ADD/ADHD	
No	73 (79.3%)
Yes	19 (20.7%)
Anxiety/Depression	
No	76 (82.6%)
Yes	16 (17.4%)
Motion Sickness[a]	
No	86 (93.5%)
Yes	5 (5.4%)

[a]One participant was missing data

Continuous data are presented as mean (SD) and categorical data are presented as n (%).

Table 3. Injury Information of Collegiate Athletes with Concussion

Variable	Mean (SD) / N (%)
Time to Presentation	3.14 (1.7)
Mechanism of Injury	
Sport-Related	79 (85.9%)
Hit by an Object	5 (5.4%)
Motor Vehicle Accident	8 (8.7%)
Loss of Consciousness	
No	81 (88.0%)
Yes	11 (12.0%)
Remember the Injury	
No	18 (19.6%)
Yes	74 (80.4%)
Continued to Play[a]	
No	53 (57.6%)
Yes	38 (41.3%)

[a]One participant was missing data

Continuous data are presented as mean (SD) and categorical data are presented as n (%).

4.2 Descriptive Analyses

Means, standard deviations, Spearman's rank-order correlations, and Cronbach alpha values (for AIMS total score and its subscales) are shown in **Table 4**. There was a statistically significant weak and positive relationship between the negative affectivity subscale and total number of symptoms ($p < 0.01$), symptom severity score ($p < 0.01$), and days to FMC ($p < 0.01$). No other significant correlations were found amongst athletic identity and outcome measures.

Table 4. Descriptive Statistics for the Independent and Dependent Variables

Variable	1	2	3	4	5	6	7	8
1. AIMS Total Score	-							
2. Social Identity	.57**	-						
3. Exclusivity	.84**	.35**	-					
4. Negative Affect	.68**	.12	.36**	-				
5. Total Number of Symptoms	.08	-.08	-.02	.30**	-			
6. Symptom Severity Score	.12	-.03	.02	.30**	.94**	-		
7. Days to Symptom Resolution	.03	-.02	-.07	.16	.51**	.49**	-	
8. Days to FMC	.02	-.06	-.08	.22*	.47**	.42**	.82**	-
Mean (SD)	37.59 (6.2)	18.57 (2.6)	8.79 (3.2)	10.23 (2.5)	10.10 (6.4)	23.39 (20.5)	12.04 (12.7)	16.76 (15.0)
Cronbach's Alpha	0.68	0.47	0.78	0.42				

Abbreviations: AIMS, Athletic Identity Measurement Scale; FMC, Full Medical Clearance.
**Statistically significant at $p < 0.01$. * Statistically significant at $p < 0.05$

4.3 Relationships among Athletic Identity and Total Number of Symptoms

A number of separate univariate linear regressions were conducted to determine which covariates should be added at Step 1 of the regression models which included age, sex, race, ethnicity, year in school, current sport, level of play, previous concussion history, history of headache or migraine disorder, history of learning disorder, history of ADHD/ADD, history of depression/anxiety, history of motion sickness, time to presentation, and continue to play. These results revealed sex, history of learning disorder or dyslexia, and history of depression/anxiety were significantly associated with total number of symptoms reported at the acute visit ($p < 0.05$) and were included at Step 1 of each of the stepwise hierarchical multiple regression models. Furthermore, all assumptions of hierarchical multiple regressions were met. More specifically, there was linearity as assessed by partial regression plots and a plot of studentized residuals against the predicted values. There was independence of residuals, as assessed by a Durbin-Watson statistics which ranged from 1.8-1.9 for each regression. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values. There was no evidence of multicollinearity, as assessed by tolerance values greater than 0.1. There were also no studentized deleted residuals greater than ±3 standard deviations, no leverage values greater than 0.2, and values for Cook's distance above 1. Finally, the assumption of normality was met, as assessed by a Q-Q Plot. The results of these four stepwise hierarchical regression analyses are summarized in **Table 5**.

The first stepwise hierarchical regression model run was to determine if the addition of the AIMS total score improved the prediction of total number of concussion symptoms reported at the acute visit over and above known variables that were entered at Step 1. The full model of sex, history of learning disorder or dyslexia, history of depression/anxiety, and the AIMS total score (Model 2) was statistically significant, $R^2 = 0.119$, $F_{(4, 87)} = 2.930$, $p = 0.025$; adjusted $R^2 = 0.078$, but the AIMS total score did not significantly add to the model, $R^2 = 0.001$, $F_{(1, 87)} = 0.102$, $p = 0.750$.

The next stepwise hierarchical multiple regression run was to determine if the addition of the social identity subscale improved the prediction of total number of concussion symptoms reported at the acute visit over and above known variables that were entered at Step 1. The full model of sex, history of learning disorder or dyslexia, history of depression/anxiety, and the social identity subscale (Model 2) was statistically significant, $R^2 = 0.124$, $F_{(4, 87)} = 3.082$, $p = 0.020$; adjusted $R^2 = 0.084$, but the social identity subscale did not significantly add to the model, $R^2 = 0.006$, $F_{(1, 87)} = 0.639$, $p = 0.426$.

Similarly, a stepwise hierarchical multiple regression was run to determine if the addition of the exclusivity subscale improved the prediction of total number of concussion symptoms reported at the acute visit over and above known variables that were entered at Step 1. The full model of sex, history of learning disorder or dyslexia, history of depression/anxiety, and the exclusivity subscale (Model 2) was statistically significant, $R^2 = 0.121$, $F_{(4, 87)} = 2.984$, $p = 0.023$; adjusted $R^2 = 0.080$, but the exclusivity subscale did not significantly add to the model, $R^2 = 0.003$, $F_{(1, 87)} = 0.295$, $p = 0.588$.

Finally, a stepwise hierarchical multiple regression was run to determine if the addition of the negative affectivity subscale improved the prediction of total number of concussion symptoms reported at the acute visit over and above known variables that were entered at Step 1. The full model of sex, history of learning disorder or dyslexia, history of depression/anxiety, and the negative affectivity subscale (Model 2) was statistically significant, $R^2 = 0.173$, $F_{(4, 87)} = 4.552$, $p = 0.002$; adjusted $R^2 = 0.135$. The addition of the negative affectivity subscale led to a statistically significant increase in R^2 of 0.055, $F_{(1, 87)} = 5.827$, $p = 0.018$.

Table 5. Stepwise Hierarchical Multiple Regression Predicting Total Number of Symptoms at the Acute Visit From Sex, History of Learning Disorder or Dyslexia, History of Depression/Anxiety, and AIMS Total Scores and Subscales

	Model 1			Model 2		
Variable	***B***	**β**	***p***	***B***	**β**	***p***
(Constant)	13.74		**<0.01**	12.52		**0.01**
Sex	-2.80	-0.22	**0.03**	-2.85	-0.22	**0.03**
Learning Disorder or Dyslexia	6.91	0.22	**0.03**	6.62	0.21	**0.047**
Depression/Anxiety	2.73	0.16	0.11	2.66	0.16	0.13
AIMS Total Score				0.04	0.03	0.75
(Constant)				17.27		**<0.01**
Sex				-2.74	-0.21	**0.04**
Learning Disorder or Dyslexia				7.27	0.23	**0.03**
Depression/Anxiety				2.83	0.17	0.10
Social Identity				-0.20	-0.08	0.43
(Constant)				14.49		**<0.01**
Sex				-2.65	-0.21	0.05
Learning Disorder or Dyslexia				7.35	0.24	**0.03**
Depression/Anxiety				2.80	0.17	0.11
Exclusivity				-0.12	-0.06	0.59
(Constant)				7.25		**0.04**
Sex				-2.70	-0.21	**0.04**
Learning Disorder or Dyslexia				5.16	0.17	0.11
Depression/Anxiety				2.35	0.14	0.16
Negative Affectivity				0.63	0.24	**0.02**

Significant *p*-values are bolded. Abbreviations: AIMS, Athletic Identity Measurement Scale; *B*, Unstandardized regression coefficient; β, Standardized coefficient.

4.4 Relationships among Athletic Identity and Symptom Severity Score

The same separate univariate linear regressions were conducted, and these revealed that sex, history of learning disorder or dyslexia, and history of depression/anxiety were significantly associated with symptom severity score reported at the acute visit ($p < 0.05$) and were included at Step 1 of each of the stepwise hierarchical multiple regression models. Additionally, all assumptions of hierarchical multiple regressions were met. The results of these four stepwise hierarchical regression analyses are summarized in **Table 6**.

A stepwise hierarchical multiple regression was run to determine if the addition of the AIMS total score improved the prediction of symptom severity score reported at the acute visit over and above known variables that were entered at Step 1. The full model of sex, history of learning disorder or dyslexia, history of depression/anxiety, and the AIMS total score (Model 2) was statistically significant, $R^2 = 0.132$, $F_{(4, 87)} = 3.300$, $p = 0.014$; adjusted $R^2 = 0.092$, but the AIMS total score did not significantly add to the model, $R^2 = 0.003$, $F_{(1, 87)} = 0.302$, $p = 0.584$.

The next stepwise hierarchical multiple regression run was to determine if the addition of the social identity subscale improved the prediction of symptom severity score reported at the acute visit over and above known variables that were entered at Step 1. The full model of sex, history of learning disorder or dyslexia, history of depression/anxiety, and the social identity subscale (Model 2) was statistically significant, $R^2 = 0.129$, $F_{(4, 87)} = 3.220$, $p = 0.016$; adjusted $R^2 = 0.089$, but the social identity subscale did not significantly add to the model, $R^2 = 0.000$, $F_{(1, 87)} = 0.024$, $p = 0.878$.

Similarly, a stepwise hierarchical multiple regression was run to determine if the addition of the exclusivity subscale improved the prediction of symptom severity score reported at the acute visit over and above known variables that were entered at Step 1. The full model of sex, history of learning disorder or dyslexia, history of depression/anxiety, and the exclusivity subscale (Model 2) was statistically significant, $R^2 = 0.130$, $F_{(4, 87)} = 3.248$, $p = 0.016$; adjusted $R^2 = 0.090$, but the exclusivity subscale did not significantly add to the model, $R^2 = 0.001$, $F_{(1, 87)} = 0.123$, $p = 0.726$.

Finally, a stepwise hierarchical multiple regression was run to determine if the addition of the negative affectivity subscale improved the prediction of symptom severity score reported at the acute visit over and above known variables that were entered at Step 1. The full model of sex, history of learning disorder or dyslexia, history of depression/anxiety, and the negative affectivity subscale (Model 2) was statistically significant, $R^2 = 0.167$, $F_{(4, 87)} = 4.361$, $p = 0.003$;

adjusted $R^2 = 0.129$. The addition of the negative affectivity subscale led to a statistically significant increase in R^2 of 0.038, $F_{(1, 87)} = 4.002$, $p = 0.049$.

Table 6. Stepwise Hierarchical Multiple Regression Predicting Symptom Severity Score at the Acute Visit From Sex, History of Learning Disorder or Dyslexia, History of Depression/Anxiety, and AIMS Total Scores and Subscales

Variable	Model 1			Model 2		
	B	**β**	***p***	***B***	**β**	***p***
(Constant)	33.33		**<0.01**	26.67		0.06
Sex	-8.11	-0.20	0.05	-8.39	-0.20	**0.048**
Learning Disorder or Dyslexia	26.61	0.25	**0.02**	23.01	0.23	**0.03**
Depression/Anxiety	10.20	0.19	0.06	9.88	0.18	0.07
AIMS Total Score				0.19	0.06	0.58
(Constant)				35.50		**0.03**
Sex				-8.07	-0.20	0.06
Learning Disorder or Dyslexia				24.83	0.25	**0.02**
Depression/Anxiety				10.27	0.19	0.06
Social Identity				-0.21	-0.02	0.88
(Constant)				34.88		**<0.01**
Sex				-7.79	-0.19	0.07
Learning Disorder or Dyslexia				25.51	0.26	**0.02**
Depression/Anxiety				10.35	0.19	0.06
Exclusivity				-0.24	-0.04	0.73
(Constant)				16.05		0.15
Sex				-7.83	-0.19	0.06
Learning Disorder or Dyslexia				19.94	0.20	0.05
Depression/Anxiety				9.20	0.17	0.09
Negative Affectivity				1.68	0.20	**0.049**

Significant *p*-values are bolded. Abbreviations: AIMS, Athletic Identity Measurement Scale; *B*, Unstandardized regression coefficient; β, Standardized coefficient.

4.5 Relationships among Athletic Identity and Days to Symptom Resolution

A number of separate univariate linear regressions were conducted to determine which covariates should be added at Step 1 of the regression models which included age, sex, race, ethnicity, year in school, current sport, level of play, previous concussion history, history of headache or migraine disorder, history of learning disorder, history of ADHD/ADD, history of depression/anxiety, history of motion sickness, time to presentation, and continue to play. These results revealed that sex, race, history of headache/migraine disorder, and total number of concussion symptoms reported at the acute visit were significantly associated with days to symptom resolution ($p < 0.05$), which were included at Step 1 of each of the stepwise hierarchical multiple regression models. Additionally, all assumptions of hierarchical multiple regressions were met. The results of these four stepwise hierarchical regression analyses are summarized in **Table 7**.

The first stepwise hierarchical multiple regression run was to determine if the addition of the AIMS total score improved the prediction of days to symptom resolution over and above known variables that were entered at Step 1. The full model of sex, race, history of headache/migraine disorder, and total number of concussion symptoms reported at the acute visit, and the AIMS total score (Model 2) was statistically significant, $R^2 = 0.191$, $F_{(5, 86)} = 4.057$, $p = 0.002$; adjusted $R^2 = 0.144$, but the AIMS total score did not significantly add to the model, $R^2 = 0.001$, $F_{(1, 86)} = 0.055$, $p = 0.815$.

Additionally, a stepwise hierarchical multiple regression was run to determine if the addition of the social identity subscale improved the prediction of days to symptom resolution over and above known variables that were entered at Step 1. The full model of sex, race, history of headache/migraine disorder, and total number of concussion symptoms reported at the acute visit, and the social identity subscale (Model 2) was statistically significant, $R^2 = 0.192$, $F_{(5, 86)} = 4.095$, $p = 0.002$; adjusted $R^2 = 0.145$, but the social identity subscale did not significantly add to the model, $R^2 = 0.002$, $F_{(1, 86)} = 0.208$, $p = 0.649$.

Similarly, a stepwise hierarchical multiple regression was run to determine if the addition of the exclusivity subscale improved the prediction of days to symptom resolution over and above known variables that were entered at Step 1. The full model of sex, race, history of headache/migraine disorder, and total number of concussion symptoms reported at the acute visit, and the exclusivity subscale (Model 2) was statistically significant, $R^2 = 0.190$, $F_{(5, 86)} = 4.044$, $p = 0.002$; adjusted $R^2 = 0.143$, but the exclusivity subscale did not significantly add to the model, $R^2 = 0.000$, $F_{(1, 86)} = 0.002$, $p = 0.968$.

Finally, a stepwise hierarchical multiple regression was run to determine if the addition of the negative affectivity subscale improved the prediction of days to symptom resolution over and above known variables that were entered Step 1. The full model of sex, race, history of headache/migraine disorder, and total number of concussion symptoms reported at the acute visit, and the negative affectivity subscale (Model 2) was statistically significant, $R^2 = 0.190$, $F_{(5, 86)} = 4.049$, $p = 0.002$; adjusted $R^2 = 0.143$, but the negative affectivity subscale did not significantly add to the model, $R^2 = 0.000$, $F_{(1, 86)} = 0.022$, $p = 0.881$.

Table 7. Stepwise Hierarchical Multiple Regression Predicting Days to Symptom Resolution From Sex, Race, Headache or Migraine Disorder, Total Number of Symptoms at the Acute Visit and AIMS Total Scores and Subscales

	Model 1			Model 2		
Variable	***B***	**β**	***p***	***B***	**β**	***p***
(Constant)	4.02		0.46	5.60		0.52
Sex	-3.24	-0.13	0.21	-3.17	-0.12	0.23
Race	5.66	0.30	**<0.01**	5.73	0.30	**<0.01**
Headache/Migraine	10.56	0.19	0.06	10.43	0.19	0.06
Number of Symptoms	0.45	0.22	**0.03**	0.45	0.23	**0.03**
AIMS Total Score				-0.05	-0.02	0.82
(Constant)				7.86		0.43
Sex				-3.19	-0.13	0.22
Race				5.74	0.30	**<0.01**
Headache/Migraine				10.76	0.19	0.05
Number of Symptoms				0.44	0.22	**0.03**
Social Identity				-0.22	-0.05	0.65
(Constant)				3.92		0.52
Sex				-3.26	-0.13	0.22
Race				5.66	0.30	**<0.01**
Headache/Migraine				10.60	0.19	0.06
Number of Symptoms				0.45	0.22	**0.03**
Exclusivity				0.02	0.004	0.97
(Constant)				4.69		0.50
Sex				-3.24	-0.13	0.22
Race				5.73	0.30	**<0.01**
Headache/Migraine				10.44	0.19	0.06
Number of Symptoms				0.45	0.23	**0.03**
Negative Affectivity				-0.08	-0.02	0.88

Significant *p*-values are bolded. Abbreviations: AIMS, Athletic Identity Measurement Scale; *B*, Unstandardized regression coefficient; β, Standardized coefficient.

4.6 Relationships among Athletic Identity and Days to FMC

The same separate univariate linear regressions were conducted, and these revealed that sex, race, history of headache/migraine disorder, and total number of concussion symptoms reported at the acute visit were significantly associated with days to FMC ($p < 0.05$) and were included at Step 1 of each of the hierarchical multiple regression models. Additionally, all assumptions of hierarchical multiple regressions were met. The results of these four stepwise hierarchical regression analyses are summarized in **Table 8**.

A stepwise hierarchical multiple regression was run to determine if the addition of the AIMS total score improved the prediction of days to FMC and above known variables that were entered Step 1. The full model of sex, race, history of headache/migraine disorder, and total number of concussion symptoms reported at the acute visit, and the AIMS total score (Model 2) was statistically significant, $R^2 = 0.140$, $F_{(5, 86)} = 2.811$, $p = 0.021$; adjusted $R^2 = 0.090$, but the AIMS total score did not significantly add to the model, $R^2 = 0.001$, $F_{(1, 86)} = 0.068$, $p = 0.794$.

The next stepwise hierarchical multiple regression run was to determine if the addition of the social identity subscale improved the prediction of days to FMC and above known variables that were entered at Step 1. The full model of sex, race, history of headache/migraine disorder, and total number of concussion symptoms reported at the acute visit, and the social identity subscale (Model 2) was statistically significant, $R^2 = 0.141$, $F_{(5, 86)} = 2.818$, p = 0.021; adjusted $R^2 = 0.091$, but the social identity subscale did not significantly add to the model, $R^2 = 0.001$, $F_{(1, 86)} = 0.102$, $p = 0.750$.

Similarly, a stepwise hierarchical multiple regression was run to determine if the addition of the exclusivity subscale improved the prediction of days to FMC and above known variables that were entered at Step 1. The full model of sex, race, history of headache/migraine disorder, and total number of concussion symptoms reported at the acute visit, and the exclusivity subscale (Model 2) was statistically significant, $R^2 = 0.141$, $F_{(5, 86)} = 2.830$, $p = 0.021$; adjusted $R^2 = 0.091$, but the exclusivity subscale did not significantly add to the model, R^2 of 0.002, $F_{(1, 86)} = 0.153$, $p = 0.696$.

Finally, a stepwise hierarchical multiple regression was run to determine if the addition of the negative affectivity subscale improved the prediction of days to FMC and above known variables that were entered at Step 1. The full model of sex, race, history of headache/migraine disorder, and total number of concussion symptoms reported at the acute visit, and the negative affectivity subscale (Model 2) was statistically significant, R^2 = 0.143, $F_{(5, 86)}$ = 2.861, p = 0.019; adjusted R^2 = 0.093, but the negative affectivity subscale did not significantly add to the model, R^2 of 0.003, $F_{(1, 86)}$ = 0.284, p = 0.596.

Table 8. Stepwise Hierarchical Multiple Regression Predicting Days to Full Medical Clearance From Sex, Race, Headache or Migraine Disorder, Total Number of Symptoms at the Acute Visit and AIMS Total Scores and Subscales

	Model 1			Model 2		
Variable	***B***	**β**	***p***	***B***	**β**	***p***
(Constant)	8.11		0.22	5.97		0.57
Sex	-3.37	-0.11	0.29	-3.46	-0.12	0.28
Race	6.53	0.29	**<0.01**	6.44	0.30	**<0.01**
Headache/Migraine	7.69	0.12	0.24	7.87	0.12	0.24
Number of Symptoms	0.42	0.18	0.08	0.41	0.18	0.09
AIMS Total Score				0.07	0.03	0.79
(Constant)				11.38		0.35
Sex				-3.33	-0.11	0.30
Race				6.60	0.30	**<0.01**
Headache/Migraine				7.87	0.12	0.24
Number of Symptoms				0.42	0.18	0.09
Social Identity				-0.18	-0.03	0.75
(Constant)				6.83		0.35
Sex				-3.61	-0.12	0.27
Race				6.50	0.29	**<0.01**
Headache/Migraine				8.09	0.12	0.23
Number of Symptoms				0.42	0.18	0.08
Exclusivity				0.19	0.04	0.70
(Constant)				5.24		0.54
Sex				-3.34	-0.11	0.29
Race				6.24	0.28	**<0.01**
Headache/Migraine				8.24	0.13	0.22
Number of Symptoms				0.38	0.16	0.14
Negative Affectivity				0.35	0.06	0.60

Significant *p*-values are bolded. Abbreviations: AIMS, Athletic Identity Measurement Scale; *B*, Unstandardized regression coefficient; β, Standardized coefficient.

CHAPTER 5: DISCUSSION

5.1 Overview

The present study examined athletic identity in collegiate athletes to predict outcomes following concussion, including concussion symptom scores, days to symptom resolution, and days to FMC. Results from this study revealed that the negative affectivity subscale was positively, significantly correlated with total number of symptoms, symptom severity score, and days to FMC. Additionally, after controlling for known predictors of concussion symptom scores (i.e., sex, history of learning disorder or dyslexia, and history of depression/anxiety), we found that collegiate athletes with stronger negative affectivity reported more total number of symptoms and higher symptom severity at the acute visit, indicating partial support of our hypotheses. However, other aspects of athletic identity including the AIMS total score, social identity and exclusivity subscales were unrelated to concussion symptom scores. Finally, after controlling for known predictors of recovery (i.e., sex, race, history of headache/migraine disorder, and total number of concussion symptoms reported at the acute visit), we found that athletic identity (the AIMS total score and its subscales) were unrelated to days to symptom resolution or days to FMC in collegiate athletes. Finally, this study also found that the confounding variables in this study were consistent with existing literature that sex,[5,70,76,341-344] race,[327,394,395] a history of learning disorder/dyslexia,[396,397] and increased symptoms[180,329] impact concussion recovery outcomes.

5.2 Athletic Identity Measurement Scale (AIMS)

This study contributes to the growing knowledge of psychosocial factors that impact concussion recovery by being the first study to characterize athletic identity and its subscales in collegiate athletes following concussion. The mean AIMS total score (37.59 ± 6.2) reported in this study was similar to previous research in a population of youth athletes following concussion (38.25±6.2),[16] as well as other research in a healthy sample of Division I ice hockey players (39.79+4.7),[33] and collegiate athletes (38.21±6.5).[22] Notably, the AIMS total score in this study was often much higher than previous studies of those with ACL injuries which ranged from a mean score of 28.45 to 32.14,[27,29,374,377] though one study with ACL injuries reported much higher scores (45.17±1.8).[398] The higher mean scores reported in this study compared to ACL injuries is likely due to the severity of injury. Those with ACL injuries typically have a much longer recovery period than those with concussion, and may attempt to de-identify from their athletic role to preserve their self-esteem, compared to an athlete following concussion who may expect a shorter recovery period.[27,399] Furthermore, 45.7% (n=42/92) of the current sample scored above the median value of 38 on the AIMS total score,[400] and would be considered athletes with a stronger athletic identity. This study also adds to the athletic identity literature which has highlighted a lack of reporting for the AIMS subscale values.[370] The mean scores on subscales of athletic identity in collegiate athletes following concussion are similar to mean scores of subscales reported in a sample of injured collegiate athletes.[31] However, research has called for a need for updated normative data for these clinical settings.[399]

Additionally, in the current study, the internal consistency of the AIMS total score was 0.68. This internal consistency is just under what is considered acceptable, but is similar to consistencies reported in other studies of injured athletes (α = .72 - .78),[31,32] as well as in a population with concussion (α = .71).[16] The exclusivity subscale had acceptable internal consistency (α=.78), but both the social identity subscale (α=.47) and the negative affectivity subscale (α=.42) were unacceptably low. The acceptable consistency of exclusivity, but not of social identity and negative affectivity were also similar to another study of injured athletes.[31]

Although these subscales had inadequate consistency in this study, the lack of reporting on subscale correlations,[370] warranted exploration. Previous research has indicated that the omission of subscale reporting may stem from two of the subscales (exclusivity and negative affectivity) consisting of only two items each. Typically, subscales require a minimum of three items to be successfully identified in latent variable models.[401] This challenges the applicability of these two-item subscales in various settings.[402] Furthermore, we must consider that this measure was not developed for this specific population and further work needs to be done to retest this measure and perhaps develop an appropriate athletic identity scale specific to the concussion population.

5.3 Relationships among AIMS Total Score and Concussion Outcomes

The only other study that has explored the impact of athletic identity following concussion, focused on a sample of youth athletes,[16] while this study expands to a population of collegiate athletes. In contrast to previous evidence,[16] we did not find a significant association between the AIMS total score and concussion outcomes including concussion symptom scores, days to symptom resolution, and days to FMC. Discrepancies with data from the O'Rourke et al.[16] study of youth athletes and this study may stem from the nature of cases seen in our university setting compared to an outpatient concussion clinic, where the concussion case may be more complex. This is further supported by the difference in symptom severity scores reported during the acute phase in O'Rourke et al.[16] (30.63±23.5) compared to the current study (23.39±20.5). Future research may consider how athletic identity is associated with specific symptom clusters/factors (e.g., migraine-fatigue, cognitive-ocular, affective if using the SCAT). Distinguishing any specific associations of symptom factors with athletic identity may better characterize how this psychosocial factor impacts specific symptoms that may be helpful in determining more appropriate treatment plans.

It was theorized that a stronger athletic identity would predict poor concussion outcomes (e.g., worse concussion symptom scores and a longer recovery) based on the notion that having a stronger athletic identity would be a risk factor for greater adjustment difficulties after injury as being injured threatens their self-concept and pulls them away from something meaningful in their lives.[27] Existing studies support this concept, suggesting that athletic identity can have a negative influence on the rehabilitation process,[31,32] and other outcomes such as depression[18,20] and playing through pain.[30] However, the lack of association between the AIMS total score and concussion outcomes seen in this study may be attributed to the relatively short recovery time for concussions. Collegiate athletes in this sample reported an average of 12 days to reach symptom resolution and about 17 days to reach FMC. Research indicates that for longer recovery periods, athletes may distance themselves from sport, and their athletic identity, as a coping mechanism.[27] This was found in a study of 108 individuals following ACL surgery, where participants reported a significant decline in athletic identity over the 24-month study period, particularly in the period spanning 6 to 12 months post-surgery. Specifically, those with a slower rehabilitation process during this 6-12 month interval exhibited significantly greater decreases in athletic identity.[27]

In the current study, it is possible that this shorter recovery timeframe is not long enough for athletic identity to make any meaningful contributions to the experiences of collegiate athletes with concussion. Additionally, these results may emphasize that a concussion is unique from other injuries.[383] Future research should consider investigating the influence of athletic identity and its subscales on concussion outcomes in a population of athletes experiencing persisting symptoms after concussion. Finally, the lack of association between the AIMS total score and concussion outcomes seen in this study could be due to different measurement time points (1-14 days in O'Rourke et al.[16] vs. <5 days in the current study). Collegiate athletes in this study may have already been involved in the return to play stepwise protocol and doing sport specific activities. This effect of earlier treatment in the collegiate setting may have helped athletes still feel engaged in sport and thus removing some of that threat to their identity or self-concept.

5.4 Relationships among AIMS Subscale Scores and Concussion Outcomes

This study also contributed to the literature by examining which of the AIMS subscales (i.e., social identity, exclusivity, negative affectivity) predicted outcomes following concussion, including concussion symptom scores, days to symptom resolution, and days to FMC. The results revealed that two of the subscales were not predictive of concussion outcomes, when controlling for variables that are known to impact recovery. Specifically, neither the social identity subscale, which assesses an individual's perception of themselves as an athlete,[22] nor the exclusivity subscale, which assesses the extent to which self-worth is tied solely to athletic performance,[22] predicted any outcomes following concussion. It may be that simply identifying as an athlete (stronger social identity) does not affect concussion outcomes, but the lack of association between exclusivity and concussion outcomes is a bit more surprising.

Hughes and Coakley[28] emphasized that individuals who identify themselves strongly and exclusively as athletes are more likely to adhere to the sociocultural "sport ethic" value system, prioritizing making sacrifices for their sport, embracing risks, and continuing to play despite pain and injuries. The lack of significant findings here may be due to the study specific methodology (e.g., sample size, psychometric properties of the social identity subscale) or it may be that these aspects of athletic identity hold less relevance for collegiate athletes following a concussion. In other words, while this population may strongly identify as athletes (stronger social identity), this does not appear to influence how they report concussion symptoms or their recovery. Additionally, collegiate athletes in this study did not strongly identify with the exclusivity subscale, as evidence by the lower mean score of 8.79$\pm$3.2 (out of a possible high score of 14), compared to the other two subscales of AIMS. It is possible that these athletes perceive themselves as having other important roles, such as "student," which may positively contribute to their ability to cope with their injury. Future research could explore capturing information such about other identity roles using a mixed-methods approach to enhance our understanding of athletic identity in this population.

Although we did not find any significant associations with the AIMS total score and two of its subscales, we did find a weak, but positive correlation between the negative affectivity subscale and concussion symptom scores as well as days to FMC. Additionally, the negative affectivity subscale accounted for a low amount of variance for total number of symptoms (5.5%) and symptom severity score (3.8%), when controlling for sex, history of learning disorder or dyslexia, and history of depression/anxiety. Furthermore, Cohen's local f^2 for the negative affectivity subscale predicting total number of symptoms was 0.14 indicating a medium effect size and Cohen's local f^2 for the negative affectivity subscale predicting symptom severity score was 0.15 also indicating a medium effect.[403] This sheds light on how athletes experience negative emotional states such as depression when unable to participate in their sport.[22] Athletes are particularly susceptible to emotional distress after injury[18] and may experience a loss of a sense of self after injury.[16,27] Research indicates that athletes at elite and recreational levels, compared to non-athletes who identified more strongly with negative affectivity derived more self-worth from sport participation and believed they would experience more-intense negative emotions as a result of undesirable sporting outcomes such as injury.[23] These findings align with the idea that athletes may have experienced negative affect as a result of their concussion and removal from play, potentially exacerbating their symptoms. However, it is important to acknowledge the psychometric limitations of the AIMS which may temper the interpretation of these results. Additionally, the marginal clinical significance ($p = 0.049$) of the stepwise hierarchical multiple regression results raises questions about whether the inclusion of the negative affectivity subscale meaningfully improved the prediction of symptom severity scores.

The results builds upon prior research published by O'Rourke et al.[16] by providing a more nuanced understanding of athletic identity in terms of which AIMS subscales predict concussion outcomes in a sample of collegiate athletes. Furthermore, these results indicate the way in which athletic identity is associated with detrimental outcomes. Our hypotheses stemmed from the aforementioned study,[16] which indicated that stronger athletic identity would be associated with worse concussion symptom scores and longer recovery. Given that this was the first study to examine the AIMS subscales with concussion outcomes, it was possible that a stronger athletic identity may have been associated with less total number of symptoms and shorter recovery due to an athlete's inclination to return to sport as quickly as possible and the prevailing belief in sport culture that encourages playing through pain and injury.[30-32,399]

Furthermore, the results of this study are guided by the integrated model of response to sport injury, which would indicate that athletes with a stronger athletic identity (in this study characterized by a stronger negative affectivity) potentially appraised their injury as more catastrophic and had difficulty adjusting given the threat to their self-concept. Consequently, these negative appraisals led to negative emotional responses (i.e., depression) and behavioral responses (e.g., not using psychological coping skills), which may have ultimately led to poorer sport outcomes (i.e., increased symptom expression).[16,399] Future research should design studies that apply the integrated model of response to sport injury to examine the relationships among athletic identity and emotional and behavioral responses following concussion to provide additional support to how the results of this study were guided by this model.

From a clinical standpoint, the findings of this study offer valuable insights for healthcare providers (e.g., athletic trainers, clinicians) when making decisions regarding treatment and rehabilitation, including helping athletes develop other important identity roles, engage in psychological skills training, keeping an athlete embedded in their sport during the recovery process, or making referrals to mental health professionals. More specifically, healthcare providers should be cognizant of those who strongly identify with the athletic role, particularly those with negative affect. Because of the concerns regarding the psychometric properties of the AIMS in this population, it may be best for healthcare providers to use this convenient tool for quickly assessment in conjunction with open-ended questions about an athlete's athletic identity. This information can be used to intervene when there are concerns about negative psychosocial consequences when the athlete is removed from sport following concussion. Athletic trainers can use psychological skills training such as self-talk and reframing to help an athlete who is stronger in negative affectivity to reframe the negative feelings associated with undesirable outcomes of sport, such as being injured and away from an important aspect of their life.

5.5 Limitations

This study is not without limitations. Firstly, the absence of a baseline assessment of athletic identity prevents understanding how a concussion may have altered an athlete's athletic identity. Future research could benefit from including baseline measures to track changes in athletic identity throughout the recovery process. Additionally, reliance on self-reported symptoms, as well as demographic, medical history, and other injury characteristics may have introduced potential inaccuracies. Furthermore, our study was limited to collegiate athletes presenting to a university laboratory setting; therefore, results may not be generalizable to other age groups, levels of sport participation, and athletes presenting to other clinical settings. Additionally, we did not correct for multiple comparisons when running our analyses which likely increased our Type I error probability and warrants caution with our results. A decision was made to not correct for multiple comparisons for this dissertation as it was not an intervention or treatment study so the potential for false positives is less detrimental or costly given that the results of this study will not change any decisions made from a clinical perspective.[404]

Lastly, the psychometric properties of the AIMS, particularly the unacceptably low internal consistencies of the AIMS total score, social identity and negative affectivity should warrant caution in our results. As mentioned previously, we must consider that this measure was not developed for this specific population and work needs to be done to develop a better measure of athletic identity in a concussion population. More specifically, when looking at the questions of the negative affectivity subscale, it does seem that the two items of the negative affectivity subscale are not related to each other and therefore, not measuring the same underlying dimension of negative affectivity. The two items that make up the negative affectivity subscale include, "I feel bad about myself when I do poorly in sport" and "I would be very depressed if I were injured and could not compete in sport." The first question may reference a poor performance while the second question specifically references being injured.

To explore this matter further and considering the significant findings of the negative affectivity subscale in this study, we ran a supplementary analysis with just one of the two items.

We choose the second item ("I would be very depressed if I were injured and could not compete in sport") as it better represented negative affect in the concussion population. Based on this analysis, we found that after controlling for known predictors of concussion symptom scores (i.e., sex, history of learning disorder or dyslexia, and history of depression/anxiety), collegiate athletes with stronger negative affectivity reported more total number of symptoms at the acute visit (see **Appendix B**). However, the negative affectivity subscale no longer significantly added to the model when predicting symptom severity score (see **Appendix C**).

5.6 Conclusions

This is the first study to examine athletic identity and its subscales in collegiate athletes to predict outcomes following concussion, including concussion symptom scores, days to symptom resolution, and days to FMC. Among collegiate athletes following concussion, the negative affectivity subscale was associated with worse outcomes on total number of symptoms, symptom severity score, and days to FMC. Additionally, the negative affectivity subscale predicted the total number of concussion symptoms and symptom severity score reported at the acute visit over and above known variables that impact concussion symptom scores. These findings further expand our knowledge and understanding about a specific psychosocial factor (i.e., athletic identity) and its relationship to concussion outcomes. The information gleaned from this study gives clinicians a starting point for addressing collegiate athletes who are stronger in negative affectivity following a concussion, but further research on the psychometric properties of the AIMS in a concussion population is warranted.

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APPENDIX A: ATHLETIC IDENTITY MEASUREMENT SCALE

7-Item Version of the Athletic Identity Measurement Scale (AIMS)

Please circle the number that best reflects the extent to which you agree or disagree with each statement regarding your sport participation.

1. I consider myself an athlete.								
Strongly disagree	1	2	3	4	5	6	7	Strongly agree
2. I have many goals related to sport.								
Strongly disagree	1	2	3	4	5	6	7	Strongly agree
3. Most of my friends are athletes.								
Strongly disagree	1	2	3	4	5	6	7	Strongly agree
4. Sport is the most important part of my life.								
Strongly disagree	1	2	3	4	5	6	7	Strongly agree
5. I spend more time thinking about sport than anything else.								
Strongly disagree	1	2	3	4	5	6	7	Strongly agree
6. I feel bad about myself when I do poorly in sport.								
Strongly disagree	1	2	3	4	5	6	7	Strongly agree
7. I would be very depressed if I were injured and could not compete in sport.								
Strongly disagree	1	2	3	4	5	6	7	Strongly agree

<u>AIMS</u>
Social Identity: 1, 2, 3
Exclusivity: 4, 5
Negative Affectivity: 6, 7

***Not included in actual survey.

APPENDIX B: SUPPLEMENTAL ANALYSES PREDICTING TOTAL NUMBER OF SYMPTOMS AT THE ACUTE VISIT AND QUESTION 7 FROM THE NEGATIVE AFFECTIVITY SUBSCALE

An additional stepwise hierarchical multiple regression was run to determine if the addition of question 7 of the negative affectivity subscale improved the prediction of total number of symptoms reported at the acute visit over and above known variables that were entered at Step 1. The full model of sex, history of learning disorder or dyslexia, history of depression/anxiety, and question 7 of the negative affectivity subscale (Model 2) was statistically significant, $R^2 = 0.177$, $F_{(4, 87)} = 4.668$, $p = 0.002$, adjusted $R^2 = 0.139$. The addition of question 7 of the negative affectivity subscale led to a statistically significant increase in R^2 of 0.059, $F_{(1, 87)} = 6.238$, $p = 0.014$.

Table 9. Stepwise Hierarchical Multiple Regression Predicting Total Number of Symptoms at the Acute Visit From Sex, History of Learning Disorder or Dyslexia, History of Depression/Anxiety, and Question 7 from the Negative Affectivity Subscale

Variable	Model 1			Model 2		
	B	**β**	***p***	***B***	**β**	***p***
(Constant)	13.74		**<0.01**	8.62		**0.005**
Sex	-2.80	-0.22	**0.03**	-2.56	-0.20	**0.047**
Learning Disorder or Dyslexia	6.91	0.22	**0.03**	4.64	0.15	0.15
Depression/Anxiety	2.73	0.16	0.11	2.21	0.13	0.19
Q7 – Negative Affectivity Subscale				1.03	0.26	**0.01**

Significant *p*-values are bolded. Abbreviations: AIMS, Athletic Identity Measurement Scale; *B*, Unstandardized regression coefficient; β, Standardized coefficient.

APPENDIX C: SUPPLEMENTAL ANALYSES PREDICTING SYMPTOM SEVERITY SCORE AT THE ACUTE VISIT AND QUESTION 7 FROM THE NEGATIVE AFFECTIVITY SUBSCALE

An additional stepwise hierarchical multiple regression was run to determine if the addition of question 7 of the negative affectivity subscale improved the prediction of symptom severity score reported at the acute visit over and above known variables that were entered at Step 1. The full model of sex, history of learning disorder or dyslexia, history of depression/anxiety, and question 7 of the negative affectivity subscale (Model 2) was statistically significant, $R^2 = 0.158$, $F_{(4, 87)} = 4.082$, $p = 0.004$, adjusted $R^2 = 0.119$, but question 7 of the AIMS subscale Negative Affectivity did not significantly add to the model $R^2 = 0.029$, $F_{(1, 87)} = 3.029$, $p = 0.085$.

Table 10. Stepwise Hierarchical Multiple Regression Predicting Symptom Severity Score at the Acute Visit From Sex, History of Learning Disorder or Dyslexia, History of Depression/Anxiety, and Question 7 from the Negative Affectivity Subscale

	Model 1			**Model 2**		
Variable	***B***	**β**	***p***	***B***	**β**	***p***
(Constant)	33.33		**<0.001**	21.79		**0.03**
Sex	-8.11	-0.20	0.05	-7.56	-0.18	0.07
Learning Disorder or Dyslexia	24.61	0.25	**0.02**	19.49	0.20	0.06
Depression/Anxiety	10.20	0.19	0.06	9.03	0.17	0.10
Q7 – Negative Affectivity Subscale				2.33	0.18	0.09

Significant *p*-values are bolded. Abbreviations: AIMS, Athletic Identity Measurement Scale; *B*, Unstandardized regression coefficient; β, Standardized coefficient.