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RETURN TO PLAY AND CLASS FOR CONCUSSED COLLEGE ATHLETES PREDICTED FROM POST-CONCUSSION SYMPTOM DOMAINS

Jazmin Nicole Mogavero
Saint John's University, Jamaica New York

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RETURN TO PLAY AND CLASS FOR CONCUSSED COLLEGE ATHLETES PREDICTED FROM POST-CONCUSSION SYMPTOM DOMAINS

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of the requirements for the degree of

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JAZMIN N. MOGAVERO

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Jazmin N. Mogavero

William F. Chaplin

ABSTRACT

RETURN TO PLAY AND CLASS FOR CONCUSSED COLLEGE ATHLETES PREDICTED FROM POST-CONCUSSION SYMPTOM DOMAINS

Jazmin N. Mogavero

Each year approximately 1.6 to 3.8 million people suffer a sports-related traumatic brain injury (Langlois, Rutland-Brown, & Wald, 2006). Concussions, a common form of mild traumatic brain injury, account for 75% of total brain injuries in the United States (Faul, Xu, Wald, & Coronado, 2010). In sports, concussions account for 1 of every 10 injuries (Marar, McIlvain, Fields, & Comstock, 2012). Overall, concussion symptoms typically remit within one to four weeks from injury (McCrea, 2007); however, conflict exists surrounding the duration of time that would be safe for a concussed student-athlete to return to functioning, both to sport and to class. According to the most recent evidence on concussion recovery and return to play statistics in a collegiate student-athlete population, an athlete, on average, will return to functioning within 16.1 days (McCrea et al, 2019). The primary role in evaluating collegiate sports-related concussions is to determine when and how a student-athlete should return to physical and cognitive activity.

Concussions are known to result in a wide array of neurologic, somatic, cognitive, and behavioral deficits. The diagnosis of a concussion is determined by the athlete’s presentation of symptoms; however, many of these symptoms are both subjective and ubiquitous. When athletes are concussed, they undergo a series of tests including a self-

reported inventory of symptoms. Previous research has identified four distinct domains of symptoms endorsed by athletes on the Post-Concussion Symptom Scale (PCSS) consisting of cognitive, physical, affective, and sleep symptoms (Merritt & Arnett, 2014).

The aim of this study is to critically examine post-concussive symptoms within a collegiate athlete sample and identify existing relationships between symptom clusters and recovery times. Identifying such relationships could be the first step in understanding symptom-based markers of concussion duration, which would inform the challenging return to play and return to class decisions.

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Introduction

There has recently been a substantial increase in the news and media coverage of sports-related traumatic brain injuries (TBIs). This is partly due to an upsurge in the scientific literature surrounding sports-related concussions and an emerging concern for determining clinical recovery. An estimated 1.6 to 3.8 million people suffer from sports-related TBI's each year (Langlois, Rutland-Brown, & Wald, 2006). However, this figure could significantly underestimate the incidence of sports-related concussions, as many individuals who have sustained a mild TBI do not seek medical care. Concussions have been known to result in a wide array of neurologic, somatic and cognitive deficits which impact return to school, return to playing sports, return to work, and other aspects of daily living (Alexander, 1995). The relatively high incidence of sports-related concussions is thus widely acknowledged as a significant health concern in the United States (CDC, 2019).

Definition of Concussion

As TBI and concussion are not synonymous, it is essential to differentiate the terms from one another within sports-related literature on head injuries. A TBI is defined as "an alteration in brain function, or other evidence of brain pathology, caused by an external force" and is categorized by severity (mild, moderate, and severe) (Menon et al., 2010). Based on the most recent systematic review of definitional literature and informed discussions at the 2016 Berlin Consensus Conference on Concussion in Sport, the operationalized definition of concussion is "a traumatic brain injury induced by biomechanical forces" (McCrory et al., 2017). A concussion is a common type of mild TBI with clinical features that result after a forceful blow is transmitted directly or indirectly to the head and is distinct from moderate and severe forms of TBI in that it typically does not result in an extended period of loss of consciousness (LOC). LOC may still occur at the time of the concussion, but it is usually short in duration (usually lasting a few seconds) if present; in fact, LOC occurred in only approximately 5% of concussed high school athletes in a study that utilized an online surveillance program (Meehan, d'Hemecourt P, & Comstock, 2010). Generally, immediate and transient neurological dysfunction defines a concussion and resolves spontaneously; however, several instances of concussion may present with the development of clinical signs and symptoms over time (i.e., minutes or hours). Clinical and cognitive symptoms will usually pursue a sequential course but may be prolonged for some cases (McCrory et al. 2017).

The development of symptoms is understood to be due to neurometabolic changes in the brain rather than parenchymal damage. As described in the classic study of the pathophysiology of concussion by Giza and Hovda (2001), there exists a "neurometabolic cascade" consisting of a series of biological changes in the brain (i.e., ionic fluxes, energy crisis, axonal injury, neurotransmission dysfunction, inflammation, and cell death) (Giza & Hovda, 2001; Giza & Hovda, 2014). These acute neuropathological impairments that may result from a concussion manifest as a functional disturbance rather than a structural injury, as standard neuroimaging reveal predominantly normal scans. The use of Diffusion Tensor Imaging (DTI) in the neuroimaging of concussion has become more popular in the last decade as it is a relatively nascent process and reveals brain white matter tracts through sophisticated structural images; however, the research is markedly controversial. A systematic review (including only eight studies) on DTI in sports-related concussion postulated DTI as more sensitive than other neuroimaging techniques in diagnostic potential (Gardner et al., 2012). However, as data and interpretations are still limited, the prognostic ability of DTI is still inconclusive (Khong et al., 2016). Computed tomography (CT) is more commonly used to detect any injury to brain tissue or brain structures, like contusions, fractures, or intracranial hemorrhages (Pulsipher et al., 2011). A difference in recovery and outcome exists when CT reveals intracranial abnormalities post-concussion, distinguishes a complicated concussion (CT abnormalities are present) from an uncomplicated concussion (no abnormalities on CT) (Williams, Levin, & Eisenberg, 1990).

Concussion Symptoms and Recovery

In pursuit of an appropriate and swift clinical recovery, a diagnosis of concussion is the necessary starting point. In fact, an accurate and well-timed diagnosis has been found to reinforce quicker recovery, decrease the possibility of consequent problems, and prevent additional head injuries (Patricios et al., 2018). However, due to the challenging nature of a concussion's heterogeneous and elusive presentation, it is sometimes difficult to make an accurate diagnosis. Signs and indicators of concussions will have common characteristics with other musculoskeletal, psychological and neurological conditions. For example, depression, post-traumatic stress disorder, migraine headache, fibromyalgia, chronic subdural hematoma, brain tumor, vertebral artery dissection, and other conditions present similarly to post-concussion syndrome. Further, there is a lack of a unified, gold standard definition, which poses difficulties for the diagnosing clinician (McCrory et al., 2017). Therefore, concussion remains a clinical diagnosis rather than a medical diagnosis (Patricios et al., 2018).

In the first 24 hours following a concussion, athletes may experience immediate adverse effects on their cognitions and vestibular balance (Dougan, Horswill, & Geffen, 2014). Within the first week of undergoing a concussion, athletes can experience an array of physical, cognitive, emotional and sleep deficiencies (Lovell, Collins & Bradley, 2004). An athlete can experience none or all of these varying symptoms. According to Iverson et al. (2017), the severity of an athlete's immediate and subsequent symptoms is the most reliable predictor of concussion recovery duration. Further, the accumulation of subacute issues (e.g., headaches or depression) may be an indicator of unremitting symptoms lasting longer than 4 weeks. Evidence based on group-level studies has found that an athlete's symptoms will improve within 2 weeks, and recovery in returning to play is usually within 10 days (Bleiberg et al., 2004; Macciocchi et al., 1996). Nevertheless, as these data are based on group-level findings, individual differences between athletes are obfuscated (Iverson et al., 2017).

Pre-injury and post-injury factors

Literature is mixed regarding the impact of both pre-injury risk factors (gender, concussion history, prior cognitive issues, prior psychiatric disorders) and post-injury factors (LOC, amnesia) on concussion presentation and recovery. According to a systematic review conducted in 2017, children, females, and people with pre-injurious cognitive issues, like attention deficit hyperactivity disorder (ADHD) or learning disabilities (LD), are most vulnerable for persistent symptoms (Iverson et al., 2017). However, according to a study conducted on athletes aged 12 to 23 years in 2019, amnesia, concussion history, ADHD, LD, and LOC did not play a significant role in recovery duration (Kontos et al., 2019). In a purely collegiate student sample, ADHD was found to be a risk factor of greater symptom severity in the first two weeks post-concussion (Houck, Asken, Bauer, & Clugston, 2019). On a study of collegiate and high school student-athletes, student-athletes who experienced amnesia had much slower symptom recovery time across measures of post-concussion symptoms, cognition, and balance, in comparison to those who did not experience amnesia (Teel et al., 2017). This same study also found LOC or previous concussion history had less bearing on symptom recovery. However, McCrea et al. (2013) found that LOC was the most significant predictor of prolonged recovery time in a population of college and high school athletes (McCrea et al., 2013). Literature is also variable regarding impact of concussion history on symptom recovery time (Iverson, 2007; Corwin et al., 2014).

Gender

A study on sports-related concussion in a mixed sex sample aged 9 to 18 found that females had higher overall total symptom scores on the PCSS when compared to males; otherwise, there were no other sex differences on balance or neurocognitive functioning (Sufrinko et al., 2017). A systematic review on sex differences and clinical outcomes of sports-related concussions confirms this finding and shows that females tend to report overall more symptoms than males, but the findings were mixed for differences in endorsement of specific symptom domains (Merritt, Padgett & Jak, 2019). This review also found that the prevalence of concussion was reported more often by females than males (Merritt, Padgett & Jak, 2019).

Concussion Evaluation

Evaluation of collegiate athlete concussion begins on the field, immediately after a possible head injury. The Sports Concussion Assessment Tool (SCAT5) is a brief and universal standardized assessment that is administered immediately after a possible concussion. This tool guides a clinician in the evaluation of red flags (e.g., LOC, vomiting), observable signs (e.g., blank or vacant look, motor incoordination), orientation to place and situation (via Maddock's Questions), level of consciousness (via Glasgow Coma Scale), and cervical spine assessment (Sport concussion assessment tool - 5th edition, 2017). The Balance Error Scoring System is also often used immediately after a concussion to detect impairments of balance (McCrea, Nelson, & Guskiewicz, 2017).

Evaluating a concussion typically consists of a battery of neuropsychological tests, including a self-reported inventory of symptoms. A widely used post-concussion neuropsychological test battery is the computerized Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT™) battery (http://www.impacttest.com). The ImPACT™ battery consists of three chief sections: demographic data, neuropsychological assessment, and the Post-Concussion Symptom Scale (PCSS) (Schatz et al., 2006). The neuropsychological component of this battery is comprised of several computerized subtests measuring attention span, reaction time, nonverbal problem solving and working memory, which yield composite scores of Verbal Memory, Visual Memory, Visual Motor Processing Speed, Impulse Control, and Reaction Time. (However, true memory is not assessed as memory is best evaluated through free recall; computerized batteries only have the capability to assess recognition memory.) The PCSS is a variation of the Pittsburg Steelers Post-Concussion Scale (McLeod & Leach, 2012). The PCSS is a self-reported symptom questionnaire that includes 22-Likert scaled items (range 0-6) that measures the severity of commonly experienced post-concussion symptoms in which higher scores represent greater symptoms (Lovell et al., 2006). The 22-items are summed to comprise a total score and is often used as an outcome measure following concussion. Recent factor analysis research has delineated four significant symptom clusters consisting of 19 items (3 items were not retained within the final factor solution) (Kontos et al., 2012; Merritt & Arnett, 2014). The four Post-Concussion Symptom (PCS) domains include Physical, Cognitive, Affective, and Sleep. Each domain consists of items that loaded above 0.4 (Merritt & Arnett, 2014), which correspond to the heuristic categories of concussion symptoms. The Cognitive domain includes the following symptoms: Feeling slowed down, feeling mentally “foggy”, difficulty concentrating, and difficulty remembering. The Physical domain includes the following symptoms: Nausea, vomiting, balance problems, dizziness, vision problems, sensitivity to light, and sensitivity to noise. The Affective domain includes the following symptoms: Irritability, sadness, nervousness, and feeling more emotional. Lastly, the Sleep domain includes the following symptoms: Fatigue, trouble falling asleep, sleeping less than usual, and drowsiness. A patient may exhibit elevated scores on all or some of these clusters.

Merritt and Arnett’s (2014) delineation of PCS domains established premorbid predictors of post-concussion symptoms following a concussion. A study done by Lovell et al. (2004) on concussed high school athletes supported the findings that symptom indicators within PCSS on the ImPACT™ battery are indicative of the concussion injury, its severity, and duration of recovery. By isolating characteristics of symptom reporting in predicting severity and duration of concussion, this research can ultimately influence return to play and return to class decisions in collegiate athletes. This information also has important clinical implications for the staff in charge of concussion management (such as athletic trainers, coaches, and directing physicians) and final concussion recovery decisions.

Concussion Management

There has been past upheaval regarding the recommended course of treatment after concussion. Until more recently, post-concussion recovery was governed by the "cocoon therapy" approach, which prescribed complete rest and refrain from the use of devices which could provoke visual or auditory symptoms such as television, smartphones, and computers in order to minimize symptoms and prevent re-injury. This approach was based on the rationale that sustaining a second concussion within a short time span could have serious, life-threatening consequences, a condition dubbed 'Second Impact Syndrome' (SIS; Saunders & Harbaugh, 1984). However, there has been much controversy over the past 35 years surrounding the pathophysiology of SIS and who is at greater risk. The most recent and comprehensive systematic review was done by McLendon et al. in 2016 and was limited to literature on athletes aged 13 to 24. Although SIS can lead to dramatic outcomes (i.e., death or permanent disability), it appears children under the age of 19 who are still experiencing post-concussion symptoms two weeks after their first concussion are most susceptible to SIS (McLendon, Kralik, Grayson, & Golomb, 2016).

Overall, return to physical or cognitive activity too soon can aggravate symptoms as well as make the player more susceptible to subsequent concussions. While an individual is more likely to sustain a second concussion following a first concussion and the symptoms may likely be aggravated, the existence of the drastic and often fatal condition of SIS, upon which many treatment guidelines are founded, is evidently rare (Wetjen et al., 2010). Furthermore, evidence has recently emerged that moderate physical activity in the week following a concussion was associated with reduced concussion symptoms 28 days later (Grool, et al., 2016). It is commonly accepted that after a brief period of rest (24-48 hours) in the acute phase post-concussion, an athlete should gradually increase his or her intensity of return to activity as soon as possible to reduce concussion symptomatology and aid in an overall successful return to class and play. Concussions usually require minimal treatment, so the primary role of evaluating collegiate sports-related concussions is to determine when and how the student-athlete should safely return to play and class.

Return to Play

Differences in return to play timelines

Return to play timeframes differ depending on level of athletic competition. According to previous literature, professional athletes generally return within 5 to 7 days, collegiate athletes within 7 to 10 days, and high school athletes after approximately 30 days (Pellman et al., 2006; Guskiewicz et al., 2003; Collins et al., 2002). However, over the past decade, there has been a substantial modification in the clinical management of sports-related concussions within the collegiate system. A previous study conducted by the National Collegiate Athletic Association (NCAA) with data from 1999 to 2001 demonstrated an average return to play time of 6.7 days (Guskiewicz at al., 2003). The most recent study conducted by the NCAA-Department of Defense Concussion Assessment, Research, and Education (CARE) gathered data from 2014 to 2017 discovered that the duration of time between injury and return to play significantly increased to 16.1 days (McCrea et al, 2019). Commensurate with this figure, student-athletes have been withheld from return to play even longer after symptoms resolved (previously 3.3 days post-symptom recovery and more recently 7.3 days).

Determining return to play

Noteworthy, only team physicians and athletic trainers have complete and autonomous authority in determining post-concussion management and resulting return to play decisions for all collegiate athletes (The National Collegiate Athletic Association [NCAA], 2014).

Return to play is frequently determined on a case-to-case basis; however, it is typical for a concussed athlete to be withheld from play for at least 24 hours to 1 week following the concussion, regardless of symptoms (McCrory et al., 2013). According to the National Athletic Trainers Association, once an athlete receives the diagnosis of concussion, the return to play protocol allegedly should not begin until the athlete reports a complete remission of previously reported concussion-related symptoms, presents with a normal clinical examination, and performs at pre-concussion baseline levels on neurocognitive and symptom assessments (Broglio et al., 2014). It is recommended that concussed athletes be withheld from activity until they are asymptomatic, followed by a graduated return to play progression. The directing athletic trainer and physician can modify an athlete's return to play timeline based on their own clinical judgment.

Stepwise return to play progression. The NCAA established a set of guidelines for the appropriate return to play progression, which is individually tailored for each and every student-athlete. This graduated process includes the following steps:

1. Symptom-limited activity.
2. Light aerobic exercise without resistance training.
3. Sport-specific exercise and activity without head impact.
4. Non-contact practice with progressive resistance training.

5. Unrestricted training.
6. Unrestricted return to play.

Each step should last at least 24 hours before progressing to the next step and the whole process is overseen by a health care professional (NCAA, 2014).

Return to Class

Determining Return to Class

Return to class is the academic counterpart to a collegiate student-athlete's return to play; however, this concept has received far less attention in previous literature. Information on this concept is predominantly limited to a pediatric population, as a return to learning is required amongst school-aged athletes (5 to 18). Therefore, the NCAA guidelines on a student-athlete's return to class is dictated by a modification of recommendations from literature geared toward youth athletes. These guidelines also acknowledge the literature on the neurobiomechanics of concussion and the consequent energy crisis (Giza & Hovda, 2001; Giza & Hovda, 2014), recognizing that an athlete's brain energy is depleted and, thus, limited after a sports-related concussion. Broglio and Puetz found that general cognitive performance is significantly negatively affected immediately after a sports-related concussion (Broglio & Puetz, 2008). Previous studies also suggest that exerting cognitions to engage in learning may exacerbate post-concussion symptoms and delay recovery (Sady, Vaughan & Gioia, 2011). According to Moser, Glatts & Schatz, findings from small-sampled studies indicate that student-athletes who are recovering from a concussion have benefitted from cognitive respite (Moser, Glatts & Schatz, 2012). Therefore, decisions of resumption of both physical and cognitive activities must follow a stepwise structure tailored to the individual athlete

(NCAA, 2014). Overall, student-athletes necessitate cognitive recess and a gradual return to a full class workload (Harmon et al., 2013).

Stepwise return to class progression. According to the NCAA, with trusted expert consensus:

1. If the student-athlete cannot tolerate light cognitive activity, he or she should remain at home or in the residence hall.
2. Once the student-athlete can tolerate cognitive activity without return of symptoms, he/she should return to the classroom, often in graduated increments.

In particular, academic accommodations (e.g., reduced workload, extended time) may be helpful during the recovery phase following a concussion (Harmon et al., 2013).

Similar to decisions on return to play, determining the best process and recommendations for returning to class is challenging and individualized. Although a student-athlete may demonstrate physical normality, he or she may be unable to tolerate extended time in a learning setting or perform at a baseline level of cognitive functioning (NCAA, 2014).

Current Study

Identifying a relationship between a symptom cluster and recovery time could be an important step in clarifying return to play and return to class decisions. The objective of the present study was to identify a relationship between PCSS symptom clusters and recovery time, as well as to better determine when collegiate student-athletes should return to physical activity and class following a concussion. The current study specifically investigated which symptom domain, if any, best predicted days to return to physical activity using the NCAA stepwise progression: return to exertion (step 1:

symptom-limited activity), return to limited play (step 4: non-contact practice with progressive resistance training), and return to full play (step 6: unrestricted return to play) (NCAA 2014), as well as which symptom domain, if any, best predicted days to return to learning.

Hypotheses

1. The cognitive domain will have better predictive value of number of days to return to class.
2. The physical domain will be a better predictor of return to exertion, limited play, and full play.

Methods

Subjects

Retrospective data was retrieved from an archive of student-athletes from Cornell University competing at the Division I level of the NCAA who had sustained a concussion, been administered the ImPACT™ battery, and had their recovery data entered into the Ivy League Concussion Registry (IRB Protocol: 1510016632).

Subjects include men and women from all sports who were at least 18 years of age who sustained concussions between August 2015 and January 2020. Unfortunately, outcome data from 2/2017 to 7/2018 were not available. Any participants missing all ImPACT battery data and/or all recovery data were excluded from the analyses. Subjects who sustained concussions in non-sports-related incidents were also excluded. Thus, the current data represents an effective sample size of 140.

Measurement Tools

The ImPACT™ battery (which included the PCSS) was administered at baseline and following a concussion.

Procedure

The Ivy League Concussion Registry includes background and demographic data, circumstances of the concussion event, symptom duration, and dates of return to exertion, return to full play, and return to class. All data were entered into the Ivy League Concussion Registry. The IDs of anonymized subjects in the Registry were matched to those from the ImPACT™ battery and PCSS, from which the concussion scale data were compiled. All 22 items on the PCSS contribute to the total symptom score; however, the current study will be investigating the presence of symptoms from specific symptom clusters of the PCSS derived from a previous factor analysis (Merritt & Arnett, 2014), which is detailed within the Analysis Plan section. The assistant athletic trainer, Katy Harris, employed by Cornell maintained the registry and accessed the Post-Concussion Scale from the ImPACT Battery, as well as relevant de-identified demographic and recovery data from the Concussion Registry, under the supervision of the director of sports medicine, David Wentzel, M.D. The data was transferred in a HIPAA compliant, encrypted spreadsheet to the current writer, who analyzed, interpreted, and wrote-up the results.

Analysis Plan

Merrit and Arnett (2014) conducted an exploratory factor analysis on the 22 items that comprise the PCSS from collegiate athlete data at baseline. As described in their data analysis approach, factors were then extracted using principal components analysis (PCA), and orthogonal rotation (varimax with Kaiser normalization). Prior to establishing symptoms within each factor, the researchers decided that individual symptoms with rotated component loadings greater than 0.4 would be preserved in the final factor solution; however, if an item cross-loaded (two or more factors with component loadings >0.4), the item would be assigned to the factor with the greatest loading (Merritt & Arnett, 2014). Of note, three of the 22 items (i.e., headache, sleeping more than usual, and numbness/tingling) were not retained in the final factor solution due to the rotated component loadings resulting in correlation estimates less than the 0.4 cutoff consistent across all factors (Merritt & Arnett, 2014). This resulted in 4-factor solution including a physical factor, cognitive factor, affective factor, and sleep factor (Table 1). Therefore, the current study derived PCSS domains (cognitive, physical, affect, and sleep) and corresponding items from this publication. Each symptom domain was dichotomized to reflect the presence of any symptom within that domain (regardless of severity) or absence of symptoms within that domain.

Table 1. PCSS Symptoms and Factor Loadings (Merritt & Arnett, 2014)

PCSS symptoms	***Factor 1: Cognitive***	***Factor 2: Physical***	***Factor 3: Affective***	***Factor 4: Sleep***
Feeling slowed down	.619*	.193	.137	.225
Feeling mentally "foggy"	.567*	.109	.150	.323
Difficulty concentrating	.717*	-.009	.251	.282
Difficulty remembering	.744*	.038	.113	.099
Nausea	.030	.647*	.079	.191
Vomiting	-.041	.692*	.116	.186
Balance problems	.261	.586*	.129	-.108
Dizziness	.363	.605*	-.005	.140
Sensitivity to light	.219	.417*	.031	.286
Sensitivity to noise	-.075	.532*	.173	.266
Visual problems	.408	.457*	.061	.028
Irritability	.424	.142	.435*	.048
Sadness	.139	.127	.847*	.111
Nervousness	.166	.110	.728*	.105
Feeling more emotional	.185	.125	.832*	.076
Fatigue	.434	.164	.139	.517*
Trouble falling asleep	.118	.105	.117	.706*
Sleeping less than usual	.066	.163	.068	.823*

Drowsiness	.415	.248	.021	.456*
Headache+	.381	.302	.139	-0.042
Sleeping more than usual+	.376	.271	.168	-.143
Numbness or tingling+	.242	.320	.056	.031

Note: +Symptom did not meet any factor loading criteria and was therefore eliminated in final factor solution

*Factor loading >0.4 for a particular symptom corresponding to a particular factor

The current study aims to evaluate associations between presence of symptoms within the PCSS domains and number of days to return to functioning (i.e., class, exertion, limited play, and full play), as well as evaluate all predictors of return to functioning. Therefore, Pearson product-moment correlations were performed between each PCSS domain and days to return to functioning. Hierarchical regression analyses of PCSS domains, gender, and concussion history were conducted to predict return to activity. One multiple regression analysis was performed on the duration of symptoms using the difference between date of concussion and return to class. Another multiple regression analysis was performed on the duration of symptoms using the difference between date of concussion and return to exertion. Another multiple regression analysis was performed on the duration of symptoms using the difference between date of concussion and return to limited play. The last multiple regression analysis was performed on the duration of symptoms using the difference between date of concussion and return to play. Symptom domains and concussion factors such as gender, protection worn, and prior concussion history were used as predictors in supplemental analyses.

Gender was used as a covariate to account for possible, and likely, gender differences. For legitimate but outlying values, the data was Winsorized. After Winsorizing extreme cases, bootstrapping was then used in all analyses as the variables were expectedly highly skewed. Therefore, resulting descriptive statistics were also based on Winsorized data. Lastly, the presence of some clinical symptoms at baseline are to be expected for at least some participants within any sample. However, as the prediction of resumption to activity relies solely on post-concussion symptom data and not necessarily influenced by baseline symptoms, the presence of any, if at all, baseline symptoms were not considered in these analyses. For that reason, post-concussion symptom scores were not adjusted in the final results. Descriptive statistics on the presence of baseline symptoms in athletes of this sample are included in the Appendix.

Results

Descriptive Data

The collegiate athletes ranged from 18 to 23 years of age (mean = 19.7, SD = 1.3) with 88 males and 51 females. The athletes within this study played a variety of sports including football (n = 21), ice hockey (n = 17), soccer (n = 13), track and field (n = 13), sprint football (n = 13), lacrosse (n = 11) gymnastics (n = 10), wrestling (n = 8), volleyball (n = 6), basketball (n = 5), rowing (n = 4), baseball (n = 3), field hockey (n = 3), sailing (n = 3), swim (n = 3), diving (n = 2), polo (n = 2), softball (n = 1), equestrian (n = 1), and fencing (n = 1). A history of previous concussions ranged from no previous concussions (n = 80), to 1 (n = 40), 2 (n = 12), 3 (n = 6) and 5 previous concussions (n = 2); therefore, 57.1% of this sample have a concussion history. Head protection varied by sport and was worn by 67 athletes (47.9% of sample). Only 2 concussed athletes (1.4% of sample) sustained loss of consciousness. Amnesia was reported by 7 athletes (5% of sample). For general participant and concussion descriptive and frequency characteristic statistics, please refer to Tables 2 and 3.

Table 2. Participant Characteristics (N = 140)

Characteristics	Mean or Frequency (SD or %)
Age	19.7 (1.3)
Gender	n = 139
Male	88 (62.9%)
Female	51 (36.4%)
Number of Previous Concussions	
0	80 (57.1%)
1	40 (28.6%)
2	12 (8.6 %)
3	6 (4.3%)
4	0 (0.0%)
5	2 (1.4%)
Sport Played	
Football	21 (15.0%)

Ice Hockey	17 (12.1%)
Sprint Football	13 (9.3%)
Track & Field	13 (9.3%)
Soccer	13 (9.3%)
Lacrosse	11 (7.9%)
Gymnastics	10 (7.1%)
Wresting	8 (5.7%)
Volleyball	6 (4.3%)
Basketball	5 (3.6%)
Rowing	4 (2.9%)
Field Hockey	3 (2.1%)
Baseball	3 (2.1%)
Swim	3 (2.1%)
Sailing	3 (2.1%)
Polo	2 (1.4%)
Diving	2 (1.4%)
Softball	1 (0.7%)
Fencing	1 (0.7%)
Equestrian	1 (0.7%)

Table 3. Concussion Characteristics

Characteristics	Frequency (%)
Head Protection Worn	
Yes	67 (47.9%)
No	73 (52.1%)
Experienced Amnesia	
Yes	7 (5.0%)
No	133 (95.0%)
Experienced Loss of Consciousness	
Yes	2 (1.4%)
No	138 (98.6%)
Concussion History	
Yes	60 (57.1%)_
No	80 (42.9%)

There were two participants who returned to exertion, limited play, full play, and class after a relatively extended amount of time; thus, these data points were Winsorized. The following descriptive statistics are based on the Winsorized data. The average time from the incident concussion to reporting the concussion to training staff or coaches was

0.79 days, ranging from 0 days to 8 day. The duration of symptoms ranged from 1 day to 102 days with a mean of 16.21 days. Return to class post-concussion ranged from 0 to 81 days (mean = 11.0 days, SD = 15.7). Return to play was divided into return to limited physical exertion, limited play and full play. Return to exertion ranged from 1 to 113 days (mean = 15.9, SD = 18.0), return to limited play ranged from 3 to 124 days (mean = 22.5, SD = 22.4), and return to full play ranged from 6 to 171 days (mean = 33.4, SD = 33.4). Refer to Table 4 for return to activity data.

Table 4. Return to Activity Characteristics

Activity	Mean days (SD)
Reported concussion after incident	0.79 (1.32)
Duration of symptoms	16.21 (18.16)
Return to class	11.03 (15.72)
Return to exertion	15.94 (18.05)
Return to limited play	22.47 (22.42)
Return to full play	33.43 (33.36)

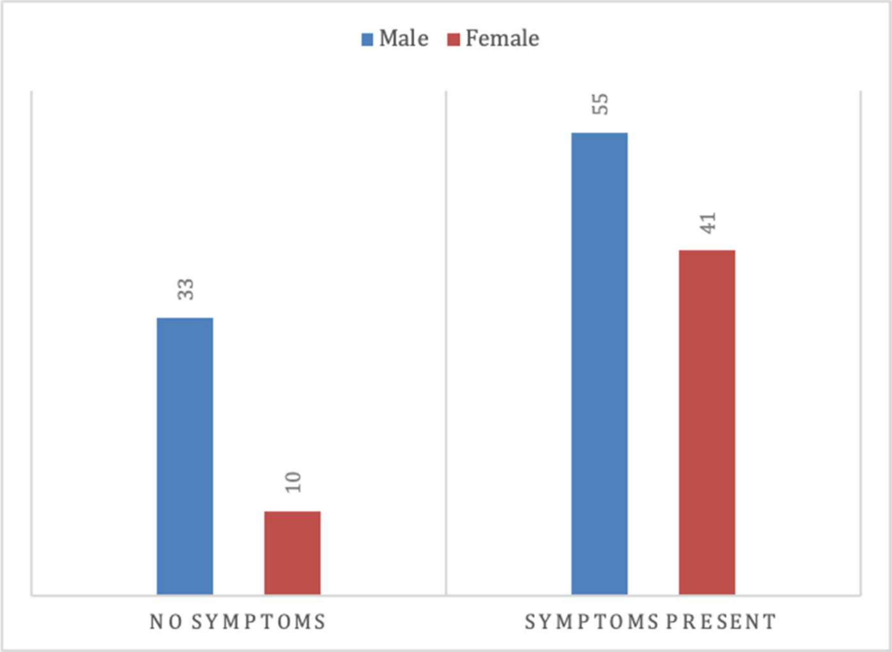
Gender Differences

There were no significant differences between males and females on measures of days of symptom duration, days until return to full play, days until return to class, or on any of the individual PCSS domains (Table 5). There was a significant difference between males and females on presence of symptoms at all; male athletes were more likely to report an absence of symptoms than female athletes X^2 (1, N = 139) = 4.838, p = 0.028 (Figure 1). No statistically significant differences were measured between athletes who wore protective gear vs. those who did not. However, males were more likely to wear protective headgear than females X^2 (1, N = 139) = 22.885, p<0.001. However, this data is highly reliant on sport played; males tend to play sports in which head protection is required (e.g., football). Chi-square tests of independence showed that there were no significant associations between gender and reported amnesia or loss of consciousness.

Table 5. Days to Return to Activity by Gender

	Male (Mean)	Female (Mean)	Mean Difference (95% CI)
Symptom Duration	14.13	17.06	-2.937 (-8.892 to 3.018)
Return to Exertion	14.57	16.53	-1.962 (-8.004 to 4.079)
Return to Limited Play	20.22	24.94	-4.721(-12.319 to 2.877)
Return to Full Play	32.05	37.81	-5.758 (-18.014 to 6.498)
Return to Class	9.81	12.79	-2.977 (-8.878 to 2.924)

Figure 1. Gender Difference in Overall Symptom Endorsement



Pearson correlations demonstrated strong internal relationships between the four concussion symptom scale loadings suggesting high multicollinearity (correlations can be found in Table 6). The only symptom domain that was not significantly correlated to a resumption of activity was the physical domain and return to class. Otherwise, all other symptom domains were highly significantly correlated with all resumption to activity.

The cognitive domain was related to return to class ($r = 0.249$, $p = 0.005$), return to exertion ($r = 0.357$, $p < 0.001$), return to limited play ($r = 0.369$, $p < 0.001$), and return to full play ($r = 0.349$, $p < 0.001$). The physical domain was related to return to exertion ($r = 0.298$, $p = 0.001$), return to limited play ($r = 0.255$, $p = 0.004$), and return to full play ($r = 0.281$, $p = 0.001$). The affect domain was related to return to class ($r = 0.258$, $p = 0.003$), return to exertion ($r = 0.341$, $p < 0.001$), return to limited play ($r = .309$, $p < 0.001$), return to full play ($r = 0.408$, $p < 0.001$). Sleep was significantly correlated to return to class ($r = 0.273$, $p = 0.002$), return to exertion ($r = 0.342$, $p < 0.001$), return to limited play ($r = 0.386$, $p < 0.001$), and return to full play ($r = 0.411$, $p < 0.001$).The presence of having any symptom at all post-concussion was also significantly correlated with each and every resumption to activity (return to class, $r = 0.201$, $p = 0.024$; return to exertion, $r = 0.301$, $p = 0.001$; return to limited play, $r = 0.297$, $p = 0.001$; return to full play, $r = 0.286$, $p = 0.001$).

The total days of duration of symptoms was related to all four concussion domains: Cognitive ($r =0.351$, $p < 0.001$), Physical ($r = 0.337$, $p < 0.001$), Affective ($r = 0.331$, $p < 0.001$), and Sleep ($r = 0.341$, $p < 0.001$). Further, there was also a strong relationship between symptom duration and return to class ($r = 0.589$, $p < 0.001$), return to exertion ($r = 0.681$, $p < 0.001$), return to limited play ($r = 0.699$, $p < 0.001$), and return to full play ($r = 0.683$, $p < 0.001$).

Table 6. Pearson Correlations of Symptom Domains and Return to Functioning

	Cognitive	Physical	Affective	Sleep	Duration	RTE	RTLP	RTFP	RTC
Cognitive	1	-	-	-	-	-	-	-	-
Physical	0.640**	1	-	-	-	-	-	-	-
Affective	0.468**	0.448**	1	-	-	-	-	-	-

Sleep	0.617**	0.655**	0.519**	1	-	-	-	-	-
Duration	0.351**	0.337**	0.331**	0.341**	1	-	-	-	-
RTE	0.357**	0.298**	0.341**	0.342**	0.681**	1	-	-	-
RTLP	0.369**	0.255**	0.309**	0.386**	0.699**	0.925**	1	-	-
RTFP	0.349**	0.281**	0.408**	0.411**	0.683**	0.709**	0.822**	1	-
RTC	0.249**	0.164	0.258**	0.273**	0.589**	0.670**	0.654**	0.640**	1

Note. RTE = Return to Exertion; RTLP = Return to Limited Play; RTFP = Return to Full Play; RTC = Return to Class

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Individual regression analyses showed that each symptom domain separately predicted each and every outcome variable (although very close, the presence of physical symptoms fell short of statistical significance in predicting return to class: B = 5.061, p = 0.052). These analyses are included within the Appendix. Combined regression analyses, which included all post-concussion domains, revealed that the combination of every symptom domain significantly predicts resumption to all activities, including return to exertion F(4,134) = 4.033, p = 0.004; return to limited play F(4,131) = 4.924, p = 0.001, return to full play F(4,125) =9.485, $p < 0.001$, and return to class F(4,132) = 3.949, p = 0.005. When put together, cognitive symptoms made the most unique contributions in predicting return to exertion (B = 5.029, p = 0.042), limited play (B = 9.412, p = 0.023), and class (B = 5.711, p = 0.043), as well as predicting overall symptom duration (B = 5.782, p = 0.019). Contrarily, return to full play was most significantly and uniquely predicted by sleep symptoms (B = 16.719, p = 0.011). Results of these regression analyses can be found in Table 7. Of note, the “Bias” column indicates the discrepancy between non-bootstrapped one-sample estimates and the average of 100 estimates. Therefore, all B's reported in text are bias-corrected.

Table 7. Multiple Regressions of Symptom Domains and Return to Functioning

Return to Exertion	B	Bias	Standard Error	p-value	Confidence Interval
Cognitive Symptoms	5.158	-0.129	2.452	0.042	0.775 to 9.465
Physical Symptoms	1.286	-0.053	3.005	0.655	-4.845 to 6.853
Affective Symptoms	6.963	-0.133	4.856	0.184	-1.632 to 16.606
Sleep Symptoms	2.037	0.052	2.701	0.421	-3.587 to 7.806
Return to Limited Play					
Cognitive Symptoms	9.437	-0.025	3.974	0.023	1.374 to 17.011
Physical Symptoms	-3.744	-0.014	4.970	0.453	-13.251 to 6.304
Affective Symptoms	5.836	0.083	6.104	0.341	-5.570 to 19.336
Sleep Symptoms	8.031	-0.099	4.761	0.113	-1.201 to 17.036
Return to Full Play					
Cognitive Symptoms	8.777	-0.447	5.098	0.082	0.254 to 17.585
Physical Symptoms	-5.344	0.167	7.287	0.488	-21.329 to 8.103
Affective Symptoms	20.664	-0.108	10.224	0.054	3.965 to 39.103
Sleep Symptoms	16.685	0.034	6.519	0.011	5.392 to 29.535
Return to Class					
Cognitive Symptoms	5.703	0.008	2.807	0.043	0.856 to 11.309
Physical Symptoms	-3.651	0.190	3.529	0.329	-11.924 to 3.126
Affective Symptoms	4.773	-0.497	4.467	0.293	-3.117 to 12.117
Sleep Symptoms	5.169	-0.002	3.524	0.159	-1.426 to 12.058
Symptom Duration					
Cognitive Symptoms	5.780	0.002	2.316	0.019	0.844 to 10.864

Physical Symptoms	3.903	-0.057	2.590	0.130	-1.183 to 8.764
Affective Symptoms	6.771	-0.096	4.788	0.155	-2.533 to 15.495
Sleep Symptoms	3.258	0.228	2.955	0.267	-2.592 to 10.085

Note: Bolded symptom domains are significantly predictive of a particular return to functioning

Multiple regressions were conducted to investigate the best predictors of symptom duration and resumption to activities. Of note, LOC and amnesia were not included as covariates in this analysis as the sample size of those who positively endorsed each variable was too small. The combination of variables to predict days until symptom remission from gender, concussion history, and protection worn was not statistically significant, *F*(3, 134) = 1.789, *p* = 0.152. The adjusted *R*2 value was 0.017. This indicates that only 1.7% of the variance in symptom duration was explained by the model. The bias-corrected B coefficients are presented in the text and regression data presented in Table 8. Note that of three variables included in the model, only concussion history (B = 12.272, p = 0.025) significantly predicts symptom duration. A hierarchical regression with the cognitive symptom domain indicated that only the presence of cognitive symptoms (B = 9.024, p = 0.001) uniquely predicted days until symptoms remitted.

The combination of variables to predict return to exertion from gender, concussion history, and protection worn was not statistically significant, *F*(3, 134) = 1.941, *p* = 0.126. The adjusted *R*2 value was 0.020. This indicates that only 2.0% of the variance in return to exertion was explained by the model. The bias-corrected B coefficients are presented in the text and all other regression data presented in Table 10.

Note that of three variables included in the model, only concussion history (B = 7.393, p = 0.027) significantly predicted return to exertion. A hierarchical regression with the cognitive symptom domain indicated that both the presence of cognitive symptoms (B = 9.024, p = 0.001) and concussion history (B = 5.668, p = 0.048) separately and uniquely predict return to exertion.

The combination of variables to predict return to limited play from gender, concussion history, and if protection was worn was not statistically significant, *F*(3, 131) = 1.763, *p* = 0.157 (adjusted *R*2 = 0.017). Within this model, no covariate significantly predicted return to limited play, but concussion history was approaching statistical significance (B = 8.198, p = 0.057).

The same model was used to predict return to full play and was also not statistically significant, *F*(3, 125) = 2.127, *p* = 0.100 (adjusted *R*2 = 0.026). Within this model, return to full play was significantly predicted by concussion history (B = 13.183, p = 0.041). A hierarchical regression with the cognitive symptom domain indicated that only the presence of sleep symptoms (B = 26.329, p = 0.001) uniquely predicted return to full play above and beyond the contribution of the other covariates.

Lastly, the same model was used to predict return to class and was not statistically significant, *F*(3, 132) = 1.648, *p* = 0.181 (adjusted *R*2 = 0.014). Within this model, no covariate uniquely predicted return to class.

Table 8. Potential Covariates and Predicting Remission of Symptoms and Return to Functioning

Return to Exertion	B	Bias	Standard Error	p-value	Confidence Interval
Gender	-1.785	0.043	3.100	0.581	-7.953 to 4.526

Concussion History	7.421	-0.028	3.393	0.027	0.812 to 14.511
Protection Worn	-2.398	-0.042	3.199	0.469	-7.959 to 3.907
Return to Limited Play					
Gender	-0.316	0.116	4.345	0.952	-9.197 to 8.489
Concussion History	8.326	-0.128	4.286	0.057	0.530 to 16.297
Protection Worn	-4.031	0.003	4.330	0.338	-13.566 to 4.602
Return to Full Play					
Gender	0.482	0.354	6.204	0.944	-12.884 to 13.434
Concussion History	12.981	0.202	6.372	0.041	0.241 to 26.525
Protection Worn	-8.106	-0.010	6.051	0.187	-20.241 to 3.251
Return to Class					
Gender	0.098	0.068	3.556	0.981	-6.382 to 7.417
Concussion History	4.971	-0.024	3.013	0.108	-1.332 to 11.098
Protection Worn	-3.592	0.061	3.113	0.245	-9.395 to 2.690
Symptom Duration					
Gender	-1.649	-0.135	3.301	0.609	-8.839 to 4.014
Concussion History	7.148	0.137	3.335	0.034	0.672 to 14.465
Protection Worn	-2.491	0.043	3.615	0.477	-10.226 to 4.834

Note: Bolded covariates are significantly predictive of a particular return to functioning

A multiple regression was conducted to determine the PCSS item that served as the best predictor of duration of symptoms among individual symptoms within the Cognitive domain (“Feeling slowed down,” “Feeling mentally foggy,” “Difficulty concentrating,” and “Difficulty remembering”). The model was significant F(4,134) = 5.982, $p < 0.001$, with “Difficulty concentrating” as the most meaningful predictor (B =

5.423, p = 0.026) of duration of symptoms. The model was repeated for all resumption to activity, using PCSS items of the domains that best predicted each return to activity in previous analyses. Return to exertion was best predicted by "difficulty concentrating" (B = 5.417, p = 0.031) from the Cognitive domain. Return to limited play was best predicted by "difficulty concentrating" (B = 6.136, p = 0.035) from the Cognitive domain. As the Sleep domain was evidently significant for predicting return to full play, accordingly a multiple regression was conducted to determine which PCSS item of the Sleep domain ("Fatigue," "Trouble falling asleep," "Sleeping less than usual," and "Drowsiness") served as the best predictor. As a result, return to full play was best predicted by "trouble falling asleep" (B = 14.848, p = 0.035) from the Sleep domain. The model for return to class was not significant and was not uniquely predicted by any particular PCSS item from the Cognitive domain.

Table 9. PCSS Items and Predicting Remission of Symptoms and Return to Functioning

Return to Exertion	B	Bias	Standard Error	p-value	Confidence Interval
Feeling slowed down	-3.613	-0.139	3.596	0.344	-11.278 to 2.892
Feeling mentally foggy	3.348	0.108	2.830	0.236	-1.971 to 9.247
Difficulty concentrating	5.242	0.175	2.347	0.031	1.102 to 10.432
Difficulty remembering	-4.353	0.051	2.929	0.144	-10.319 to 1.037
Return to Limited Play					
Feeling slowed down	-6.100	-0.079	4.235	0.148	-15.414 to 1.281
Feeling mentally foggy	6.098	0.356	3.922	0.120	-1.519 to 15.595
Difficulty concentrating	6.070	0.066	2.858	0.035	0.325 to 12.081
Difficulty remembering	-5.283	-0.043	3.617	0.142	-12.950 to 1.756

Return to Full Play					
Fatigue	4.333	-0.578	5.030	0.421	-5.229 to 11.971
Trouble falling asleep	14.495	0.353	6.910	0.035	0.069 to 29.101
Sleeping less than usual	-5.713	0.463	10.663	0.550	-26.003 to 17.772
Drowsiness	-2.349	0.755	5.245	0.650	-13.039 to 11.356
Return to Class					
Feeling slowed down	-1.483	0.077	3.849	0.686	-8.841 to 6.645
Feeling mentally foggy	3.084	0.078	3.011	0.291	-2.638 to 9.269
Difficulty concentrating	1.633	-0.223	2.122	0.448	-2.249 to 4.932
Difficulty remembering	-2.470	0.360	3.148	0.455	-8.806 to 4.496
Symptom Duration					
Feeling slowed down	-2.961	-0.190	2.462	0.225	-7.078 to 1.260
Feeling mentally foggy	2.412	0.713	3.298	0.469	-4.231 to 11.143
Difficulty concentrating	5.889	-0.466	2.656	0.026	1.165 to 9.692
Difficulty remembering	-1.768	-0.244	3.240	0.558	-8.298 to 3.846

Note: Bolded covariates are significantly predictive of remission of symptoms, or a particular return to functioning

Discussion

The primary purpose of this study was to investigate if the presence of post-concussive symptoms in the main symptom domains of the PCSS (Physical, Cognitive, Sleep, Affective) could help predict symptom recovery and return to activities of class, exertion, limited play, and full play. Ultimately, this goal could support the exploration of symptom-based markers of concussion duration in sports-related concussions of collegiate athletes and all other levels of competition.

Descriptive Outcomes

The current sample consisted of both males and females from an elite athletic collegiate population (NCAA Division I) from twenty different sports. The current data show a mean return to play time of 33.43 days, which is about 17 days longer than the most recent mean return to play data analyzed by the NCAA CARE (16.21 days) (McCrea et al, 2019). In comparison to the current sample, the NCAA CARE study included only football players from multiple universities with differing divisional levels (I, II, and III); therefore, the current sample differs in that it is representative of a more diverse subsection of athletes (and presumably, genders). The current data also show a mean return to class time of 11.03 days, which is less days than the mean of overall symptom recovery for this sample (16.21 days). A mean return to any physical activity at all (i.e., return to exertion) was also less than the mean of a full remission of symptoms, but was generally closer in proximity at an average of 15.94 days. It appears that the current return to learning protocols will allow resumption of cognitive exertion prior to a full resolution of symptoms. However, this is particularly nuanced because concussion recovery and management is heavily regarded as a graduated procedure. Physically returning to a class may promote cognitive stimulation during recovery and promote even more improvement in symptoms. In a review of "recovery from acquired developmental brain injury," Giza et al. (2009) reported that stimulating environments will ultimately lead to improved neurotransmission, reinforced synaptic firing, proliferations in neurotrophins, thickening cortices, and overall recovered mental abilities (Giza et al., 2009). Physical and mental rest is exceptionally important in the initial days following a concussion; however, extended rest can delay recovery and therefore be detrimental to a student-athlete's recovery and return to activity timeline. According to a commentary by leading concussion researchers, "prolonged absences from school, anxiety, depression, deconditioning, sleep disturbances, and other problems were increasingly seen as challenges in the recovery from mTBI" (Giza, Choe & Barlow, 2018). With this information, health care professionals in the world of sports have increasingly incorporated briefer respite periods, subsequent to a stepwise progression of increased mental and physical activity. Of course, return to any activity should and will continue to be individually tailored per student-athlete.

As described previously, literature is mixed regarding the impact of predisposing and post-injury factors on concussion recovery (Kontos et al., 2019; Iverson et al., 2017; McCrea et al., 2013). The current study found that males are more likely than females to be asymptomatic following a concussion, which is consistent with previous literature (Sufrinko et al., 2017; Merritt, Padgett & Jak, 2019). Otherwise, males and females did not differ on any post-injury characteristics, symptoms, or recovery time. In regression analyses, concussion history was the only factor which significantly impacted symptom duration, as well as a return to exertion and full play, in which having a previous concussion resulted in prolonged recovery/return to initial activity. This suggests concussion history is important in determining duration of symptom recovery and an initial return to activity, while also supporting in the determination of more distal goals like return to full play. A history of concussions did not inform the return to class trajectory.

Main Outcomes

Overall, the main outcome measures suggest that each separate symptom domain of the PCSS has predictive ability in ascertaining how long symptoms will persist, as well as the number of days it may take for a collegiate student-athlete to return to class and various levels of physical activity. However, when considered in combination, not all symptom domains prove to make individually unique contributions to the prediction of return to activity. In fact, the cognitive domain, specifically, makes unique contributions to predicting return to class, exertion, and limited play. There is more unique variance predicting return to activity, even when controlling for possible covariates (gender, concussion history, if head protection was worn). This data suggests that, in general, the cognitive domain may be more important in predicting remission of symptoms and resumption of regular activities in their academic and athletic pursuits, including when to resume classes and when to begin exertion and limited play of their sport. Meanwhile, a complete return to full athletic practice is best predicted by the sleep domain.

Upon further investigation of the specific symptoms within each symptom domain, the PCSS item of “Difficulty concentrating” within the cognitive domain carried more weight in predicting symptom duration, as well as return to exertion and limited play. No particular PCSS item of the cognitive domain uniquely predicted a return to class. This may be because all cognitive domain symptoms are equally important in predicting a full return to learning. As learning, in general, may require varying capacities of cognitive application and functioning, this data may hold value in our understanding of cognition within an academic environment. As the sleep domain was the most significant predictor, items from the sleep domain were analyzed for predicting return to full play. As a result, the PCSS item of "Trouble falling asleep" from the sleep domain had the most predictive value in determining a full resumption of sport. This may suggest that a lack of consistent, quality sleep could negatively impact the long-term recovery process necessary for fully re-engaging in any particular sport.

Clinical Implications

Clinically, there is a need for diagnostic markers as objective means to assess for severity and accompanying symptomatology of sports-related concussion and, thus, clinical recovery outcome. Although self-reported symptoms are subjective and the resulting treatment and recommendations are tailored to the individual, identifying objective measures of severity and successive recovery is vital for making appropriate decisions of clinical management. Differentiating the presence of particular post-concussion symptoms within pre-determined domains could be important for the student-athlete, as well as the training and health professional staff. For example, this information may have implications for an athlete's own understanding of their prognosis and possible return to functioning timeline. The training staff and health care professionals could also gain insight on certain symptom domains to help inform their return to activity decisions. Consequently, findings from the current study could promote increased utilization of self-reported, post-concussive symptom presentation in clinical decisions.

As found in the present study, potential for prolonged recovery from graduated activity and academia should be considered, especially when cognitive symptoms are present. Long-term recovery and the most distal outcome of return to sport appear to be more heavily dictated by sleep disruption in the acute phase following a concussion. Therefore, it may be clinically relevant to engage in appropriate care for confronting sleep-related difficulties early in the concussion recovery process. Future research could further investigate sleep disturbances following a concussion and optimize the recovery process by evaluating its impact. At a macro level, the NCAA can incorporate current findings into detailed prognosis, recovery, and decisions for resumption of activity. Ultimately, incorporating information from symptom domain presentation can carry prognostic value for making important decisions for elite athletes at all levels of post-concussive care. Continued research and application of findings is necessary for progress within an area of limited knowledge and subjective diagnostic criteria.

Limitations

Several limitations of this study warrant consideration. As the current sample consisted of Cornell University student-athletes (NCAA Division I), these results may not be necessarily generalizable to differing levels of ability (Division II or III), levels of competition (professional or high school sports), or age ranges (any age beyond 18-23). Although the effective sample consisted of 140 athletes, the sample size per sport ranged from 1 to 21. Therefore, this study only investigated outcomes of concussions across a broad range of sports and analyses of concussion outcomes for specific sports were limited.

The current study did not collect information on predisposing risk factors of delayed recovery, like previous psychological concerns or learning disabilities. Although previous literature is mixed regarding the impact of pre-injury factors, some studies claim that there are factors that predispose athletes to longer duration of symptoms and extended amount of time between concussion and return to activity. For example, previously diagnosed mental illness was significantly correlated to the affective domain while previously diagnosed attention deficit-hyperactivity disorder was more related to the cognitive domain (Asken et al., 2017). Therefore, it would be important to understand the current results in the context of previously endorsed psychiatric and cognitive concerns.

Moreover, in regard to predisposing factors affecting clinical recovery from a concussion, baseline findings were not presented in the current study. According to the training director at Cornell University, the baseline scale for particular athletes in this study may reflect their post-concussion scores from a previously suffered concussion, where relevant. Although this baseline symptom data was available, post-concussion symptoms were determined to be important for predicting symptom remission and return to activity independent from baseline findings. However, it is noteworthy to recognize that previous literature on baseline ImPACT scores have found that collegiate students, in general, will endorse a lot of symptoms at baseline testing, even if no previous concussions were experienced. Post-concussion symptoms are ubiquitous and present similarly to a range of psychological disorders, like mood disorders, anxiety, substance abuse, post-traumatic stress disorder, and ADHD, among others. As mental health problems are especially prevalent within a college-aged population, baseline symptom reporting on the PCSS may be capturing this symptom ubiquity. For example, a recent study on collegiate athletes with premorbid diagnoses of anxiety and/or depression found that these athletes reported higher overall symptom severity scores on baseline testing (Wallace et al., 2020). According to a study on baseline symptom reporting within a collegiate sample, 120 of 738 athletes (16.3%) already met criteria for ICD-10 post-concussion syndrome (Asken et al., 2017). This study also demonstrated that previously diagnosed depression and anxiety may influence and possibly lengthen recovery after concussion (Asken et al., 2017). Therefore, baseline scales can reflect a multitude of presentations, including an athlete's previous concussion history or an athlete's current symptomatic complaints due to reasons other than a concussion. The current study did not incorporate baseline presentations into the final results, which could support in accounting for symptomatic changes that were found in the current post-concussion symptom domains.

There is also the possibility of the underreporting of symptoms following concussion, which may have altered the current results and return to activity trajectory. Student-athletes competing at a high level of sport may feel obligated to report a lesser severity of their symptoms due to pressure from training staff, parents, teammates, or future prospects in their sport. According to Meier et al. (2015), NCAA Division I student-athletes significantly underreported their number and severity of symptoms on ImPACT testing when compared to a separately administered and confidential self-report during the acute phase of post-concussion assessment (Meier et al., 2015).

Conclusions

Results of the present study revealed that symptom domains of the PCSS have predictive value in determining symptom remission and return to activity timelines. All of the post-concussion symptom domains are predictive of symptom improvement over time and return to activity, athletic and academic alike. (Of note, the physical domain was not independently predictive of return to class.) The Cognitive domain significantly predicted remission of symptoms, as well as return to exertion, limited play, and class. However, the Sleep domain contributed more variance in predicting return to full play. Attention to specific domains could help in assessing a collegiate student-athlete's ability and trajectory to return to play or class.

Appendix

Table A. Baseline Symptom Descriptives

Baseline Domain	Frequency (%)
Cognitive Symptoms	
Yes	16 (11.4%)
No	116 (82.9%)
Physical Symptoms	
Yes	8 (5.7%)
No	124 (88.6%)
Affective Symptoms	
Yes	25 (17.9%)
No	107 (76.4%)
Sleep Symptoms	
Yes	36 (25.7%)
No	96 (68.6%)
Any PCS Symptoms	
Yes	54 (38.6%)
No	78 (55.7%)

Table B. Regression analyses of individual PCSS domains in predicting symptom duration and return to activity

Regression Analysis	B	Bias	Standard Error	p-value	Confidence Interval
Return to Exertion Cognitive symptoms	9.905	-0.044	2.858	0.001	3.883 to 15.479
Return to Exertion Physical symptoms	8.503	-0.092	2.952	0.006	2.440 to 13.919
Return to Exertion Affective symptoms	11.728	0.001	4.512	0.009	3.994 to 20.784
Return to Exertion Sleep symptoms	9.144	0.119	2.974	0.003	3.469 to 15.684
Return to Limited Play Cognitive symptoms	14.025	0.238	3.544	0.001	6.972 to 21.654
Return to Limited Play Physical symptoms	9.628	0.041	3.679	0.010	2.490 to 16.683
Return to Limited Play					

Affective symptoms	13.889	0.258	5.801	0.017	3.600 to 26.429
Return to Limited Play					
Sleep symptoms	13.627	-0.179	3.836	0.003	6.767 to 20.483
Return to Full Play					
Cognitive symptoms	23.563	-0.160	4.993	0.002	14.506 to 33.089
Return to Full Play					
Physical symptoms	18.760	0.005	5.649	0.001	7.484 to 29.750
Return to Full Play					
Affective symptoms	33.000	0.126	9.767	0.001	14.945 to 52.843
Return to Full Play					
Sleep symptoms	27.191	-0.237	5.452	0.001	17.384 to 36.822
Return to Class					
Cognitive symptoms	8.506	-0.124	2.378	0.002	4.077 to 12.816
Return to Class					
Physical symptoms	5.061	0.016	2.585	0.052	-0.145 to
Return to Class					
Affective symptoms	9.063	-0.085	3.712	0.020	2.579 to 16.343
Return to Class					
Sleep symptoms	8.531	-0.036	2.655	0.004	3.200 to 13.774
Symptom Duration					
Cognitive symptoms	12.788	0.019	2.812	0.001	7.238 to 18.288
Symptom Duration					
Physical symptoms	12.226	-0.006	2.844	0.001	6.714 to 17.886
Symptom Duration					
Affective symptoms	14.071	-0.142	4.015	0.001	6.698 to 21.788
Symptom Duration					
Sleep symptoms	12.362	0.014	3.016	0.001	6.470 to 18.583

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VITA

Name	Jazmin N. Mogavero
Baccalaureate Degree	Bachelor of Science Boston College Chestnut Hill, MA Major: Psychology
Date Graduated	May, 2013
Other Degrees	Master of Arts St. John’s University Jamaica, NY Major: Clinical Psychology
Date Graduated	May, 2018