Examination of Subjective and Objective Cognitive Impairment Discrepancies in Sports-Related Concussion of Elite Athletes

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

School and Clinical Child Psychology

Department of Educational Psychology

University of Alberta

Abstract

Assessments of sports-related concussion (SRC) include tests of athletes' cognitive performance and self-reports of perceived cognitive impairment. Both anecdotal and empirical evidence have shown occurrences of discrepancies between athletes' subjective and objective indicators of cognitive impairment (SCI and OCI), which can pose challenges to clinical decisions of SRC diagnosis, management, treatment, and return-to-play (RTP) clearances. This dissertation is an examination of the relationship between SCI and OCI, an assessment of change in SCI and OCI scores between baseline and post-SRC assessments, and an examination of factors that may be associated with cognitive impairment discrepancies demonstrated in SRC assessments. Forty Canadian elite (i.e., collegiate and professional) football players concussed during the 2017 or 2018 seasons completed baseline and post-SRC assessments of cognitive functioning through objective testing (SAC and ImPACT) and subjective self-reports (S3SE), as well as a measure of psychological distress (BSI-18). Results from the study demonstrated overall high consistency between SCI and OCI; however, only post-injury S3SE endorsements of memory difficulties and/or confusion and ImPACT verbal memory scores were significantly related. From the cases of cognitive impairment discrepancies, higher post-injury psychological distress scores predicted SCI detection, whereas prior concussion history decreased the likelihood of SCI detection. Additionally, SCI, prior concussion history, psychological distress, and other personal factors did not predict OCI. Altogether, these findings suggest affective factors may play a more significant role to athletes' perceived postconcussive dysfunction than cognitive factors. This interpretation implies considerations of including more measures and targets of intervention focused on psychological distress to address and treat SRC outcomes.

Keywords: assessment, cognitive impairment, psychological distress, sports-related concussion, symptom perception and interpretation

Preface

This dissertation is an original work by Hanna Schultz. The data analyzed for this project, however, originate from an international research collaboration known as the Active Rehab study, led by Professor Johna Register-Mihalik of the University of North Carolina. Dr. Martin Mrazik was one of the Canadian-site investigators of the project at the University of Alberta. The Active Rehab study, to which this dissertation is ancillary, received ethics approval from the University of Alberta Ethics Board, Project Name "Role of Rehabilitation in Concussion Management: A Randomized, Controlled Trial", No. RES0036946, November 9, 2017.

Dedication

For athletes of all sports, genders, and ages, who have struggled or are currently struggling with concussive injuries and outcomes, I dedicate my dissertation to you.

"We can no longer ignore the stupidity of the hits that are still happening today despite the fact that the players know the concussion aspect is such a big part of the game and sports in general."

– former NHL player Jeremy Roenick

"When I first heard the term 'mental health,' the first thing that came to mind was mental toughness. Masking pain. Hiding it. Keeping it inside. That had been embedded in me since I was a kid. Never show weakness. Suck it up. Play through it. Live through it. Now, I realize that mental health means the total opposite."

– former NFL player Brandon Marshall

Acknowledgements

I am grateful for the opportunity to acknowledge the people who were integral to the development and completion of my dissertation and my doctoral degree. I attribute my personal and professional growth to all of you. First, I could not have achieved my accomplishments without my husband David. You encouraged me to pursue graduate studies when settling with my Master's degree and my job seemed appealing at the time. Thank you for going outside of our American comforts by moving to Edmonton and enjoying Canada's charm with me. Thank you for your constant support, encouragement, and humor, especially during times of adversity and setback.

My gratitude is also in order to my advisor Dr. Mrazik, for his ongoing feedback, support, and reminders that I am the expert of this "professional show-and-tell". You have not only been a major contribution to the development of this project, but also to my professional development through clinical experiences within the CFL and the NHL, and to feeling welcome to Edmonton through your and your family's kindness. I also wish to thank my supervisory committee members Dr. Gierl and Dr. Sevigny for their time, effort, and specialized professional guidance toward my research development and its execution. Dr. Truscott, Dr. Carbonaro, and Dr. Czarnota also have my thanks for providing valuable feedback and unique perspectives to my project and its importance in the field of clinical psychology. I also could not have completed this project without the approval of the Active Rehab research team; I am grateful for the opportunity to examine, analyze, and make sense of the data collected for the primary study.

I deeply thank my family and friends (both American and Canadian, both human and canine) for their steadfast support, critical love, and physical and virtual presence throughout this journey. I appreciate your listening of my ramblings, rants, and tangents over the years. Your creative ways of keeping me grounded, distracted, and/or motivated at the appropriate times have been so valuable.

Finally, I wish to acknowledge myself. I could not have done all of this without my determination, my passion for learning, or my willingness to be vulnerable and to take risks. I no longer know what a “comfort zone” is anymore, which I recall Dr. Pei saying in EDPY 641 this is a “healthy and humbling” sign of growth. I have learned to give myself more credit and to see myself as a true contributor to the field of clinical psychology. This dissertation is a major milestone to this self-reflection, and I could not be prouder of myself (as of yet).

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Chapter One: Introduction

Psychological assessments are a core component to the practice of psychology. Psychologists typically administer assessments as part of their clinical practice to determine the presence and/or degree of psychopathology. Psychological assessments are important for addressing specific referral objectives, such as exploring whether a child with a history of reading problems has a learning disability, when evaluating the cognitive competence of a senior for operating a vehicle, or assessing when someone who sustained a head injury can return to work or school (Neukreg & Fawcett, 2010; Sattler, 2008; Zillmer et al., 2008). Psychologists assess clients by using multiple methods and standardized psychological tools including observations, norm-referenced measures, interviews, and informal assessment procedures such as past tests and records (Sattler, 2008).

It is critical for psychologists to use a multimethod approach to assessment because it enhances their capacity to make accurate clinical judgements about diagnosis, treatment, and prevention. Although multimethod assessment is advantageous for comprehensive data collection and case conceptualization, it also creates challenges. For example, it is common for psychologists to receive clinical symptom self-reports that contradict from performance-based functioning (Merckelbach et al., 2019). This discrepancy can manifest as either symptom overestimations (i.e., when symptoms are endorsed while no signs are observed and dysfunction is not actually present) or symptom underestimations (i.e., when symptoms are not endorsed while signs are observed and/or dysfunction is actually present). Overestimations and underestimations of functioning through symptom report can make the tasks of assessment interpretation, case conceptualization, and treatment recommendation difficult for psychologists. There is a need to understand why these types of discrepancies between subjective and objective indicators of functioning occur, for it has implications for optimizing diagnoses, interventions, and treatments used in the field of psychology.

Indicators of Cognitive Impairment

Self-reported endorsements of cognitive dysfunction represent an indicator of subjective cognitive impairment (SCI), whereas cognitive performance scores below what is expected based on normative data and established clinical criteria represent an indicator of objective cognitive impairment (OCI). When someone presents with cognitive deficits, the expectation is that SCI will align with cognitive dysfunction. However, the literature currently shows mixed results about the association between SCI and OCI scores in assessment of concussions and other traumatic brain injuries (TBI; Clarke et al., 2012; French et al., 2014; Jamora et al., 2012; Stulemeijer et al., 2007). On one hand, in a sample of 61 outpatient participants who sustained a mild or moderate-to-severe TBI, Jamora et al. (2012) found significant predictive relationships between self-report questionnaire scores (i.e., the predictor) and neuropsychological scores (i.e., the outcome) on (a) attention and concentration difficulties for participants who had a mTBI, and (b) memory and learning difficulties for participants who had a moderate-to-severe TBI.

On the other hand, French and colleagues (2014) found that approximately 40% of their sample of United States military service members who sustained a TBI self-reported cognitive dysfunction in spite of neurocognitive test scores falling within normal limits. Self-reported cognitive complaints were significantly correlated with only 5 of the 17 measures that assessed neurocognitive functioning, with weak strength ($r = 0.19 – 0.27$). Most complaints of cognitive difficulties were significantly correlated with psychological distress and with larger effect sizes ($r = 0.50 – 0.58$). Byrne et al. (2017) published similar findings: In a sample of adults who sustained an acquired brain injury (ABI, specifically either a TBI, a cerebral vascular accident, an ABI due to infection, or an ABI due to a brain tumor), there was no statistically significant correlation between SCI and OCI. Yet, psychological affect indicators such as anxiety and depression were highly correlated with SCI (r = 0.51 – 0.82). Upon further analysis via a hierarchical regression, psychological affect was a predictor of SCI, but not of OCI. Altogether, these results support the idea that patients who over-report their symptoms relative to their cognitive performance may not necessarily be faking or malingering, as some experts and laypeople may come to conclude (Merckelbach et al., 2019). Rather, one's psychological wellbeing may influence their perceptions of cognitive dysfunction to be overestimated.

Sports-Related Concussion Assessments

Psychological assessments have been applied to a variety of contexts including sports-related concussion (SRC). In fact, standardized cognitive assessments of athletes is now core to medical clearance protocols for athletes who have sustained SRC. In this context, psychologists administer multiple concussion assessment methods to obtain meaningful information about the athlete, just as it is typically done with standard psychological assessments (Neukrug & Fawcett, 2010; Sattler, 2008). The Sideline Concussion Assessment Tool, 5th Edition (SCAT5), is one example of a well utilized clinical assessment. The SCAT5 includes measurement of behavior through an athlete's self-reported testimony to perceived concussion symptoms (i.e., subjective assessment) and an administration of standardized, neurocognitive performance tests based on norm-referenced data (i.e., objective assessment).

Mixed findings about the relationship between self-reported cognitive dysfunction and cognitive performance have also been found in concussed athletes. On one hand, in a study with 32 concussed collegiate athletes to determine the relationship between subjective symptom reports and objective clinical measures, Broglio and colleagues (2009) found endorsements of "difficulty concentrating" and "difficulty remembering" to be negatively correlated with verbal memory scores. They also found greater endorsements of "feeling mentally foggy" and "difficulty remembering" to be associated with slower reaction time scores. On the other hand, in a sample of over 600 adolescent competitive ice hockey players, researchers found significantly more self-reported concussion symptoms from players who sustained two or more concussions than players with one or zero, but they did not demonstrate significantly different scores in neurocognitive functioning (Brooks et al., 2013). In a different study examining multiple concussions in high school football players, Brooks et al. (2016) did not find significant differences between groups in objective cognitive performance based on concussion history; however, athletes with at least 3 previous SRCs self-reported significantly more concussion symptoms than did athletes with no or one prior SRC. Additionally, they found previous concussion history was significantly related to symptom reporting, but less so than other factors including endorsements of attention or learning problems, previous headache and migraine histories, and past treatment for psychiatric problems. Based on this evidence, SCI and OCI scores may or may not be consistent with each other when assessing cognitive impairment, and there are other factors to consider with respect to athletes' perceptions of their cognitive functioning.

The Problem

Self-reported symptoms and objective neurocognitive performance are important components for a comprehensive assessment of SRC with respect to detection, management, and recovery (McCrory. Meeuwisse, Dvořák, et al., 2017). Findings from examinations of lingering post-concussive effects from adolescent hockey players with prior concussions (Brooks et al., 2013) and of differences between symptom reporting and cognitive performance with the consideration of previous concussion history of adolescent football players (Brooks et al., 2016) exemplify the importance of understanding differences between previously concussed athletes' cognitive dysfunction based on both their perceptions and their cognitive performance. However, there is a need to examine these constructs in other sports contexts, such as for elite (i.e., professional and collegiate) athletes and across multiple concussion assessments. For example, to maximize playing time for their careers, some elite athletes may downplay, or "sandbag," their cognitive performance during baseline assessments to increase chances of being medically cleared after SRC because their results post-injury would not reflect significant decline when compared to an invalid "sandbagged" baseline assessment (Marvez, 2011; Reilly, 2011; Schatz & Glatts, 2013). Furthermore, athletes may over-report their concussion symptoms during baseline testing as an alternative to increase chances to obtain medical clearance and return-to-play (RTP) status upon comparison of baseline and post-injury self-reports of their concussion symptoms.

The issue of invalid (sandbagged) assessments aside, understanding why people may underestimate cognitive dysfunction (i.e., self-reports of normal cognitive functioning when objective tests show significant cognitive dysfunction) is of extreme importance when making clinical decisions. This is especially true for athletes. In a study assessing neurocognitive functioning of concussed collegiate athletes who reported to be asymptomatic, Broglio et al. (2007) found that 38% of athletes continued to show impaired neurocognitive performance despite self-reports of being asymptomatic. This study serves as a caution to not rely solely on self-reports when evaluating an athlete's ability to RTP. There are many possibilities that could contribute to these findings, such as athletes not reporting symptoms to expedite the process of obtaining RTP status (e.g., Kerr et al., 2016) or athletes experiencing symptoms while completing neurocognitive tasks to the point of detrimentally affecting performance (e.g., Covassin, Crutcher, & Wallace, 2013).

Researchers have recently examined and found predictors to subjective and cognitive functioning and discrepancies between them from concussed individuals (Hromas et al., 2020). To my knowledge, it is unclear as to whether or not any of these predictors apply to elite athletes or in the context of discrepancies in subjective and objective indicators of cognitive impairment rather than of cognitive functioning as a spectrum. These issues are potential barriers to accurate interpretation of assessment results for case conceptualization and decision-making for concussion management and RTP procedures for elite athletes. Suppose an athlete endorses significant cognitive problems while demonstrating adequate cognitive performance. Does the assessor reassure the athlete and approve medical clearance for the coach to put them back in play, or do they pause to further evaluate the athlete's endorsements? To what extent should each indicator of cognitive functioning contribute to conclusions about an athlete's ability to rejoin the active team roster, including when cognitive performance scores are within normal ranges? What other factors must be considered for such evaluations? Given the current cultural, social, and financial pressures in sports, especially of collegiate or professional status, questions like these pose concerns about the health and safety of athletes who are at high risk of SRC, and about the process medical examiners and athletic therapists follow to determine the best course of action for concussed athletes.

To my knowledge, there is currently no clear scientific literature with investigations on the association between self-reported cognitive appraisals and objective cognitive functioning of professional athletes who sustained an SRC, including when comparing baseline and post-injury assessments. It is important to examine this issue to understand facilitators of self-reported endorsements of cognitive dysfunction when cognitive performance scores through objective measures indicate otherwise. It may help further elucidate which factors to consider for diagnostic assessments of concussion, as there may be instances when athletes report experiencing no symptoms despite meeting criteria for a medical diagnosis. It can also affect how athletic therapists, clinicians, and other medical personnel interpret concussion assessment results (e.g., the consideration of malingering/sandbagging vs. psychological or demographic factors) and approach RTP decisions. Additionally, it may affect how athletes and medical personnel work through concussion management, recovery, and re-injury prevention in the context of preexisting mental health issues.

Research Purpose

It is important to investigate why these discrepancies in cognitive impairment may happen and what it can mean for interpretations of cognitive assessments in sport, concussion management, and RTP evaluations. To this end, I conducted a research study to (a) examine the relationship between SCI and OCI for collegiate and professional athletes, (b) assess for change in SCI reporting and OCI scores between baseline and post-injury assessments, and (c) examine factors that may be related to how these athletes report overestimations or underestimations of cognitive impairment prior to and since sustaining an SRC.

Organization of Dissertation

Following the introduction of this dissertation are four chapters and supplemental materials. Chapter two is a literature review on the nature of symptom perception and interpretation, theoretical models and frameworks to SRC symptom reporting, and potential factors that may correlate with SRC symptom reporting. The third chapter comprises the methods to the study, selected measures, study design, and procedures to participant sampling and data analysis. Participant characteristics, development of SCI and OCI indicators through analyses of outcome measures, and descriptive and inferential results to my research questions are included in chapter 4. The last chapter includes a discussion of the study, including the results and their clinical implications, strengths and limitations to the study as designed, and suggestions for future research.

Chapter Two: Literature Review

Definition of Sports-Related Concussion

When most people hear the word "concussion", they understand it to be a clinical condition associated with the brain. The simplicity of its understanding, however, ends there. Concussion as a clinical construct has been observed, termed, defined, and investigated by clinical experts for centuries (McCrory & Berkovic, 2001) and its conceptualization has been, and continues to be, a confusing and evolving process (McCrory, Feddermann-Demont, Dvořák , et al., 2017; Sharp & Jenkins, 2015). For example, there are numerous definitions of concussion across multiple fields of study (e.g., medicine, physiatry, public health, neuropsychology, etc.) and across individual authors, research groups, and accredited institutions (McCrory, Feddermann-Demont, Dvořák, et al., 2017). It is important to acknowledge and appreciate the complexities and ambiguities of concussion in historical and current contexts. However, the focus of this overview for my literature review is specified to the definition of sports-related concussion as it stands presently. The most recent publication of the Concussion in Sport Group's (CISG) consensus statement (McCrory, Meeuwisse, Dvořák, et al., 2017) defines sports-related concussion as the following (p.839):

> "…a traumatic brain injury induced by biomechanical forces. Several common features that may be utilized in clinically defining the nature of a concussive head injury include:
>
> - SRC may be caused either by a direct blow to the head, face, neck or elsewhere on the body within an impulsive force transmitted to the head.
> - SRC typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously. However, in some cases, signs and symptoms evolve over a number of minutes to hours.

- SRC may result in neuropathological changes, but the acute clinical signs and symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies.
- SRC results in a range of clinical signs and symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive features typically follows a sequential course. However, in some cases symptoms may be prolonged.
- The clinical signs and symptoms cannot be explained by drug, alcohol, or medication use, other injuries (such as cervical injured, peripheral vestibular dysfunction, etc.) or other comorbidities (e.g., psychological factors or coexisting medical conditions)."

Overview of Psychological Assessment Methods

Psychologists determine the presence and sequelae of SRC through both objective and subjective forms of assessment (McCrory, Meeuwisse, Dvořák, et al., 2017; Neukrug & Fawcett, 2010). Objective forms of assessment involve impartial interpretations of performance-based testing or observations to determine (a) how one's functioning compares to other members of a specified group of people (i.e., norm-referenced) and/or (b) whether or not the functioning of the measured construct in question meets clinical criteria of psychopathology (i.e., criterion-referenced; see Neukrug & Fawcett, 2010). Objective measurements are designed to minimize errors in measuring a specific construct through reliance on empirically established psychometric properties and standardized interpretations of scores and results. A disadvantage, however, is that objective forms of assessment, when utilized alone, cannot always account for individual characteristics or environmental contexts, which can lead to inaccurate case conceptualizations (APA Presidential Task Force, 2006; Neukrug & Fawcett, 2010).

In contrast, subjective forms of assessment such as interviews and self-reports through questionnaires or checklists involve individualized interpretations based on a client's self-disclosure. Although many questionnaires and checklists were developed through standardization procedures (e.g., the Patient Health Questionnaire-9, see Kroenke & Spitzer, 2002; the Symptom Checklist 90-Revised, see Derogatis, 1994), these tools are subjective in that clients are divulging information that is salient to them at the time of the assessment. Subjective methods are client-centered such that they allow psychologists to better understand their client's unique perspectives and personal narratives (Dozois et al., 2014; Riddle at al., 2002). Limitations to subjective forms of assessment include the possibility of dishonesty, bias, and possible misperceptions from clients and/or misinterpretations by assessors (Neukrug & Fawcett, 2010). Altogether, both objective and subjective methods of assessment are valuable and necessary to ensure psychologists obtain sufficient information to address referral aims and to make clinical judgements about diagnosis, management, and prevention.

As previously stated in the introduction, multimethod assessment can make the interpretation and integration of data for case conceptualization difficult when psychologists are presented with discrepant objective and subjective assessment results. There are various reasons overestimations and underestimations of functioning through symptom report may occur. For example, self-reported symptoms that contradict objective performance-based results are often found in psychological diagnoses including somatic symptom disorder, malingering, or a psychiatric disorder associated with low awareness of dysfunction (American Psychiatric Association, 2013; Merckelbach et al., 2019; Pinxteren, 2016). It is also possible for there to be no clinical or medical explanation to a client's distressing experiences (Chapman et al., 2018). In other cases, situational stress can lead to augmented symptom report. There may also be social, financial, or psychological barriers that preclude or inflate symptom disclosures, such as when athletes do not disclose concussion symptoms as they occur to maintain active roster status (Delaney et al., 2018; Kerr et al., 2016). In any case, discrepancies between objective and subjective indicators of functioning through assessment can make interpretation of the findings, report development, and clinical decisions and recommendations difficult. Thus, there is a need to understand occurrences and implications of impairment overestimations and underestimations through symptom reporting to move forward with clinical approaches to psychopathology.

Overview of Symptoms and Signs

A *symptom* is a clinical domain described as a physical or mental disturbance a person experiences that may indicate any pathology, including psychopathology. Symptoms can manifest in many ways that affect a person's mind and body. For example, symptoms of an SRC can be physical (e.g., headache, fatigue), psychological (e.g., anxiety, depression, emotional lability), and/or cognitive (e.g., brain fogginess, trouble remembering or concentrating; McCrory, Meeuwisse, Dvořák, et al., 2017). Symptom report is a subjective form of evidence in assessment of psychopathology because it represents significant, meaningful changes that someone experiences (Pennebaker, 2000; Teel et al., 1997). Clinical experts can translate symptoms into objective *signs* of psychopathology, or external projections of symptoms other people observe (King, 1982). Consider an athlete who endorses information processing and concentration difficulties after sustaining an SRC. If the athlete demonstrates delayed response time and high distractibility during their assessment, the assessor may note their observations of these symptom manifestations as signs of cognitive dysfunction. Like SRC symptoms, signs of

SRC per the most recently published CISG consensus statement (McCrory, Meeuwisse, Dvořák, et al., 2017) can be physical (e.g., loss of consciousness, unbalanced gait), psychological through projected emotions and behaviors (e.g., drastic shifts in mood, irritability), and/or cognitive (e.g., slower reaction time).

Symptom Perception and Interpretation

The presence of SRC signs does not necessarily imply the athlete interprets these issues as SRC symptoms. Symptom reports can be viable evidence upon confirmation or ruling-out of clinical signs of SRC or of any psychopathology based on typical findings from clinical populations. Although this interpersonal perspective of symptoms as manifestations of clinical psychopathology is necessary, it is also essential to know how people come to perceive, interpret, and experience symptoms through an intrapersonal lens. In other words, researchers and clinical experts need to recognize how individuals internally process the symptoms they experience and, in turn, disclose them as such. This is because people's sensations, perceptions, and cognitions associated with stimuli combine to set the context as to how they will respond (Teel et al., 1997). This section includes consideration of physical, psychological, and cognitive symptoms upon examining symptom perception and interpretation.

Historical Foundations

Researchers have come a long way in understanding the relationship between perceptual information and one's awareness and interpretation of bodily experiences, including symptoms. In the late 19th century, Gustav Fechner coined *psychophysics*, or the study of the relationship between physical stimuli and one's psychological reactions to them (Foley & Matlin, 2010). The main idea of psychophysics is that the detection of one's subjective experience of a stimulus (e.g., sound, light, touch, etc.) can be calculated, as long as any extraneous situational cues are controlled (Pennebaker, 1994; 2000). Researchers continue to use psychophysical techniques to understand perceptual information affecting one's symptomatic experiences, such as the examination of cognitive performance from college students and athletes with or without a history of concussion (Arciniega et al., 2019; Patoilo et al., 2018). In fact, one of the most common computerized tests of neurocognitive functioning, the Immediate Post-Concussion Assessment and Cognitive Tests (ImPACT; Lovell, 2016), applies psychophysical principles. This controlled approach to symptom detection and perception can be advantageous because it minimizes error by focusing on one source and testing for significant change. However, removing seemingly extraneous contexts apart from the precept source may remove additional salient contributions to the individual's processing toward identifying the precept as a symptom.

A century later, psychologist J. J. Gibson (1966, 1979; cited in Pennebaker, 1994; 2000) challenged the relative simplicity of psychophysics by proposing a more ecological approach to perception. Specifically, he posited that one's perception and interpretation of a physical stimulus are not just from one source, but from multiple sources in the environment. Additionally, he suggested that perception does not involve the person passively receiving perceptual information before interpreting and responding to it. Rather, the person is an active participant who interacts with the environment and other situational cues as part of the perception and interpretation processes. For example, consider an athlete who experiences a headache while jogging. According to Gibson's logic, they are not going to just interpret the aerobic activity as the only source. Instead, they are going to consider other conditions that make up their current situation or environment at the onset of the headache. Such conditions may include time of day, the amount of sleep they had the previous night, their nutritional or fluid intake for the day, or the fit or pressure of their jogging headband.

Gibson's work was a pivotal contribution to understanding sensation and perception. His input led to the development of multiple theoretical models and frameworks that account for multiple sources to further understand the processes involved in symptom detection and recognition. A detailed discussion about all of these models and frameworks would go beyond the scope of this literature review. However, I will focus on relevant research that elucidates symptom interpretation and perception in the context of SRC symptoms.

Relevant Theoretical Models and Frameworks

Researchers conceptualized a Symptom Interpretation Model (SIM; see Teel et al., 1997) to represent symptom perception and interpretation processes. The model includes three components: input, interpretation, and outcome. The *input* involves the detection and recognition of an atypical physical or mental disturbance caused by one's internal and/or external environment. *Interpretation* occurs when the person identifies and appraises the disturbance (i.e., the symptom) by activating stored information and knowledge about the symptom. Finally, the *outcome* component involves decision-making as to what to do about the symptom, whether it is to seek help, to manage the symptom independently, or to do nothing (Teel et al., 1997). The simplicity of the SIM is a strength such that it can help team medical staff, coaches, and parents understand how athletes perceive and interpret their symptoms in relation to their endorsements or lack thereof. For instance, consider a headache, which is a common SRC symptom for youth and adult athletes (Gioia et al., 2012; Guay et al., 2016; McCrory, Meeuwisse, Dvořák, et al., 2017). An athlete who sustained a head collision may detect pain caused by increased pressure in the head, loud game noises, and dehydration (i.e., input). They appraise their experiences as a concussion-related headache based on what they learned from their coach about concussions (i.e., interpretation). Through this recalled information, and through their appraisal of the headache as being severe, they decide to tell the coach (i.e., outcome).

The SIM is a simplified framework that Teel and colleagues (1997) proposed based on original theory, as well as revised and synthesized models, of symptom perception and interpretation. Two of these preceding models are Pennebaker's "competition-of-cues" model (Pennebaker, 1982) and Cioffi's "cognitive-perceptual" model (CPM; Cioffi, 1991). Commonalities between these models include the importance of cognitive meaning to both internal and external aspects of their situation beyond physiological changes, and the recursive and dynamic nature of these processes depending on situational changes. Pennebaker's competition-of-cues model is based on attentional focus; he proposed that symptom perception depends on the strength in salience between internal sensory cues and external environmental cues (Pennebaker, 1982). Specifically, people should perceive and report more symptoms when they are more aware of, and more focused on, their mental and physical state, which would occur when there are fewer external cues to occupy their attention (e.g., a boring, unstimulating environment). The CPM focuses on social psychological factors as to how people cognitively interpret their symptoms. According to Cioffi (1991), symptom perception and interpretation are not just based on somatic sensations. They are also based on the perceiver's internal representations of the symptom such as the beliefs, assumptions, and attributions they developed through their experiences and social interactions.

Pennebaker and Cioffi understood that somatic stimuli are minor contributions to symptom perception and interpretation, and there are environmental factors as well as other biological, psychological, and cognitive functions influencing these processes. Their models, however, are still limited such that they do not account for preexisting conditions. Kolk and colleagues (2003) acknowledged this limitation and developed an integrated model of symptom perception and interpretation (see Figure 1). This model divides the processes into information input, attention, detection, attribution, and experience. Normal body fluctuations, preexisting pathological or psychopathological conditions, emotions, and the environment can contribute to somatic information. The somatic information translates to somatic sensations; the degree of detection depends on one's level of trait negative affectivity (NA), attentional focus, and external life demands. As one detects somatic sensations, they attribute them to physical or psychological mechanisms, resulting in interpretations of physical or psychological symptoms.

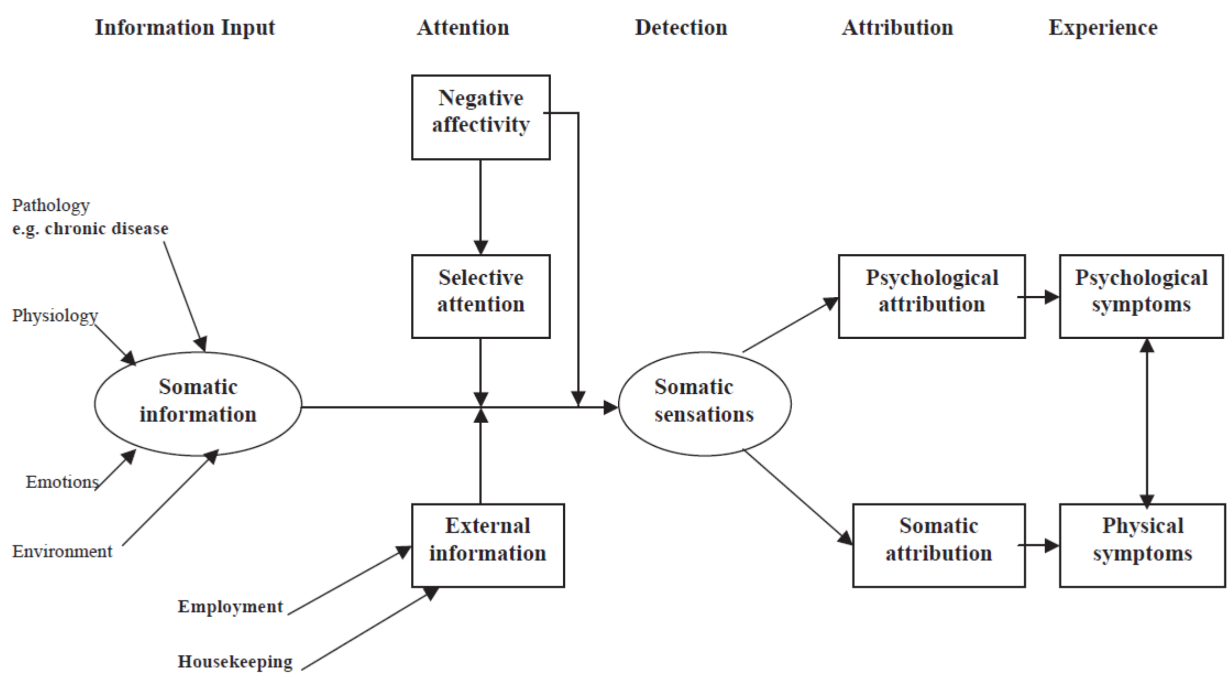

Figure 1. Simplified version of the integrated cognitive-perceptual model for symptom perception and interpretation. Please note the authors of this model do not assume complete linearity to this process, as depicted here. Created by Kolk et al. (2003, p. 2344).

Application of Frameworks and Models to Sports-Related Concussion

SRC as a type of traumatic brain injury (TBI) induced by direct or indirect biomechanical forces that cause the brain to hit the skull. Although neuropathological changes to the brain may occur from the impact to the skull, the clinical presentation of SRC is more of a functional disturbance than a structural injury, which is why neuroimaging may not necessarily show brain abnormalities (Giza & Hovda, 2001; 2014; Giza & Kutcher, 2014; McCrory, Meeuwisse, Dvořák, et al., 2017). The concussive impact to the brain causes neurometabolic reactions to occur, including altered cerebral blood flow (CBF), glucose metabolic changes, and temporary neural activity impairment that lasts about a day (Churchill et al., 2017; Giza & Hovda, 2001; 2014). Then, metabolic rest (i.e., an impaired state of brain metabolism) occurs a few days after the impact to initiate brain recovery (Giza & Hovda, 2014). These neurometabolic mechanisms are believed to be the cause of many signs and symptoms of SRC. Additionally, researchers believe physical and cognitive demands during this metabolic resting period may exacerabate these symptoms (Giza & Hovda, 2014), which is likely why most concussion laws and guidelines call for removing athletes from the game if SRC is suspected (Davies et al., 2018; Glang, 2018; McCrory, Meeuwisse, Dvořák, et al., 2017).

Somatic Symptoms. Based on the integrated symptom perception and interpretation model (Kolk et al., 2003), the neurometabolic changes that occur after the concussive impact are antecedents to the somatic information an athlete would detect post-injury. Past concussions or multiple concussions as a preexisting pathological condition may also be contributing antecedents, as they are associated with increased symptom endorsements from adolescent and young adult athletes, even during preseason assessments (Brooks et al., 2016; Gardner et al., 2020). The environment also plays a major role, especially if the athlete is still in the stimulating game environment where there is likely excessive noise, light, and movement that the brain is trying to process (Guay et al., 2016). Additionally, emotions are greatly affected by SRC, as they can trigger emotional lability, irritability, and feelings of sadness and anger (McCrory, Meeuwisse, Dvořák, et al., 2017). Other demographic factors to consider include age and sex; research has shown that younger and female athletes tend to report greater amount of and more severe symptoms than older and male athletes (Covassin et al., 2012).

The contribution of selective attention appears to contradict with part of the competition-of-cues model. Athletes are likely going to detect somatic sensations of SRC when they are in a stimulating environment (e.g., while attending school or during sports practice), which is opposite of Pennebaker's claim. According to Giza and Hovda (2001; 2014), excessive physical and/or cognitive demand post-injury before the brain has fully recovered can make symptoms worse, meaning the athlete will attend more to these internal sensory cues as they participate in physical or cognitive activity. However, this may not necessarily be the case after the metabolic resting period ends and the athlete is asymptomatic for a period of time. Attributing their sensations to the head injury would most likely be time-sensitive to the impact because (a) SRC symptoms typically resolve within 7 to 10 days post-injury (McCrea et al., 2012), and (b) many of these symptoms are common experiences that have multiple or ambiguous causal sources (Chrisman et al., 2013; McCrory, Meeuwisse, Dvořák, et al., 2017). For example, headaches can occur for many reasons apart from SRC including dehydration, medication side-effects, and viral infections (Mayo Clinic, 2018). It is important to note, however, that not all SRC symptoms resolve within 10 days; research has shown that about 10% to 17% of adolescent and adult athletes continue to experience symptoms after 10 days (Makdissi et al., 2013). Thus, it is important to educate coaches and athletes about the possibilty of prolonged SRC symptom recovery so that athletes do not rule out their symptoms to be residual to the injury even after 10 days.

Cognitive Symptoms. The integrated symptom perception model (Kolk et al., 2003) works well for identifying and interpreting physical and psychosocial symptoms of SRC. However, the researchers did not elaborate upon cognitive dysfunction, which is a specific area of psychological functioning. The simplified version of the model (see Figure 1) does not fully apply to perception and interpretation of cognitive symptoms because cognitive issues are not necessarily detected by somatic sensations. Rather, people typically become aware of cognitive problems when they realize they are unsuccessful in their conscious efforts to remember, concentrate on, or pay attention to information (i.e., a different type of input issue). This realization is upon reflection of one's own thinking and processing abilities, known as metacognition (Robinson-Riegler & Robinson-Riegler, 2016). Therefore, cognitive symptom perception and interpretation through cognitive-perceptual processes need to be conceptualized differently from somatic symptoms.

The types of antecedents to cognitive symptom perception and interpretation are similar to those associated with somatic symptoms. However, the actual effects and implications of some of these antecedents, including physiology and age in the context of brain development, are different. The most common cognitive symptoms of SRC include mental fogginess, confusion, and memory and/or concentration difficulties (McCrory, Meeuwisse, Dvořák, et al., 2017). Cognitive processes such as attention, memory, and decision-making activate from multiple cortical and subcortical regions, including the prefrontal cortex, hippocampus, insula, caudate nucleus, and anterior cingulate cortex (Churchill et al., 2017; Freberg, 2009; Zillmer et al., 2008). Reports of greater and prolonged cognitive symptoms from concussed collegiate athletes correlated with brain neuroimages of reduced cerebral blood flow (CBF) to the prefrontal regions (Churchill et al., 2017; Maugans et al., 2012), which is opposite of what they found for concussed athletes who reported greater somatic concussion symptoms (i.e., increased CBF; see Churchill et al., 2017). This difference in physiological effects between somatic and cognitive symptoms may be related to differences in detecting them (i.e., sensations in the body vs. cognitive awareness from the brain). However, more research to examine subgroup differences (e.g., age, symptom type) in physiological changes after an SRC is needed. Nevertheless, it is clear that, although the effects are different and they do not necessarily trigger detectable somatic information that would evoke bodily sensations, physiological processes are antecedents to the perception of cognitive symptoms of SRC. The athlete's age also plays a significant role in the severity and duration of cognitive symptoms. The brain regions important for cognitive functioning (e.g., areas in the frontal lobe) continue to develop later into adulthood (Diamond, 2002; Freberg, 2009), meaning youth athletes are more vulnerable to SRC effects compared to adult athletes. Physiological disturbances in these areas of the brain appear to affect adolescent and adult athletes differently in terms of cognitive symptom duration (i.e., 15 days for adolescents vs. 6 days for young adults), but not necessarily in cognitive functioning recovery rates (Williams et al., 2015).

The attentional process involved in symptom detection, perception, and interpretation is also different for cognitive symptoms. It would be most appropriate to consider that selective attention would be toward both metacognitive information and external information for athletes to detect cognitive problems post-SRC. In this case, the external information would be their ability to interact with their surroundings to which they strive to accomplish cognition-based goals such as memory recall, information processing, and sustained or divided attention (Guay et al., 2016; Robinson-Riegler & Robinson-Riegler, 2016). The athlete would then appraise the cognitive disturbances and potentially interpret them to be cognitive symptoms. This conceptualization works based on the assumption that athletes are aware of their cognitive deficits. It is possible an athlete's ongoing cognitive deficits are beyond their detection when they become asymptomatic (Broglio et al., 2007; McClincy et al., 2006). It is important to also consider evidence of poor self-awareness of cognitive deficits as a common outcome of TBI (Robertson & Schmitter-Edgecombe, 2015; Sherer et al., 2003). However, the literature currently reflects this phenomenon to be evident in moderate and severe TBI as opposed to concussions (Azouvi et al., 2017).

In summary, researchers have found that symptom perception and interpretation involve more than just the physical stimulus people subjectively experience. Several models and frameworks have been proposed to include social-psychological, cognitive, and demographic variables as factors that contribute to the mechanisms of symptom detection, perception, and experience. The processing of SRC symptoms can apply to the integrated model (Kolk et al., 2003) with the understanding that the process is different between somatic-based (i.e., physical, psychosocial, emotional) symptoms and cognition-based symptoms.

Sports-Related Concussion Symptom Reporting

The models of symptom perception and interpretation imply that people will report their symptoms and seek help if they interpret their symptoms to be severe enough to require clinical attention. This response should apply to athletes who sustained an SRC, but the current literature suggests it is not that simple. Researchers have consistently found that fewer than half of all events of suspected SRC are reported by high school and collegiate athletes (McCrea et al., 2004; Register-Mihalik et al., 2013). Furthermore, of the 23% of professional Canadian football players who believed to have sustained an SRC during the 2017 season, 82% of these athletes did not report it or seek medical attention at the time (Delaney et al., 2018). Such a problem has become a catalyst for researchers to find out what influences athletes to not disclose events of SRC and their symptoms.

To direct their investigations of understanding these alarming circumstances, researchers turned toward theoretical frameworks of health behaviors. Some of these frameworks that could apply to concussion reporting include Social Cognitive Theory (Bandura, 2001), the Health Belief Model (Rosenstock, 1974), and the Health Action Process Approach (Schwarzer & Luszczynska, 2008). However, to date, the most frequently applied and accepted framework to examine concussion symptom reporting is the Theory of Planned Behavior (TPB; Ajzen, 1991; Kroshus et al., 2014). Ajzen (1991) theorized that behavior is not a product of personality traits or fixed dispositional characteristics. Rather, behavioral intention, or the cognitive representation of deciding to perform a behavior, is the best measurable predictor of behavior (see Figure 2). The summation of attitudes toward the behavior, subjective norms, and one's perceived behavioral controllability equate to behavioral intention (Ajzen, 1991). TPB also posits that both actual and perceived behavioral control also impact behavior because these factors account for the degree to which one believes they can (and actually can) control the situation through their behavior regardless of personal attitudes and subjective norms.

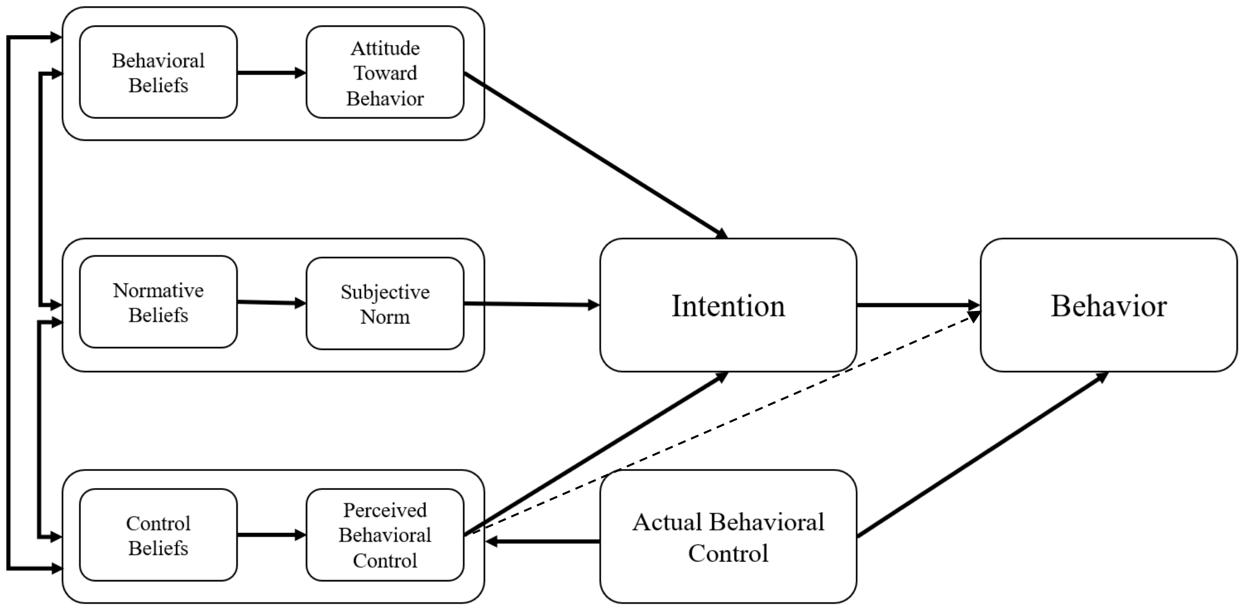

Figure 2. Initial model of the Theory of Planned Behavior. Adapted from Ajzen (1991, p. 182).

Based on recent research, TPB is a valuable framework to implement in predicting and understanding SRC reporting behaviors. Through structural equation modeling analyses, Kroshus and colleagues (2014) found the TPB model fit the data well for concussion reporting behaviors. Other researchers published similarly fruitful findings of connections between TPB constructs and behavioral intentions and responses of concussion reporting through other analytical means including thematic analysis (Chrisman et al., 2013; Kneavel et al., 2019), descriptive analyses from surveys (Delaney et al., 2015; 2018; McCrea et al., 2004), and linear regression modeling (Baugh et al., 2014; Register-Mihalik et al., 2013). Athletes have stated or endorsed several personal attitudes that have affected their decisions to report SRC symptoms. Such attitudes include the fear of losing current or future standings as an athlete or teammate, the belief that their symptoms were not serious enough to report, and internalization of what they learned from concussion education (Chrisman et al., 2013; Delaney et al., 2015; 2018; McCrea et al., 2004; Register-Mihalik et al., 2013). Subjective norms that are associated with SRC reporting include pressure to continue playing from coaches, teammates, parents, and fans, negative feedback from coaches, teammates and teachers, and perceived positive support from coaches (Baugh et al., 2014; Chrisman et al., 2013; Kneavel et al., 2019; Kroshus et al., 2015). Regarding perceived and actual behavioral control, the availability and accessibility of medical staff, athletic trainers, and coaches to report SRC symptoms are important factors for some athletes, as well as financial constraints (Delaney et al., 2015; 2018).

Although TPB as a theoretical framework fits well with SRC symptom reporting behaviors in intrapersonal and interpersonal contexts, researchers have acknowledged the model alone is insufficient to explain concussion reporting behaviors because the model is limited as constructed (Kroshus et al., 2014; Register-Mihalik et al., 2013). Apart from subjective norms and actual behavioral control, the model does not account for external factors beyond the individual that can affect SRC reporting behaviors. For example, factors related to policy such as regional legislation and training/education mandates across sports organizations may be related to SRC reporting behaviors, especially if these policies result in negative consequences for the athlete or the team (LaRoche et al., 2016; McCrory et al., 2017; Register-Mihalik et al., 2017). Other environmental factors such as sport culture and media influences can play significant roles in SRC reporting for athletes (Chrisman et al., 2013; Kerr et al. 2014; Register-Mihalik et al., 2017). Another issue to consider with regards to the TPB model for SRC symptom reporting is not a limitation to the model per se, but it is important to note nevertheless. Specifically, the current research reflects partiality to using the TPB model in order to understand SRC symptom reporting behaviors in the context of underreporting and nondisclosure. Relative to the former, the literature on SRC symptom over-reporting as a health behavior is limited, which is likely due to current conceptualizations of health behavior through intentional means rather than through natural occurrence. Of the existing literature, there are many ambiguities about factors associated with over-reporting SRC symptoms. Thus, it is crucial to examine what is currently known about what can be related to symptom self-reports, including both underestimations and overestimations of dysfunction, to inform and guide researchers toward needed research pursuits.

Occurrences of Inaccurate Symptom Self-Reports

Under what circumstances do athletes self-report symptoms of SRC that do not align with their cognitive performance? Many people, including clinical experts, would often interpret symptom over-reporting as malingering for personal gain (Martin et al., 2015), but it is neither simple nor accurate to assume athletes fabricate SRC symptoms intentionally. Equally assuming that athletes underreport or do not disclose SRC symptoms only to maintain active roster status is also inaccurate. Merckelbach and colleagues (2019) show there are multiple external and internal factors that can affect symptom over-reporting. In this section of the review, I describe and evaluate social, psychological, cognitive, assessment-based, and personal factors of inaccurate SRC symptom reporting. I describe each factor separately between underreporting or over-reporting symptoms, but these factors should not be interpreted as only affecting one type of reporting and not the other. Rather, there should be consideration of some of these factors possibly contributing to both symptom underreporting and over-reporting.

Factors of Underreporting Sports-Related Concussion Symptoms

Stigma of Concussion. Negative societal attitudes and beliefs about psychopathology may compel athletes to underreport SRC symptoms. Mental health stigma is a serious ongoing issue that precludes individuals from seeking appropriate help (Clement et al., 2015), and it is evident in sports culture regarding concussions as well (Cranmer & LaBelle, 2018; Sanderson et al., 2017). Even when athletes want to seek medical support post-injury, they may hesitate and/or refrain from disclosing their symptoms to avoid mental health stigma from their coaches, parents, teammates, and fans. They do not want to be seen as “weak” as athletes are perceived to be if they do not continue to play (Chrisman et al., 2013; Kroshus et al., 2015; Sanderson et al., 2017). This possibility aligns with the TPB framework such that stigma would represent a subjective norm that influences the intention of reporting symptoms (Ajzen, 1991; Kroshus et al., 2014). Stigma can also contribute to one’s personal attitudes about a concussion diagnosis, further strengthening the act of symptom underreporting or nondisclosure. For example, stronger negative attitudes about mental illness (i.e., perceived differentness and perceived inability to treat) was associated with underestimations of concentration problems relative to their actual performance as a way to avoid the label of being “mentally ill” (Hahm et al., 2019). The current stigma around concussions is a serious factor to consider regarding an athlete’s underestimations of physical, psychological, and cognitive dysfunction after sustaining an SRC.

Method of Symptom Reporting. The amount of symptom information athletes accurately disclose may also depend on the method in which they report concussion symptoms. For example, when comparing open-ended interviews to self-report questionnaires as methods of SRC reporting from Canadian college football and hockey players, researchers found that athletes randomly assigned to the self-administration condition had significantly greater SRC symptom total and symptom severity scores than athletes in the open-ended interview condition (Krol et al., 2011). Similar findings were found upon assessment of adolescent athletes. Specifically, when comparing four different approaches to administering the Post-Concussion Symptom Scale (PCSS), athletes had significantly lower SRC symptom total and symptom severity scores through an open-ended interview version than through a computer-based version, a clinician-guided version, or a parent-informed version (Elbin et al., 2016). It is important to note this study had a fixed order for how athletes completed each of the approaches to SRC reporting, which means the researchers could not account for differences in method order as a potential factor to varied symptom reporting. Nevertheless, the findings still enlighten clinicians about the nature and extent of SRC symptom disclosures across different reporting methods. The association between assessment method and SRC symptom reporting may be dependent on other factors. For example, a recent study showed support of greater SRC symptom reporting from collegiate athletes by computer-based self-report than by interview, but only for male athletes (Kissinger-Knox et al., 2019). Altogether, the literature alludes to the possibility of athletes unintentionally underreporting or not disclosing SRC symptoms if they are asked to spontaneously report them. Likewise, it is also possible for athletes to over-report symptoms when asked to endorse SRC symptoms and their severity through a self-administered questionnaire or checklist, especially if the listed symptoms can be attributed to other conditions (Iverson & Lange, 2003; Merckelbach et al., 2019; McCrory, Meeuwisse, Dvořák, et al., 2017).

Factors of Over-Reporting Sports-Related Concussion Symptoms

Psychological Conditions. An athlete's history of psychological conditions (e.g., psychiatric, neurodevelopmental, etc.) may report elevated levels of SRC symptoms relative to their actual functioning. Athletes, especially adolescents and young adults, are susceptible to psychiatric or mental health issues such as anxiety and depression (Reardon, 2017). Manifestations of psychiatric conditions are common following SRC, and preinjury psychiatric problems may be comorbid or premorbid to SRC outcomes (Guay et al., 2016; McCrory, Meeuwisse, Dvořák, et al., 2017). Several studies show that history of psychiatric conditions, particularly anxiety, depression, and distress, is a strong predictor of greater concussion symptom endorsements from injured and non-injured adolescents and adults, including athletes (Brooks et al., 2016; Cottle et al., 2017; Edmed & Sullivan, 2012; French et al., 2014; Hromas et al., 2020; Iverson et al., 2015; Lange et al., 2011). In a correlational study assessing post-concussion syndrome (PCS) symptom reporting from adults with mild TBI compared to matched controls, significantly higher symptom endorsement amount and severity totals across all areas (i.e., psychological, physical, and cognitive) were reported by participants who met diagnostic criteria for depression than from participants who did not, regardless of whether or not they sustained a mild TBI (Lange et al., 2011). High endorsements of depressive symptoms and stress were also predictive of higher concussion symptom scores for university students with no history of concussion (Edmed & Sullivan, 2012). These findings suggest athletes with past and/or current psychiatric conditions will likely report greater and more severe symptoms of SRC that are not necessarily attributed to the concussive impact from the injury, especially if no neurocognitive or psychological impairments are evident through objective testing. This occurrence is likely due to the fact that many symptoms of SRC overlap with symptoms of psychiatric conditions (Edmed & Sullivan, 2012; Iverson, 2006; McCrory, Meeuwisse, Dvořák, et al., 2017).

History of attention-deficit hyperactivity disorder (ADHD) also appears to be associated with concussion symptom reporting (Brooks et al., 2016; Cottle et al., 2017; Nelson et al., 2016). Brooks and colleagues (2016) found that a diagnosis of ADHD from adolescent football players was a stronger predictor of higher SRC symptom reporting than multiple past concussions. Another study revealed that high school and collegiate athletes with ADHD reported more SRC symptoms at baseline assessments than athletes who did not have ADHD, and even more so if they had multiple concussions in the past (Nelson et al., 2016). Similar to psychiatric problems, symptoms of ADHD such as difficulty concentrating align with SRC symptoms, which could contribute to possible overestimations of neurocognitive dysfunction at post-concussion. Another possibility to consider with this group of athletes is inattentive responding (Merckelbach et al., 2019). Adolescents and adults diagnosed with ADHD may have difficulty maintaining their attention to completing symptom checklists or questionnaires (APA, 2013; Zillmer et al., 2008), leading to inaccurate symptom endorsements.

Previous Concussion History. It is reasonable to consider the possibility of a history of past concussions affecting symptom endorsements. Athletes who have sustained head injuries and experienced SRC symptoms in the past may be more aware of, and sensitive to, these symptoms as they occur. The evidence shows that previous concussion history impacts some aspects of neurocognitive functioning (Guskiewicz et al., 2005; Patoilo et al., 2018), but at different assessment timepoints. For example, Covassin, Moran, and Wilhelm (2013) found that high school and college athletes who sustained at least three previous concussions demonstrated prolonged impairment at 8 days post-injury than concussed athletes with no previous concussion history. Yet, multiple past concussions do not appear to be associated with baseline neurocognitive functioning (Broglio et al., 2006; Brooks et al., 2013; 2016). Interestingly, the evidence shows that previous concussion history impacts symptom reporting consistently across assessments. Specifically, athletes who had multiple previous SRCs reported significantly more symptoms at post-injury and during preseason baseline testing than players with no or one past SRC (Brooks et al., 2013; 2016; Covassin, Moran, & Wilhelm, 2013; Register-Mihalik et al., 2009). Altogether, athletes who had multiple past SRCs may report experiencing cognitive deficits when assessed at any time throughout the season, even if results from objective measures of neurocognitive functioning are within normal ranges.

Personality Characteristics. Personality or trait-based characteristics can affect people's perceptions, interpretations, and behavioral responses to physical and mental disturbances. Trait-based negative affectivity (NA; also known as Neuroticism), has been most commonly assessed regarding symptom reporting. High NA levels can predispose people to report more symptoms than low NA levels, regardless of whether or not signs are present (e.g., Costa & McCrae, 1987; Deary et al., 1997; Watson & Pennebaker, 1989). Other personality domains such as Agreeableness, Conscientiousness, and Extraversion were also associated with reported complaints of both physical and psychological symptoms (Vassend & Skrondal, 1999), but the effect sizes were much weaker (β's ranging from -0.06 to 0.06) compared to NA ($\beta = 0.36$).

Evidence of the extent to which personality variables correlate with SRC symptom reporting from athletes who sustained a concussion is currently limited and unclear. For example, Merritt et al. (2015) found that higher levels of NA were associated with increased SRC symptom reports at baseline testing for collegiate athletes, even after controlling for previous concussion history. This finding implies that athletes with high NA may over-report SRC symptoms, even if they never had a head injury. Other researchers have published similar findings from healthy populations; they have expressed caution in interpreting SRC symptom reporting due to this issue because SRC symptoms are not specific to SRC (Iverson & Lange, 2003; Wang et al., 2006). More research in this area is needed to make definitive conclusions. However, it appears that personality variables, especially high NA levels, may affect how athletes report SRC symptoms post-injury such that researchers should further investigate this possibility.

Symptom Deception. Some clients intentionally attempt to deceive psychologists by portraying dysfunction for their benefit, known as malingering (APA, 2013). Most athletes want to continue playing after sustaining a head injury (Chrisman et al., 2013; Kneavel et al., 2019) and they do not want to demonstrate significant dysfunction with the risk of play removal. To navigate around this issue, athletes may downplay neurocognitive functioning during baseline testing so that post-injury assessments would be comparable to their pre-injury results. This technique is known in sports culture as "sandbagging," and it is a well-known practice for professional athletes (Marvez, 2011; Reilly, 2011). Many non-professional athletes have reported sandbagging in the past as well, but recent research suggests it is now not as common as initially reported (Schatz et al., 2017). Clinical experts are more aware of sandbagging and are now skilled at detecting sandbagging through the ImPACT's validity scale scores (Erdal, 2012; Schatz & Glatts, 2013). With greater risk of sandbagging detection through objective measures in mind, athletes may resort to over-reporting SRC symptoms at baseline as a different avenue to receive medical clearance after a head injury faster. At this time, there is currently no clear scientific literature with investigations of intentional assessment deception through self-reported symptom appraisals of SRC. Future research in this area is critical to determine the possibility of symptom over-reporting as a deliberate practice for the athlete's benefit.

Summary of Review

Psychologists frequently have the arduous task of interpreting contradictory results between client disclosures and performance-based measures. The same is true for clinicians who assess athletes who sustained injuries that are suspected to be concussive. The current literature provides an understanding of the processes involved in detecting physical, psychological, and cognitive disturbances, as well as in perceiving and interpreting these disturbances as symptoms associated with SRC. Researchers have also investigated health behavior frameworks to better understand athletes' intentions of symptom reporting, but primarily in the context of underreporting or nondisclosures. Based on the current evidence, there are various factors that may influence athletes to not only underreport cognitive SRC symptoms, but also to over-report them. Both impairment underestimations and overestimations relative to cognitive performance based on symptom reporting leave clinicians, athletic trainers, and coaches in a difficult situation as to deciding the best course of action for athletes. Thus, a research focus on the examination of predictors to discrepancies between symptom reports and actual cognitive performance is needed to better inform clinical experts on how to progress with SRC diagnosis, management, treatment and recovery plans, and prognosis toward obtaining return-to-play status.

One study by Hromas and colleagues (2020) examined the relationship between subjective concussion symptoms and objective cognitive testing, and potential factors that predict discrepancies between them, of patients who presented with concussion at an interdisciplinary concussion clinic. Their findings revealed that patients with lower endorsements of concussion symptoms had better cognitive performance scores. Additionally, increased affective distress (i.e., anxiety and depression), increased sleep disturbance, and shorter time since injury were predictors of increased endorsements of concussion symptoms *and* of greater overestimations of cognitive dysfunction in relation to their cognitive performance scores. This study is a great start to understanding the relationship between subjective and objective indicators of cognitive functioning post-concussion, and to understanding predictors of discrepancies between these indicators. However, the project (Hromas et al., 2020) tells a different story from my research inquiries in three ways. First, the sample included patients with multiple mechanisms of injury including SRC, falls, vehicular accidents, and hits/strikes by an object. The additional mechanisms confound my ability to conclude these findings are applicable exclusively to athletes, especially to elite athletes. Second, the researchers' operationalizations of cognitive functioning indicators and their discrepancies do not necessarily reflect cognitive impairment as determined by norm- and criterion-referenced clinical thresholds, which means whether or not impairment was present in one, both, or none of the indicators was unknown. Third, I am also interested in the examination of these relationships and potential predictors of SRC symptom reporting outcomes and discrepancies to objective cognitive performance prior to their concussive injury.

Study Hypotheses

Between my introduction to the present study and my review of the existing literature to better understand the present knowledge about SRC symptom reporting and its discrepancies to objective functioning in the context of cognitive impairment, I identified the following hypotheses to my research questions:

1. Are elite football athletes' appraisals of their cognitive concussion symptoms (i.e., degree of SCI) correlated with their actual cognitive performance (i.e., degree of OCI) at baseline and/or within 48 hours post-injury?

   Hypothesis: Because discrepancies exist between athletes' endorsements of concussion symptoms and their cognitive functioning scores through objective testing, these indicators will not be correlated at baseline or within 48 hours of sustaining an SRC.

2. Are there significant differences in (a) the presence of SCI, (b) the presence of OCI, and/or (c) the frequency of cognitive impairment discrepancies between pre- and post-concussion assessments?

   Hypothesis: Based on preseason medical day procedures to ensure athletes are cleared to play at the start of the season, there will be significantly higher frequencies of SCI, OCI, and cognitive impairment discrepancies at post-injury compared to baseline.

3. Are there demographic, medical, and/or psychological factors that predict SCI/OCI scores, athletes' overestimations or underestimations of cognitive impairment, and/or the relationships between them?

   Hypothesis: Expected factors to moderate the relationship between post-injury SCI and cognitive impairment overestimations (CIO) include level of play (i.e. collegiate vs. professional), psychological distress, prior concussion history, and history of diagnosis of a neurodevelopmental disorder (i.e. ADHD and/or learning disability). Level of play and prior concussion history are also expected to moderate the relationship between post-injury OCI and cognitive impairment underestimations (CIU). No other relationships between these variables are expected.

Chapter Three: Methods

The purpose of this chapter is to provide an overview of the methods of the thesis. To this end, I first describe the participants who comprised the research sample and the sampling procedures. Next, I explain the definitions and operationalizations of each examined construct, as well as the measures I chose to represent each construct. Then, I describe the study design and its procedures. Finally, I explain the data analyses and statistical tests I ran to answer my research questions.

Participant Sampling Procedure

Athletes who played for the Canadian Football League (CFL) and/or the University of Alberta who played during the 2017 or 2018 season and sustained SRC were included in the study. I used purposive and convenience nonprobability sampling to acquire participants. Additional inclusion criteria for this study included athletes who (a) were on the team roster in either the 2017 and 2018 seasons or 2018 and 2019 seasons; (b) sustained SRC during the aforementioned season; (c) completed concussion assessments at preseason baseline (Timepoint 1) and within 48 hours of the injury when applicable (Timepoint 2); and (d) provided necessary demographic, medical, and psychological information during indicated assessment points. Exclusion criteria included athletes who (a) were removed from the team roster during the season, (b) did not complete concussion assessments or provided demographic information, (c) endorsed a diagnosis of any medical condition during their baseline assessment that would cause significant cognitive dysfunction, and/or (d) sustained a concussion within 30 days prior to their baseline assessment. Details of necessary information are provided in the Measures section of this chapter.

Definitions and Operationalizations

Sports-Related Concussion (SRC)

For this study, SRC for diagnostic purposes was defined as "a change in brain function following a force to the head, which may (or may not) be accompanied by temporary loss of consciousness, but is identified in awake individuals with measures of neurologic and cognitive dysfunction, as indicated by 1 or more of the 22 symptoms from the Sport Concussion Assessment Tool [third edition; SCAT3] symptom checklist." This definition corresponds directly with a recent systematic review conducted by Carney et al. (2014) and aligns with the most recent consensus statement from the Concussion in Sport Group (CISG; McCrory, Meeuwisse, Dvořák, et al., 2017). All participants in the study were diagnosed by team physicians using this definition and in accordance to CFL and University of Alberta policy on concussion.

Objective Cognitive Impairment (OCI)

The definition for OCI I used for this study is based on one of the two diagnostic criteria for Major or Mild Neurocognitive Disorder (NCD; see American Psychiatric Association, 2013). Specifically, evidence of significant cognitive decline is partially based on "a substantial…impairment in cognitive performance, documented by standardized neuropsychological testing or, in its absence, another quantified clinical assessment" (pp. 602, 605). I operationalized OCI as below average (i.e., at least 1 standard deviation from the mean) or clinically significant negative change in cognitive performance evaluated through significantly correlated domains of cognitive functioning from measures used during athletes' baseline and post-injury assessments. Objective measures used for these assessments include the computer-based Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) and the

Standardized Assessment of Concussion (SAC) screener. The Measures section of this chapter includes domain-related and psychometric properties of the ImPACT and SAC. Details on how I determined the development of OCI as a measurable construct through correlated cognitive domains are in the Data Analyses section.

Subjective Cognitive Impairment (SCI)

The definition I used for SCI derives from part of the diagnostic criteria for Major or Mild NCD (APA, 2013) such that evidence of cognitive impairment is partially based on "concern of the individual…that there has been a significant decline in cognitive function" (pp. 602, 605). For the study, I operationalized SCI as cognitive symptom total score and/or severity score at least one standard deviation (SD) above the mean of SCAT3 Symptom Evaluation (S3SE) baseline scores, regardless of the presence of OCI at the time of assessment. The SD of mean scores is a common statistical indicator of significant change in clinical assessment (Neukrug & Fawcett, 2010; Sattler, 2008). Details on potential "cognitive" symptoms from the S3SE are in the Measures section.

Although the term is frequently interchanged with subjective cognitive decline (SCD; see Jessen et al., 2014), I intentionally used the word "impairment." The word "impairment" suggests the cognitive dysfunction may be temporary and can occur through active, acute means such as injury, whereas "decline" suggests a more permanent, continuous trend of dysfunction through gradual, chronic means such as aging or disease development. Although cognitive decline can happen as a long-term outcome of TBI or concussion (Langlois et al., 2006), I was interested in the assessment of cognitive impairment as reported by athletes who obtain RTP status during the season in which the injury occurred.

Cognitive Impairment Discrepancies

I examined two types of cognitive impairment discrepancies in the present study: cognitive impairment overestimation (CIO) and cognitive impairment underestimation (CIU). CIO was defined as the instance in which the athlete endorsed SCI, but none of the objective measures indicate the presence of OCI. In contrast, CIU was defined as the instance in which the athlete does not endorsed SCI, but OCI is present through any of the objective measures used to assess cognitive functioning.

Measures

Demographic and Medical Information

At the beginning of each preseason medical day, athletes completed standardized questionnaires after providing consent, which included disclosure of demographic information and a Concussion Summary Report to provide information about their concussion history. Research has shown many demographic characteristics may be predictors of post-concussive cognitive functioning outcomes (Finnoff et al., 2011; Patoilo et al., 2018) and concussion symptom reporting patterns (Asken et al., 2017; Edmed & Sullivan, 2012; Nelson et al., 2016). In support of the current literature, I chose to include level of play (collegiate vs. professional), diagnosis of psychiatric disorder (e.g., anxiety, depression), diagnosis of neurodevelopmental disorder (e.g., ADHD, learning disorder), and past concussion history as control variables to examine potential contributions to correlational relationships and/or regression models. Players' age, education level, and race are additional characteristics I included to describe the sample obtained for the present study.

Measures of Psychological Profile

I defined an athlete's psychological profile by the athletes' self-reports of psychological distress. Athletes rated their psychological distress by completing the Brief Symptom Inventory-18 (BSI-18; Derogatis, 2001). The BSI-18 demonstrated good internal consistency (α's ranging from 0.66 to 0.83) and medium-to-high convergent validity with self-report concussion symptom severity scores (*r*'s ranging from 0.42 to 0.58) from high school and college athletes with SRC (Lancaster et al., 2016). The measure has also shown good internal consistency (α's ranging from 0.75 to 0.91) and convergent validity with self-report psychological and affective distress (*r*'s ranging from 0.49 to 0.68) for a sample of an out-patient sample of adults who sustained a TBI (Meachen et al., 2008). Athletes rated their levels of distress based on 18 symptom items related to depression, anxiety, and somatization within the past 7 days of completing the questionnaire. Ratings are on a 5-point Likert scale from 0 "not at all" to 4 "extreme". I assessed the subscale scores for each domain (each a range of 0-24) and the Global Severity Index (GSI; range of 0-72). Specifically, I ran inter-correlations between subscale scores and scores from other measures. The GSI was used to define "psychological affect" as a moderating variable for part of the data analyses.

Measures of OCI

Two measures were used to develop the construct of OCI. The Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) is a computerized measure for neurocognitive functioning consisting of 6 modules that, altogether, assess verbal memory, visual memory, visual motor speed, reaction time, and impulse control, with the lattermost applied as a test of response validity (Iverson et al., 2003; Lovell, 2016). Statistical and psychometric properties of the ImPACT as assessed across multiple studies and samples of athletes are located in the testing manual (Lovell, 2016, Chapter 4). For this study, I used the composite scores of each domain (excluding impulse control) to look at group differences in relation to mean scores, and Reliable Change Indices (RCI) of these composite scores to look at individual change based on the error variance of the measure (Jacobson & Truax, 1991). Assuming the cognitive performance at the time of assessment is at least below average, values that indicate significant change in scores compared to baseline (assuming the baseline assessment is at least average) were considered as OCI.

The Standardized Assessment of Concussion (SAC; McCrea et al., 1997) is a clinical screening tool used to assess mental status, including cognitive orientation, immediate and delayed memory recall, and concentration (McCrory, Meeuwisse, Dvořák, et al., 2017). Athletes answered general questions (e.g., day of the week) to evaluate orientation (max score of 5). For immediate memory recall (max score of 15), the test administrator read a list of 5 words 3 times. Immediately after each read-through, athletes stated words that they remembered. Delayed memory involved recalling words from the same list after a 10-minute delay (max score of 5). Concentration tasks included reciting numbers and words in reverse order (max score of 5). Analyses across several studies have shown the SAC has moderate-to-high internal consistency (α's ranging from 0.42 to 0.71; Guskiewicz et al., 2013), and it has a 80-94% sensitivity and 76-91% specificity in detecting concussions in high school and college football players (Barr & McCrea, 2001; Guskiewicz et al., 2013). I examined total SAC scores (out of 30) across all timepoints. The presence of OCI through the SAC were operationalized with (1) a cutoff score of < 26 points, (2) a ≥ 3-point difference from the mean initial baseline assessment score, and/or (3) an RCI that indicates significant change in scores compared to the initial baseline. The first two operationalizations are based on previous studies that reflect differences in SAC scores between concussed and healthy football players (McCrea et al., 1998; 2003). Details on calculating RCIs are included the Data Analyses section.

Measure of SCI

To assess SCI, I used items from the S3SE (McCrory et al., 2013). This checklist contains 22 SRC symptoms to which athletes rate their severity based on how they feel "on a normal day" at baseline and "now" at post-injury. Ratings are on a 7-point Likert scale ranging from 0 "none" to 6 "severe." The scale is also split into 4 categories: None (i.e., score of 0), Mild (i.e., score of 1 of 2), Moderate (i.e., score of 3 or 4), and Severe (i.e., score of 5 or 6). The S3SE includes a total symptoms score (range of 0-22) and a symptom severity score (range of 0-132). Higher scores indicate greater symptom burden and severity, respectively. The S3SE has demonstrated high internal consistency in a large sample of high school and college male athletes, with Cronbach's α ranging from 0.88 to 0.93 (Lovell et al., 2006), as well as 64% to 89% sensitivity and 91% to 100% specificity in detecting concussions from young adult athletes (Guskiewicz et al., 2013). I used the total symptom scores and symptom severity scores across these items at all timepoints to represent the degree of SCI. The process I used to determine which S3SE items to select to represent SCI as a measurable construct is located in the Data Analyses section.

Study Design and Procedure

The overarching objective of the study was to identify relationships between and among factors that may predict and/or associate with elite athletes' appraisals and reports of cognitive dysfunction before and after sustaining a concussion. The design of this quantitative study was correlational, prospective, and cross-sectional such that the timespan of baseline and post-injury data comprised two football seasons. A correlational design prevents researchers from making definitive causal inferences or conclusions about the relationships between variables. However, experimental design for this study would neither be feasible nor appropriate at this time due to lack of definitive information about the mechanism(s) involved when athletes to over- or underestimate presence of cognitive dysfunction in relation to cognitive performance. This problem hinders the ability to manipulate variables and set conditions successfully for the experiment. Thus, the application of a correlational design to better understand these phenomena by examining relationships between variables and testing for potential moderating factors in predicting CIU or CIO was most appropriate for this study.

To minimize participation burden and overlap of data collection with multiple active research projects, I conducted secondary data analyses to address the research questions to my thesis (Trzesniewski et al., 2011). These data were part of an international multi-site clinical trial named "Role of Rehabilitation in Concussion Management: A Randomized, Controlled Trial" (clinicaltrials.gov; NCT02988596). Coined as The Active Rehab Study, the purpose of the primary project was to determine the effectiveness and feasibility of integrating early multi-dimensional rehabilitation with current return-to-sport protocol (i.e., enhanced graded exertion [EGE] progression) compared to using EGE alone for SRC treatment. The Active Rehab Study was first approved by the Institutional Review Board of the University of North Carolina, Chapel Hill, with Dr. Johna Register-Mihalik as the principal investigator. As one of the sites included in the project, the University of Alberta Ethics Board also approved the project under the same title (No. RES0036946, November 9, 2017). Dr. Martin Mrazik was the lead co-investigator for the data collected from the University of Alberta and the CFL athletes, which made up the sample for the study.

Per the Active Rehab Study protocols, participants were fully informed of the procedures of the study during the preseason assessments and provided informed consent prior to engagement in any study activities (Register-Mihalik et al., 2019). Trained examiners administered all assessments, including baseline and post-injury assessments, at each team's sport stadium. Assessments relevant to the present study include measures of neurocognitive functioning through computer-based testing (i.e., ImPACT; Lovell, 2016) and paper-and-pen and observational examination (i.e., the SCAT3; McCrory et al., 2013), self-reports of concussion symptoms (i.e., the S3SE; Guskiewicz et al., 2013; McCrory et al., 2013), and questionnaires measuring current psychological distress (i.e., the BSI-18; Derogatis, 2001). Other areas of the concussion assessment include balance, gait, near-point convergence, and eye-tracking. However, these measures were not included in the proposed project because the cognitive aspects of concussion are the focus of the study, and eye-tracking was not assessed consistently. All administrators of the assessments went through yearly training either in-person or virtually. Altogether, it took approximately 60 minutes for athletes to complete the baseline concussion assessment.

Athletes completed forms on the computer, through which they provided their demographic information, general medical history, concussion history, and ratings of their current psychological distress and quality of life. Per the CFL protocol, and the recommended CISG consensus guidelines (McCrory et al., 2013; McCrory, Meeuwisse, Dvořák, et al., 2017), trained examiners administered the SCAT3 to each athlete. Altogether, the SCAT3 includes the symptom checklist (i.e., the S3SE), which athletes completed themselves, as well as the SAC's objective measures of mental status, memory, concentration, balance, gait, and near-point convergence. Athletes also completed the ImPACT in small groups in a separate room, where a trained professional supervised the testing and managed troubleshooting issues as needed. In keeping with CFL concussion protocol, any athlete suspected of a concussion was evaluated by team physician. Athletes were again evaluated within 48 hours of their injury with the SCAT3. Like with the baseline assessments, examiners used the symptom checklist, the screening tool, and computerized testing to assess their post-injury status. Each athlete provided ratings of their current psychological distress. The post-injury assessment took approximately 45 minutes for each athlete to complete.

Overview of Analyses

I ran statistical tests through the Statistical Package for Social Sciences (SPSS v. 28.0; IBM Corp, 2021). Statistical significance for inferential statistical analyses were defined as a p-value of less than or equal to an alpha (α) of 0.05, which is the typical value applied to minimize type 1 error (Cohen, 1990; 1992).

I created dichotomous variables to represent the presence of SCI, OCI, CIO, and CIU (i.e., 1=present; 0=absent). Normal percentiles and RCI values were used to indicate significant group differences and individual differences (respectively) between scores for each measure of OCI to determine its presence. RCIs were calculated based on a modified version of the formulas proposed by Jacobson and Truax (1991). Specifically, rather than using an estimated error of difference in scores (which would be appropriate if re-test data were not available), I calculated the value by using the standard error of measure (SEM) for baseline and re-test scores, as applied in a previous study that tracked neuropsychological recovery through ImPACT scores (Iverson et al., 2003). I used the estimated error of difference for baseline scores because some athletes played their first professional or collegiate season at that timepoint, meaning they did not have previous scores to use for comparison (see Table 1).

Table 1

Formulas for Calculating Reliable Change Index with Baseline and Re-Test Data

$RCI = (X_2 - X_1) / S_{diff}$	$S_{diff} = \sqrt{(SEM_1^2 + SEM_2^2)}$
$SEM_1 = SD_1 \sqrt{(1 - r_{12})}$	$SEM_2 = SD_2 \sqrt{(1 - r_{12})}$

Notes. RCI = Reliable Change Index; X2 = re-test score; X1 = baseline test score; S_{diff} = standard error of the difference; SEM = standard error of measurement; SD = standard deviation; r12 = test re-test reliability coefficient.

Next, I ran descriptive statistical tests to gather a basic understanding of the sample and the data. Specifically, I calculated means and standard deviations of the collected demographic information and scores, as well as inter-correlations through a correlational matrix to view their degrees of association within the sample. I also ran chi-square tests to test for associations between categorical variables (e.g., self-reported diagnosis of neurodevelopmental disorders).

Then, I developed SCI and OCI as latent constructs of cognitive impairment based on the findings from the correlation analyses. Factor analyses of the S3SE (Anderson et al., 2020; Brett et al., 2020; Nelson et al., 2018) and the ImPACT's Post-Concussion Symptom Scale (PCSS; Kontos et al., 2012; Merritt & Arnett, 2014; Pardini et al., 2004) identified the following items as potential indicators for SCI: "feeling like in a fog", "difficulty concentrating", "difficulty remembering", "confusion", "drowsiness", and "fatigue or low energy". Factor analyses and validity assessments of the ImPACT and SAC have been conducted in previous research; the findings indicate they are valid objective indicators of cognitive impairment (Barr & McCrea, 2001; Guskiewicz et al., 2013; Lovell et al., 2006; Masterson et al., 2019; McCrea et al., 2003). These analyses were necessary to ensure SCI and OCI were operationalized appropriately based on the data collected from this sample for the present study.

To answer my first research question, I ran correlation tests on baseline and post-injury data to examine the association between the degrees of SCI and OCI. I used the following recommended cut-off values in classifying effect sizes: small = 0.1, medium = 0.3, and large = 0.5 (Cohen, 1992). For any statistically significant correlation coefficients, I included control variables and ran more specific correlation tests by breaking down scores by domains when applicable (e.g., symptom checklist scores by each cognitive symptom item, ImPACT scores by each domain). Demographic characteristics and previous concussion history were also used as control variables to determine whether or not any of these variables contributed to any statistically significant relationships.

To address my second research question, I compared the frequency of when SCI, OCI, CIO and CIU (i.e., my dependent variables) occurred between baseline and post-injury (i.e., my independent variable). To this end, I ran McNemar tests for each dependent variable. The McNemar test is a nonparametric test that, like a paired t-test, helps researchers determine if there is a statistical difference in the dependent variable that has two outcome categories across two timepoints for the independent variable (Field, 2018).

Finally, for my third research question, I ran point-biserial correlation analyses to assess the relationships between baseline and post-injury SCI scores, OCI scores, and the presence of each cognitive discrepancy variable (i.e., CIO and CIU). Point-biserial correlation analyses were also conducted to determine the relationships between the number of concussions prior to the SRC, baseline and post-injury psychological distress scores (i.e., BSI-18 total scores), the presence of SCI and OCI at baseline and post-injury, and the presence of CIO and CIU at baseline and post-injury. Chi-square tests were computed to identify associations between athlete level of play (collegiate vs. professional), diagnosis of a neurodevelopmental disorder (i.e., ADHD and/or LD), the presence of baseline and post-injury SCI and OCI, and the presence of baseline and post-injury CIO and CIU. Logistic regressions were conducted on statistically significant relationships to ascertain the effects of possible factors as predictors on the likelihood of (a) endorsements of SCI, (b) cognitive performance that reflects OCI, and (c) of athletes who demonstrate CIO or CIU. Because the dependent variables were labeled as dichotomous and the predictor variables were a combination of continuous and categorical variables, logistic regression models were most appropriate (Tabachnick & Fidell, 2012).

Chapter Four: Results

To determine the necessity in application of parametric vs. nonparametric analyses, the assumption of normality was assessed via the Shapiro-Wilk test, which is considered to be especially appropriate for small sample sizes (i.e., $n < 50$; Field, 2018). This assumption was met for the athlete's age ($p = .82$) and ImPACT visual memory composite scores at baseline ($p = .85$) and post-injury ($p = .24$). The remaining variables did not meet the assumption of normality; further analyses including these variables were nonparametric to accommodate to deviance of normality.

Development of Cognitive Impairment Indicators

OCI

To determine the operational definition of OCI in the present study, Spearman's rank correlation analyses were conducted on baseline and post-injury SAC total scores and ImPACT domain scores from the concussed group (see Table 2). Scores from both timepoints were essential to ensure consistency in construct representation. The SAC total scores significantly correlated with the ImPACT verbal memory composite score at both baseline and post-injury; however, it was not correlated with the remaining ImPACT domain scores are baseline. Thus, the SAC was removed as an indicator of OCI for the present study. ImPACT's visual motor speed and reaction time scores were also removed due to because the relationship between other ImPACT variables were inconsistent between baseline and post-injury. Based on these analyses, the ImPACT verbal memory and visual memory composite scores represented OCI for the present study. The RCI was used to detect clinically meaningful change in ImPACT verbal memory and visual memory composite scores between baseline and post-injury assessments. Table 3 includes the statistical parameters used to calculate the RCI for each variable. The estimated error of difference calculated to determine the RCI for baseline scores for the verbal memory composite and the visual memory composite scores were 9.03 and 8.98, respectively.

Table 2

Spearman's Correlations of Potential OCI Indicators

Variable	Baseline					Post-Injury				
	1.	2.	3.	4.	5.	1.	2.	3.	4.	5.
1. SAC Total	--					--				
2. ImP_VeM	.37*	--				.32*	--			
3. ImP_ViM	-.01	.39*	--			.33*	.48**	--		
4. ImP_ViMS	.14	.35*	.30	--		.47**	.52**	.49**	--	
5. ImP_RXN	-.08	-.08	-.33*	-.56**	--	-.36*	.01	-.20	-.49**	--

Notes. * $p \leq .05$, ** $p \leq .01$, OCI = Objective Cognitive Impairment, SAC = Standardized Assessment of Concussion, ImP_VeM = ImPACT Verbal Memory, ImP_ViM = ImPACT Visual Memory, ImP_ViMS = ImPACT Visual Motor Speed, ImP_RXN = ImPACT Reaction Time.

Table 3

Descriptive Statistics, SEMs, Sdiffs, for Concussed Players

Measure	M (SD) [N=40]		r_{12}	SEM_1	SEM_2	S_{diff}
	Baseline	Post-Injury				
IMP_VeM	87.30 (10.67)	88.13 (12.09)	.62	6.58	7.45	9.94
IMP_ViM	77.65 (8.56)	79.28 (10.85)	.45	6.35	8.04	10.25

SCI

The processes to develop SCI as a construct was similar such that I ran two correlation analyses on baseline and post-injury S3SE ratings. Anderson et al. (2020) and Brett et al. (2020) found in their EFA of the checklist that items 14 (i.e., "difficulty concentrating") and 16 (i.e., "confusion") appeared to represent a cognitive factor for concussed athletes. To determine if the data show other items as representative of SCI, I included items 10, 11, 12, 13, 15, and 17 into the analyses. Inclusion of these items was based on previous studies that reflected their grouping into cognition-related clusters (Kontos et al., 2012; Merritt & Arnett, 2014; Pardini et al., 2004). Table 4 shows the Spearman's rank correlations between these items at baseline and post-injury assessments. Significant correlations between S3SE items 14 and 16 were found at baseline (ρ = 0.59, $p < .001$) and post-injury ($\rho = .34$, $p = .03$); thus, these items were included in the representation of SCI. Although some of the remaining items significantly correlated with either item 14 or item 16, none of these items significantly correlated with both items in order to be included as an indicator for SCI. S3SE cognitive symptom total and severity scores in future analyses were represented by scores from their ratings of "difficulty remembering" and "confusion".

Table 4

Spearman's Correlations of Potential SCI Indicators from Selected S3SE Items

S3SE Item	10.	11.	12.	13.	14.	15.	16.	17.
10. Slowed down	--	_.72**_	_.55**_	_.31_	_.27_	_.46**_	_.02_	_.53**_
11. "In a fog"	.72**	--	_.49**_	_.37*_	_.18_	_.39*_	_-.01_	_.39*_
12. Don't feel right	.72**	.52**	--	_.56**_	_.16_	_.36*_	_.35*_	_.50**_
13. Difficulty concentrating	.50**	.34**	.72**	--	_.28_	_.53**_	_.31_	_.29_
14. Difficulty remembering	.40**	.55**	.59**	.82**	--	_.27_	_.34*_	_.38*_
15. Fatigue/low energy	.48**	.51**	.33*	.18	.18	--	_.13_	_.50**_
16. Confusion	.72**	.52**	1**	.72**	.59**	.33*	--	_.20_
17. Drowsiness	.51**	.55**	.39*	.22	.14	.82**	.38*	--

Notes. Italicized values represent correlations from post-injury data. * $p \leq .05$, ** $p \leq .01$, SCI = Subjective Cognitive Impairment, S3SE = Sport Concussion Assessment Tool—Third Edition Symptom Evaluation.

Participant Characteristics

A total of 1,054 professional (n = 809) and collegiate athletes (n = 245) enrolled in the Active Rehab study in 2017 and 2018. Participants were excluded from analyses for the present study due to participation in a different sport than football (n = 132, all collegiate players) or due to incomplete assessment data for SCI and OCI indicators (n = 129). Of the 793 elite football players enrolled in the study who completed baseline and post-injury concussion assessments, 40 sustained an SRC. Descriptive and inferential statistical comparisons of demographic characteristics between healthy and concussed athletes can be viewed at Table 5; such comparisons of baseline assessment scores between these two groups can be viewed at Table 6.

Independent t-tests and Mann-Whitney U tests were conducted to assess for differences in demographic information and in baseline assessment scores between healthy and concussed players eligible for the present study. Levene's test of sphericity revealed a violation in the assumption of equal variances between groups for baseline ImPACT visual memory composite scores (F = 10.63, p = .001); therefore, the degrees of freedom were adjusted from 791 to 50. Overall, there were no statistically significant differences in age, number of past concussions, or baseline scores on OCI indicators, SCI indicators, or full SRC symptom ratings between healthy and concussed athletes. Chi square tests were also conducted to compare categorical data such as race, education level, concussion history, and psychiatric/mental health history. Fisher's exact test values were utilized when more than 20% of the expected frequencies were less than 5 (Field, 2018; Howell, 2012). The proportion of athletes who endorsed having a past concussion history differed by group $\chi^2(1, N = 793) = 6.34, p = .01$, indicating players who sustained an SRC while enrolled in the present study were more likely to have past concussion(s) than healthy players. There were no statistically significant differences between healthy and concussed athletes' year of enrollment in the primary research study, level of play, race, education level, and psychiatric/mental health history.

Table 5

Demographic Comparisons of Eligible Healthy and Concussed Athletes

Characteristic *N* (%), Mean (SD), **Median**	Non-Concussed Players (*n* = 753)	Concussed Players (*n* = 40)	*t* (χ^2) ***U***	df ***z***	*p*-value
Study Enroll (% 2017)	474 (62.9%)	30 (75%)	(2.35)	1	.13
Collegiate (vs. pro)	97 (12.9%)	6 (15.0%)	(0.15)	1	.70
Age	25.16 (3.22)	25.50 (3.26)	-0.65	791	.52
Race			(1.13)	2	.57
Black	377 (50.1%)	17 (42.5%)			
White	294 (39.0%)	17 (42.5%)			
Other/Unknown	82 (10.9%)	6 (15.0%)			
Education Level			(0.06)	1	.74
University (any)	688 (91.4%)	37 (92.5%)			
Other	49 (6.5%)	3 (7.5%)			
Past Conc(s) (vs. no)	333 (44.2%)	26 (65.0%)	(6.34)	1	.01
Number of Past Conc	**1.00**	**1.00**	**3833**	**-.01**	**.99**
ADHD (vs. no)	83 (11.0%)	6 (15.0%)	(.50)	1	.45
Learning Disability (vs. no)	31 (4.1%)	2 (5.0%)	(.06)	1	.69
Psychiatric Dx (vs. no)	14 (1.9%)	--	(.78)	1	1

Note. Bolded values represent Mann-Whitney U test values for continuous variables that violated assumption of normality.

Table 6

Comparison of Baseline Assessment Scores of Eligible Healthy and Concussed Athletes

Measure Mean (SD) **Median**	Non-Concussed Players (*n* = 753)	Concussed Players (*n* = 40)	*t* ***U***	df ***z***	*p*-value
IMP_VeM	**88.00**	**91.00**	**14064.5**	**-.71**	**.48**
IMP_ViM	76.63 (13.58)	77.65 (8.56)	-0.71	50	.48
S3SE Total SXs	**0.00**	**0.00**	**14404.5**	**-.53**	**.60**
S3SE SX Severity	**0.00**	**0.00**	**14581**	**-.38**	**.70**
S3SE Cog SXs	**0.00**	**0.00**	**15052.5**	**-.01**	**.99**
S3SE Cog SX Severity	**0.00**	**0.00**	**15044.5**	**-.02**	**.98**

Notes. Bolded values represent Mann-Whitney U test values for variables that violated assumption of normality.

Most of the concussed athletes completed post-injury S3SE assessments within the 2-day timeframe (n = 31, M = 1.39, SD = 0.50); however, some completed these 3-7 days post-injury (n = 9, M = 3.89, SD = 1.27). Table 7a shows a comparison of scores for these measures based on time of completion (i.e., within 48 hours post-injury vs. past 48 hours post-injury). Mann-Whitney U tests show there are no statistically significant differences in S3SE total symptoms scores $U(n_1 = 31, n_2 = 9) = 119.5$, $z = -.65$, $p = .52$ and severity scores $U(n_1 = 31, n_2 = 9) = 117$, $z = -.73$, $p = .47$, or in SCI-related S3SE total symptom scores $U(n_1 = 31, n_2 = 9) = 118.5$, $z = -.94$, $p = .35$ and severity scores $U(n_1 = 31, n_2 = 9) = 117$, $z = -.99$, $p = .32$. There were also differences in time of completion of ImPACT post-injury assessments. Sixteen athletes completed the ImPACT post-injury assessment within 2 days (M = 1.31, SD = 0.60) while the remaining participants completed this assessment either 3-7 days post-injury (n = 18, M = 4.17, SD = 1.20) or beyond (n = 6, M = 21.83, SD = 13.30). Table 7b includes a comparison of scores for post-injury ImPACT verbal memory and visual memory composite scores based on time of assessment completion. Kruskal-Wallis tests show no significant differences between the 3 groups on post-injury ImPACT verbal memory composite scores $H(2) = 4.02$, $p = .13$ or visual memory composite scores $H(2) = 2.03$, $p = .36$. Altogether, participants who completed their post-injury assessments after 48 hours were included in the analyses.

Table 7a

Comparison of Post-Concussion S3SE Scores Based on Time of Completion

S3SE Measure Mean (SD) [Median]	0-2 Days Post-Injury (*n* = 31)	3-7 Days Post-Injury (*n* = 9)
Total SXs		
All 22 items	7.10 (5.52) [6]	8.00 (5.17) [5]
Cognitive (SCI) items	0.29 (0.53) [0]	0.11 (0.33) [0]
SX Severity		
All 22 items	11.84 (11.52) [8]	15.44 (14.69) [11]
Cognitive (SCI) items	0.48 (0.99) [0]	0.11 (0.33) [0]

Note. Higher values indicate higher number of cognitive symptoms or greater severity of cognitive symptoms endorsed by athletes.

Table 7b

Comparison of Post-Concussion ImPACT Scores Based on Time of Completion

ImPACT Measure M (SD) [Median]	0-2 Days Post-Injury (*n* = 16)	3-7 Days Post-Injury (*n* = 18)	8+ Days Post-Injury (*n* = 6)
VeM	82.94 (14.92) [86]	90.67 (9.22) [92]	94.33 (5.16) [96]
ViM	76.44 (12.69) [76]	80.78 (9.89) [83]	82.33 (7.63) [82]

Note. Higher values represent greater functioning in each domain.

Relationship Between Appraisals and Performance of Cognitive Functioning

I ran Spearman's correlation analyses of baseline and post-injury OCI and SCI data to determine the relationship between concussed athletes' self-reported appraisals of cognitive symptoms of SRC and their performance in assessments of cognitive functioning. Table 8 shows the baseline and post-injury correlation matrices. As expected, because of its representation through the same two items on the S3SE, the correlations between S3SE total cognitive symptom scores and cognitive symptom severity scores was perfect at baseline ($\rho = 1$; $p < .001$) and near-perfect at post-injury ($\rho = 0.99$; $p < .001$). Similarly, moderate positive correlations between ImPACT verbal memory and visual memory composite scores were found at baseline ($\rho = .39$, $p = .01$) and post-injury ($\rho = .48$, $p = .002$). Correlations between baseline SCI indicators and OCI indicators were not statistically significant, suggesting baseline indicators of cognitive impairment through subjective appraisals and objective assessment tools are not related to each other. At post-injury, total cognitive symptom scores were negatively, moderately correlated with ImPACT verbal memory composite scores ($\rho = -.33$, $p = .04$), suggesting the number of cognitive impairment symptoms athletes endorsed is lower when they perform better on assessments of verbal attentional, learning, and memory processes at post-concussion. No other significant correlations between post-injury SCI indicators and OCI indicators were found.

Table 8

Spearman's Correlations of Baseline and Post-Injury of SCI and OCI Indicators

Variable	Baseline				Post-Injury			
	1.	2.	3.	4.	1.	2.	3.	4.
1. S3SE Cog_T	--				--			
2. S3SE Cog_S	1**	--			.99**	--		
3. ImP_VeM	-.18	-.18	--		-.33*	-.29	--	
4. ImP_ViM	-.09	-.09	.39*	--	-.25	-.23	.48*	--

Notes. * $p \leq .05$, ** $p \leq .01$, S3SE Cog_T = S3SE Cognitive Total Symptom Score, S3SE Cog_S = S3SE Cognitive Symptom Severity Score, ImP_VeM = ImPACT Verbal Memory, ImP_ViM = ImPACT Visual Memory

Cognitive Impairment Differences Over Time

To determine if there were differences in the presence of SCI, OCI, and cognitive impairment discrepancies between pre- and post-concussion, I ran a McNemar test for each variable. For this sample of concussed elite football players, the tests determined there were no statistically significant differences in frequency of SCI (p = .07) or of OCI (p = .06) between pre- and post-concussion assessments, though they appeared to trend toward significance. In general, there were significantly more cognitive impairment discrepancies present at post-injury (i.e., 22.5% of cases) than at baseline (i.e., 5% of cases; p = .04). However, there were no statistically significant differences in the frequency of cognitive impairment underestimation (CIU, p = .25) or of cognitive impairment overestimation (CIO, p = .22) individually between baseline and post-injury assessments.

Predictors of Cognitive Impairment Indicators and Discrepancies

Point-biserial correlation analyses were conducted to assess the relationship between scores that represent each indicator variable (continuous) and each discrepancy variable (dichotomous) at each assessment timepoint. As applied in a recent study, cognitive symptom severity was used to represent SCI as a continuous variable while the average between ImPACT verbal memory and visual memory scores represented OCI as a continuous variable (Hromas et al., 2020). Point-biserial correlations could not be computed with baseline CIU because there was no split in distribution between its two categories (i.e., there were no cases of baseline CIU). Athletes who overestimated their cognitive dysfunction had significantly higher cognitive symptom severity scores than athletes who did not at both baseline ($r_{pb} = .85$, $p < .001$) and at post-injury ($r_{pb} = .60$, $p < .001$). Athletes who underestimated their cognitive dysfunction during their post-injury assessment had significantly lower ImPACT composite scores altogether than those who did not ($r_{pb} = -.33$, $p < .04$). No other correlations were found to be statistically significant.

Point-biserial correlation coefficients were computed to assess relationships between number of previous concussions, psychological distress (i.e., BSI-18 total scores), the presence of SCI and OCI, and the presence of CIO and CIU. Significantly higher psychological distress was found in athletes with SCI when assessed at baseline ($r_{pb} = .81$, $p = .01$) and at post-injury ($r_{pb} = .40$, $p = .01$) compared to athletes without SCI. Significantly higher psychological distress was also found in athletes who overestimated their cognitive impairment at baseline ($r_{pb} = .52$, $p < .001$) and at post-injury ($r_{pb} = .34$, $p = .04$) assessments compared to athletes who did not demonstrate CIO. However, psychological distress was not significantly associated with the presence of OCI or with the presence of CIU. The number of previous concussions athletes sustained was not significantly related to the presence of any cognitive impairment or of discrepancies of such at any assessment timepoint.

Chi-square tests were conducted to examine associations between prior concussion history (yes vs. no), diagnosis of a neurodevelopmental disorder, athlete's level of play, the presence of SCI and OCI, and the presence of CIO and CIU. Whether or not athletes had previous concussions at the time of assessment was significantly related to post-injury SCI $\chi^2(1, N = 40) = 5.12$, $p = .04$. The proportion of athletes with SCI was significantly different between athletes who had previous concussions and athletes who had not. Specifically, of the 26 athletes who had a concussion in the past, 11.5% endorsed SCI ($n = 3$); of the 14 athletes who did not have a past concussion, 42.9% endorsed SCI ($n = 6$). The presence of SCI and the presence of OCI were not significantly related to athletes' level of play or diagnosis of a neurodevelopmental disorder. Prior concussion history, diagnosis of a neurodevelopmental disorder, and athlete's level of play were not significantly associated with baseline or post-injury CIO or CIU.

Based on these findings, logistic regression analysis was used to ascertain the effects of psychological distress and previous concussion history on the likelihood of athletes endorsing SCI at post-concussion. The model with psychological distress alone as a predictor of SCI at post-injury was significant $\chi^2(1, N = 40) = 5.57$, $p = .02$ with 20% (Nagelkerke's R) of the variance explained and 79.5% correctly classified cases. Athletes were 22% more likely to endorse SCI for every one-unit increase in psychological distress at post-concussion (OR = 1.22, 95%CI [1.02, 1.47], $p = .03$). The model with previous concussion history alone a predictor of post-injury SCI was also significant $\chi^2(1, N = 40) = 4.67$, $p = .03$ with 17% of the variance explained and 77.5% correctly classified cases. An endorsement of at least one concussion prior to SRC was associated with an 83% decrease in the odds of an athlete endorsing post-injury SCI

(OR = .17, 95%CI [.03, .86], p = .03). Finally, the model with both psychological distress and previous concussion history as predictors of post-injury SCI was significant $\chi^2(2, N = 40)$ = 10.85, p = .004 with 37% of the variance explained and 84.6% correctly classified cases. When controlling for previous concussion history, athletes are 30% more likely to endorse SCI at post-injury for every one-unit increase in psychological distress (OR = 1.30, 95CI [1.01, 1.68], p = .04); when controlling for psychological distress, athletes who endorsed at least one prior concussion are 88% less likely to endorse SCI at post-injury (OR = .12, 95%CI [.02, .89], p = .04. It is important to note, however, that the Hosmer and Lemeshow test of goodness of fit reflected these data may not fit well with the accumulative model $\chi^2(6, N = 40)$ = 12.76, p = .05, which means its results for the accumulative model should be interpreted with caution in relation to this sample.

Logistic regressions were also conducted to determine the effects of psychological distress on the likelihoods of baseline SCI and of athletes who demonstrate CIO at baseline and post-injury assessments. Psychological distress does not significantly predict SCI endorsements at baseline $\chi^2(1, N = 40)$ = 3.33, p = .07, though it appears to trend toward statistical significance. Although the model with psychological distress as a predictor to CIO at baseline was statistically significant $\chi^2(1, N = 40)$ = 4.76, p = .03, the Hosmer and Lemeshow test of goodness of fit did not support this model $\chi^2(2, N = 40)$ = 8.74, p = .01. Finally, although nonsignificant, the model with psychological distress as a predictor to CIO at post-injury approached statistical significance $\chi^2(1, N = 40)$ = 3.67 p = .055.

Chapter Five: Discussion

The risks of adverse outcomes as a result of SRC, including cognitive impairment, continue to be of concern for athletes. For elite athletes, assessments of cognitive impairment postconcussion rely on both cognitive symptom self-reports (i.e., S3SE) and standardized tests of cognitive performance (i.e., SAC, ImPACT). Results between these measures may contradict each other, which means athletes may overestimate or underestimate their cognitive dysfunction. It is necessary to understand the nature and underlying mechanisms of such occurrences to facilitate clinical decision-making and RTP transitions. The aim of the present study was to contribute to the emerging research through secondary data analyses of concussion assessments completed by Canadian elite football players. To my knowledge, this study is the first to examine subjective and objective indicators of cognitive impairment and its discrepancies from elite athletes through S3SE cognitive symptoms. This section includes evaluations of the hypotheses based on the results, theoretical and clinical implications of the findings, strengths and limitations of the study, and suggestions for future research.

Evaluations of Study Hypotheses

Question One

The first question was an examination of the relationship between elite football players' symptom reports of cognitive dysfunction and their cognitive performance through objective testing at baseline and/or within 48 hours post-injury. I hypothesized SCI and OCI scores were not significantly correlated with each other due to the literature showing mixed findings on consistency between symptom reports and neurocognitive test scores (Broglio et al., 2009; Brooks et al., 2013, 2016; Fazio et al., 2007). The results from the present study supported this hypothesis for baseline assessment scores, meaning baseline cognitive symptom reports and cognitive performance scores do not significantly correlate with each other. Athletes who are active on the team roster do not typically demonstrate cognitive dysfunction at preseason assessments. This point is likely true regardless of prior concussion history, as evidenced by a study that showed prior concussion history was not a predictor of collegiate athletes' neurocognitive performance through ImPACT scores (Broglio et al., 2006). Furthermore, most athletes recover from acute cognitive deficits from SRC within 7-10 days (McCrea et al., 2012), which means they are likely to present as asymptomatic with normal cognitive performance scores unless their baseline assessments take place within a week of a concussive injury.

In contrast, the hypothesis was not fully supported for post-injury assessment scores. Athletes who endorsed more cognitive symptoms for SCI (i.e., "difficulty remembering" and "confusion") had lower ImPACT verbal memory composite scores. This correlation suggests athletes' appraisals of cognitive impairment are generally consistent with their cognitive performance. There is some support of this finding as evidenced by a previous study that found increased self-reports of "difficulty remembering" to be associated with poorer ImPACT verbal memory scores (Broglio et al., 2009). Interestingly, like the present study, they did not find a significant relationship between cognitive symptom reports and visual memory composite scores from collegiate athletes, most of whom were football players (i.e., 72%; Broglio et al., 2009). It is possible different S3SE items not included in the SCI construct correlate with visual memory, such as somatic symptoms (e.g., visual problems, headaches, dizziness). In a study assessing the relationship of postconcussion symptoms and cognitive performance scores to perceived recovery of adolescent athletes, decreased somatic symptoms, shorter reaction time, and higher visual memory scores were the only significant predictors to perceived recovery from concussion (Sandel et al., 2013). Furthermore, different brain regions are responsible for verbal memory (i.e., left medial temporal region; Jansen et al., 2009) and visual memory (i.e., right medial temporal region, posterior parietal region, occipital lobe; Todd & Marois, 2004), meaning athletes' perceptions and appraisals of symptoms from different clusters may be attributed to different neurocognitive domains of dysfunction. Interestingly, cognitive symptom severity scores were not significantly correlated to verbal memory scores despite the near-perfect correlation between S3SE cognitive symptom total and severity scores. It is likely there was insufficient statistical power to assess the spread in severity scores (i.e., out of 12) compared to the smaller spread of total symptom scores (i.e., out of 2). Athletes from this cohort may have also rated severity of cognitive symptoms similarly regardless of their cognitive performance.

Question Two

The second question was an assessment of differences in frequency of SCI, OCI, and of cognitive impairment discrepancies between assessment timepoints. I hypothesized significantly higher frequencies of all variables at post-injury than at baseline. This hypothesis was supported with respect to a higher frequency of cognitive impairment discrepancies in general at post-injury than at baseline. This finding is not surprising because indicators of impairment are likely to be detected post-injury, which leads to increased opportunities for discrepancies between subjective symptom reports and objective cognitive performance scores. The number of cases of each cognitive impairment discrepancy (i.e., CIO, CIU) was low at both baseline and post-injury, which likely influenced the amount of statistical power available to detect significant change between the two timepoints. Unexpectedly, the hypothesis was not supported such that frequencies in SCI, OCI, and each cognitive impairment discrepancy individually (i.e., CIO and CIU) did not change significantly at post-injury from baseline.

Most cognitive signs and symptoms of SRC are acute and resolve in a short period of time. For example, the SAC was able to detect significant differences in cognitive dysfunction between injured and healthy "control" athletes at the time of injury and 15 minutes post-injury, but not at 48 hours post-injury (McCrea, 2001). Thus, 48 hours may be sufficient time for the athletes from this sample to recover from cognitive impairment, which could account for no significant change in OCI scores. Athletes likely experience additional symptoms and may perceive and report these rather than cognitive symptoms, and they may also interpret them to be more severe and indicative of impairment (Sandel et al., 2013). This possibility could account for no significant change in SCI endorsements at post-injury. It is important to note the differences in SCI and OCI between baseline and post-injury assessments approached statistical significance; an increase in sample size and, in turn, statistical power, may reveal different results. Although statistical significance was not obtained, these findings reveal clinical significance such that both subjective and objective indicators of cognitive impairment are detected more so at postconcussion than at baseline. This means the measures used for concussion assessments are capturing cognitive dysfunction after a concussive injury as intended.

Question Three

The third question was an examination of personal factors as predictors of SCI, OCI, cognitive impairment discrepancies, and/or the relationships between the indicators and discrepancies. I hypothesized level of play, psychological distress, prior concussion history, and diagnosis of a neurodevelopmental disorder to be predictors of post-injury cognitive impairment indicators and discrepancies to various degrees. Specifically, I expected reports of at least one concussion, higher number of concussions, and level of play (i.e., collegiate athletes) to predict

SCI and OCI, and to moderate relationships between (a) SCI and CIO and (b) OCI and CIU. I also expected higher score of psychological distress and a diagnosis of a neurodevelopmental disorder to predict SCI and to moderate the relationship between SCI and CIO. In this sample, post-injury psychological distress and prior concussion history as separate predictors of post-injury SCI supported my hypotheses.

Athletes who experienced greater psychological distress across anxiety, depression, and somatization at post-injury were more likely to also report, and in greater severity, memory difficulties and confusion than athletes who did not. This finding supports previous research documenting correlational and predictive relationships between psychological distress and cognitive SRC symptoms (Brooks et al., 2016; Clarke et al., 2012; Cottle et al., 2017; Edmed & Sullivan, 2012; Hromas et al., 2020; Lange et al., 2011). Anxiety, depression, and somatization often interfere with cognitive abilities such as attention, memory, and processing speed (American Psychiatric Association, 2013; Arnett et al., 2019; Hall et al., 2011). These mental health conditions are also common in SRC (Arnett et al., 2019; McCrory, Meeuwisse, Dvořák, et al., 2017). Furthermore, previous research has shown higher levels of anxiety and depression to be associated with poorer cognitive performance from adolescent and young adult athletes at baseline and postconcussion (Arnett et al., 2019; Bailey et al., 2010; Meyer & Arnett, 2017). The data from the present study did not support a significant correlation between psychological distress and OCI, which is likely due to methodological parameters and limitations (e.g., specific cutoffs for defining OCI as a dichotomous variable, low cases of detected OCI). Low statistical power also likely contributed to the nonsignificant findings of regression models of psychological distress in predicting baseline SCI and post-injury CIO although results approached statistical significance. Nevertheless, psychological distress was related to, and a predictor of, post-injury SCI, which suggests psychological distress influences athletes' endorsements of cognitive symptoms of their SRC. Psychological distress may also be a factor driving presentations of cognitive impairment overestimation based on athletes' perceptions of cognitive dysfunction.

Prior concussion history was also related to and a predictor of post-injury SCI in the present study. Prior concussion history has been shown to be associated with increased symptom reporting from athletes at baseline and post-injury assessment across multiple studies ((Brooks et al., 2013; 2016; Covassin et al., 2013; Register-Mihalik et al., 2009). The present study, however, did not support this hypothesis with respect to reports of cognitive SRC symptoms specifically. Rather, upon examination of cognitive SRC symptoms exclusively, athletes with at last one past concussion were over 80% less likely to endorse symptoms of cognitive impairment than athletes with no past concussion. Based on evidence from previous research, plausible reasons for decreased likelihood of cognitive symptom endorsements from athletes with prior concussions include poor self-awareness or detection (Robertson & Schmitter-Edgecombe, 2015; Sherer et al., 2003), intentional underreporting (Bruce & Echemendia, 2004; Delaney et al., 2015; 2018; McCrea et al., 2004; Register-Mihalik et al., 2013), and desensitization (Broglio et al., 2007; Bruce & Echemendia, 2004; McClincy et al., 2006) of cognitive difficulties.

Theoretical and Clinical Implications

The integrated symptom model (Kolk et al., 2003) does not account for one's perception, interpretation, and experiences of cognitive symptoms. Through the present study, I attempted to investigate potential antecedents (i.e., prior concussion history, neurodevelopmental disorder diagnosis) and concurrent internal and external information (i.e., psychological distress, level of play, assessment timepoint) to elucidate the mechanisms to athletes' perception, interpretation, and endorsement of cognition-based SRC symptoms. Based on the results, past concussion(s) is not an antecedent to endorsed cognitive symptom experience as initially conceptualized from past evidence (Brooks et al., 2016; Gardener, 2020); rather, no history of concussions prior to their SRC appears to be an antecedent, or a preinjury factor, of athletes' endorsements of cognitive difficulties. Psychological distress also seems to fit in this model as concurrent psychological attributions and experienced symptoms in relation to prospective measurement of cognitive symptoms, which is different from its relation to physical symptoms when only measured retrospectively (Kolk et al., 2003). In other words, cognitive and affective/psychological symptoms are at tandem to perceived and endorsed dysfunction from the SRC. The remaining variables do not appear to apply to the integrated symptom model of SRC cognitive symptoms for this sample of elite athletes. However, this interpretation must be treated with caution due to restricted methodological parameters (e.g., application of nonparametric analyses, specificity of SCI and OCI operationalizations). These parameters are further described in the Strengths and Limitations section of this discussion.

The majority of athletes in this sample did not endorse cognitive symptoms. They also demonstrated adequate cognitive performance through ImPACT verbal and visual memory composite scores, which makes their self-assessments of cognitive functioning consistent with their actual functioning. Although few in prevalence, there were cases of postconcussion cognitive impairment discrepancies that warranted attention. Of the athletes who demonstrated OCI since their SRC (n = 6), half of them did not endorse experiencing cognitive symptoms (i.e., CIU; n = 3), meaning there were an equal amount of "hit" (i.e., endorsement of SCI when OCI is present) and "miss" (i.e., no SCI when OCI is present) reports of cognitive impairment. It is possible these athletes perceived cognitive problems at the time of completing the S3SE, but did not endorse them for several reasons. Common themes athletes disclosed to be barriers to reporting concussion symptoms, as found in qualitative studies, include uncertainty of the symptoms being due to the concussive injury and low/no severity in the symptom (Chrisman et al., 2013; Kerr et al., 2016; Kneavel et al., 2019; Sanderson et al., 2017). However, these barriers are unlikely to apply to the current cohort of athletes due to their concussion assessment protocols at the time of data collection. Athletes were removed from play by team medical staff to assess for acute dysfunction from their injury. Although one post-injury assessment was analyzed in the present study, the primary study (i.e., Active Rehab Study) included multiple post-injury assessment timepoints (e.g., 1 month post-injury). Furthermore, athletes are instructed to endorse any listed symptoms they experience at the time of the post-injury assessment (or any symptoms they typically experience throughout the day at baseline), regardless of the symptom being due to concussion or otherwise. These factors reduce the likelihood of athletes perceiving cognitive problems and not appraising them to be relevant or serious enough to endorse. With such considerations in mind, there are two major possibilities. First, elite athletes may not typically present with skewed perceptions of their cognitive functioning. Second, as the current literature suggests in studies that apply the Theory of Planned Behavior (TPB; Ajzen, 1991), there are likely other internal and external factors influencing these athletes' reporting behaviors (Baugh et al., 2014; Delaney et al., 2015; 2018; Kroshus et al., 2014; Register-Mihalik et al., 2013).

Of the few athletes who perceived, interpreted, and endorsed cognitive difficulties (i.e., SCI) at postconcussion ($n = 9$), 66% of them demonstrated endorsed SCI when OCI was not present (i.e., CIO; $n = 6$). In other words, there were more "false alarm" reports of cognitive impairment than of "hits". These athletes may have had a greater sensitivity to detecting sensations associated with dysfunction from their SRC. For example, Bruce and Echemendia (2004) found fewer symptom reports from recently concussed male collegiate athletes with prior concussion history (PC) than from recently concussed players with no prior concussions (NPC) at 2 hours post-injury, yet similar symptom reports at 48 hours post-injury and greater symptom reports at 1 week post-injury. These data imply that, although PC athletes endorsed symptoms for longer periods of time than NPC athletes, the latter endorsed more symptoms immediately after the concussion. These athletes are not familiar with concussion symptoms like PC athletes, which likely increased their distress and endorsements of symptoms (Bruce & Echemendia, 2004). In relation to the current study findings, athletes with prior concussion history may be less likely to endorse cognitive symptoms because they are familiar with, and are less distressed by, the perceptual and somatic changes from the SRC.

Based on the current findings of SCI not predicting OCI and of cases of CIO, SRC symptoms may be its own sufficient indicator of postconcussion dysfunction without the necessity of OCI or injury-specific signs of SRC dysfunction to be present. In other words, athletes who endorse postconcussion symptoms that are distressing to them, regardless of whether or not their cognitive functioning was impaired, can be indicative of postconcussion syndrome (PCS) and poor functional outcomes post-SRC. One study found that greater endorsements of Post-Concussion Symptoms Scale (PCSS) items from the cognitive-migraine-fatigue cluster (see Kontos et al., 2012) within 1 week of their SRC did not predict cognitive impairment through ImPACT testing at 2-4 weeks post-injury; however, it did predict, along with PCSS symptoms from the affective cluster, perceived postconcussion symptom burden at the follow-up visit (Cohen et al., 2020). Although neurocognitive testing has been helpful to increase sensitivity in detection of SRC (van Kampen et al., 2006; Alsalaheen et al., 2016), OCI may not be required or relevant to diagnose SRC or, over time, PCS in the context of what athletes are experiencing. For example, Skandsen and colleagues (2021) found personal preinjury factors (i.e., higher neuroticism, preinjury pain and other somatic symptoms, symptoms of ADHD) were more predictive of worse postconcussion outcomes at 3 months post-mTBI than injury-related variables (i.e., CT scan abnormalities and posttraumatic amnesia). Altogether, from a clinical perspective, athletes may present with different symptomatic profiles of SRC-related impairment and/or PCS that delineate from the typical presentation of cognitive deficits, which calls for not just multimethod assessment of concussion for diagnostic purposes, but also for multimethod assessment of targets for concussion intervention through evidence-based treatments (Musahl et al., 2018).

The definition and assessment of cognitive impairment in SRC should be reevaluated based on the present findings. The ImPACT and SAC are the most widely used tools to assess cognitive dysfunction from SRC (Asalaheen et al., 2016; LeMonda et al., 2017), and ample evidence exists on the validity and reliability of these measures (Asalaheen et al., 2016; Barr & McCrea, 2001; Guskiewicz et al., 2013; Lovell, 2016). However, the ImPACT and the SAC are not exhaustive in their measurements of cognitive processes. Domains of cognitive functioning measured through these tools include memory, processing speed, reaction time, impulsive responses, and attention and concentration. However, there are other cognitive processes not formally assessed through these measures, including distorted negative thinking patterns that manifest from excessive worry and negative outlooks on self, the future, and the world. Such distorted thinking are symptoms of anxiety and depression (APA, 2013), which can be potential mental health outcomes to SRC (Arnett et al., 2019; Kerr et al., 2014; Meyer & Arnett, 2017; Rice et al., 2018) and, based on findings from the present study, predict baseline and post-injury endorsements of cognitive impairment. Thus, the representation of the ImPACT and the SAC as indicators of cognitive impairment in SRC may be insufficient; there should be consideration of additional cognitive domains in assessments of post-SRC sequelae that reflect on psychological distress.

Strengths and Limitations

The present study has some strengths such as being the first in an attempt to define SCI and OCI in sports concussion through a process of group membership that accounted for both group normative differences (i.e., deviations from sample mean scores) and individual athlete differences (i.e., RCI) of correlated variables within this sample. Comprehensiveness in the differentiation between adequate cognitive functioning and impairment is important because examination through one area (i.e., group differences vs. individual differences) can be misleading with respect to the presence of cognitive dysfunction (Iverson et al., 2003). It is also the first study to examine cognitive impairment discrepancies in sports concussion with operational definitions of cognitive impairment overestimation and underestimation. There are several studies with examinations of (a) commonalities and differences between subjective and objective measures of concussion (e.g., Brooks et al., 2016; Fazio et al., 2007), (b) predictors of postconcussion dysfunction (e.g., Broglio et al., 2006; Cohen et al., 2020; Skandsen et al., 2021), and (c) predictors of concussion symptom (under)reporting behaviors (e.g., Kerr et al., 2016; Kroshus et al., 2014). However, there is a gap in the literature that does not explicitly address discrepancies between scores from objective and subjective measures of postconcussion cognitive impairment. One recent study started to address this issue by examining factors that may be associated with discrepancies between subjective and objective indicators of cognitive functioning from 86 participants who sustained a concussive injury (Hromas et al., 2020). The present study added to this gap with a more specific examination of discrepancy in cognitive impairment rather than cognitive functioning, and within SRC rather than within multiple sources of concussion. To my knowledge, the present study is the first project to add to the SRC literature an exclusive analysis of cognitive symptoms rather than all symptom types (i.e., somatic and affective). This is an important strength because it eliminated other symptom items as confounding variables to the relationship between, discrepancies between, and predictors of, subjective and objective cognitive impairment.

There were also limitations to the present study. First, because many of the variables from the dataset violated statistical assumptions (e.g., normality, linearity, independence, homoscedasticity, and expected frequencies), the statistical power and rigor of analyses were limited such that nonparametric tests were necessary to address the research questions. Parametric tests are considered to be more rigorous with greater statistical power because they require smaller sample sizes and they are more sensitive in detection of significant effects compared to nonparametric tests (Field, 2018; Tabachnick & Fidell, 2012). In combination with the small sample size obtained for the present study ($N = 40$), it is possible some of the results reflect type-II error such that the tests show no effects when they actually exist. We can say with greater certainty, however, that the detected significant effects exist because a less powerful test managed to detect the effect despite the small sample size. Second, the number of observations of SCI and OCI were sparse, which also compromised statistical power for analyses. It is possible the variables used to operationally define SCI and OCI were too specific with just two cognitive symptom items (SCI) and two memory composite scores (OCI). Confirmatory factor analyses (CFA) would have been helpful to ascertain which variables best represented each construct for this sample of athletes; however, the small sample size prevented such analyses to be effective for the measures used in the present study. In a study that determined changes in sample size requirements for CFA and other structural equation models (SEM) based on number of factors, number of indicators per factor, and factor loading values (Wolf et al., 2013), a sample size of 40 is suitable for a one-factor model with 4-8 indicators and a minimum factor loading of 0.80. This factor loading is difficult to obtain when identifying specific factors for a measure with evidence of a primary factor and items that load onto multiple additional factors (Brett et al., 2020). Thus, a CFA was not feasible to conduct effectively, which led to the use of correlation analyses across both baseline and post-injury data to develop SCI and OCI. Third, the observational design of the present study precluded my ability to control and manipulate variables and to make assumptions about causal relationships between variables. For instance, I am not able to conclude that athletes' psychological distress caused endorsements of SCI. Nevertheless, the conditions for data collection were both as natural and as controlled as possible within both the team organization's (i.e., the CFL, the University of Alberta) concussion assessment protocols and the Active Rehab (i.e., the primary study) research protocols. Specifically, concussion assessments were conducted in each team's stadium during preseason medical days (i.e., baseline) and/or after the athlete's concussive injury. These protocols align with the Sports Laboratory Assessment Model (SLAM), an idiographic model for mTBI assessment found to be optimal for tracking residual cognitive deficits from concussive injuries (Bailey et al., 2010; Barth et al., 1989). Thus, the design of the present study has increased internal validity such that it captures the authenticity of concussion assessment administration and results for elite athletes, particularly Canadian football players.

Future Research Directions

The ability to generalize the results to other athletic populations (e.g., youth athletes, athletes in different sports, female athletes, athletes from different countries) is also limited. Thus, the first suggestion to future research is to include multiple athletic populations to increase external validity of understanding cognitive impairment assessment results in SRC. This expansion of the sample pool would likely increase the sample size, also increasing statistical power for data analyses (Field, 2018; Tabachnick & Fidell, 2012). Future research should also continue to examine relationships between symptom endorsements and cognitive performance, though with closer inspection of each cluster of symptoms and/or of each symptom item. The current study and recent studies (Cohen et al., 2020; Hromas et al., 2020) are starts to narrower investigations of symptom endorsements (specifically cognitive symptoms) in relation to cognitive performance; however, to my knowledge, we have yet to know whether or not specific cluster(s) or individual items of the S3SE are related to ImPACT scores. One way to address this inquiry is to compare each S3SE symptom cluster score between athletes with the most severe OCI (e.g., ImPACT composite scores at least 2 SD lower from the mean) and athletes with no clinical evidence of OCI (i.e., ImPACT composite scores at most 1 SD lower from the mean). To better ascertain the S3SE symptom clusters to use for the elite athlete population, a CFA of this measure should be included in the project. Another direction of research is to incorporate a longitudinal design with concussion assessments across multiple seasons of an athlete's career. This design would be beneficial for researchers to examine differences in symptom endorsements and cognitive performance across post-injury assessments at different times since the SRC, as well as across multiple baseline assessments to further clarify the relationship between prior concussion history and symptom endorsement and/or cognitive performance.

Finally, continuation of research on discrepancies between SRC-related cognitive impairment indicators is needed, including inquiries about representativeness of subjective and objective cognitive impairment indicators, the prevalence of each type of discrepancy, and factors associated with and/or predictive of discrepant results.

Conclusion

In summary, consistency in results between subjective and objective indicators of cognitive impairment through the tools used to assess elite Canadian football players appeared to be high. However, endorsement of memory difficulties and/or confusion and verbal memory composite scores was the only significant relationship found between SCI and OCI. Although few in number within this sample, there were cases of overestimation and underestimation of cognitive impairment when comparing symptom reports and cognitive performance scores. Higher post-injury psychological distress scores predicted SCI detection. Although we cannot definitively say it also predicts CIO based on these data, there is some evidence that psychological distress plays a role in how athletes perceive, appraise, and report cognitive impairment. Prior concussion history, conversely, decreased the likelihood of SCI detection. The current literature shows exploration of reasons as to why athletes do not report symptoms, though future research continues to be necessary to understand which factors apply under which circumstances. This is also true with respect to understanding detection of OCI and CIU; in the present study, cognitive symptom reports, prior concussion history, and other personal factors were not predictive of these outcomes.

The findings from the present study contribute to the ongoing inquiries about the utility and implications of multimethod SRC assessments. Neuropsychological testing of cognitive dysfunction has been shown through decades of research to be beneficial to determine the diagnosis of SRC (McCrea et al., 2017; Webbe & Zimmer, 2014). With respect to assessing SRC through symptomatology, however, the extent of cognitive symptoms contributing to perceived and appraised dysfunction by athletes is unclear, and may not hold as much weight to endorsements of postconcussive dysfunction compared to somatic and affective symptoms. Additionally, cognitive deficits as currently defined by the assessed domains of SRC-related cognitive functioning (i.e., memory, visual and auditory processing, reaction time, attention and concentration) may not be indicative of SRC-related dysfunction; athletes who present with many and/or severe SRC symptoms though demonstrate adequate cognitive performance should not be dismissed from an SRC diagnosis or intervention. These interpretations raise additional questions about SRC assessment development. For example, is there clinical utility to include clinical mental health measures as part of the SRC assessment protocol? Should other facets of cognitive functioning (e.g., distorted thinking patterns, problem-solving) also be assessed? Are there additional or other tools that measure cognitive functioning that should be considered upon developing a battery to assess for SRC? Individualized consideration to clinical decision-making in SRC diagnosis, management, and treatment are also implied based on the current findings. Specifically, if an athlete's cognitive functioning remains at or returns to baseline scores regardless of perceived dysfunction, then targets for intervention and rehabilitation toward RTP should accommodate to addressing their psychological distress and endorsed symptoms. SRC is a complex condition that renders continuous extensive research to understand how to best support athletes who are vulnerable to postconcussive dysfunction, especially when multimethod assessment results are not straightforward to interpret.

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Appendix A: Measures

Sport Concussion Assessment Tool—Third Edition (SCAT3)
*For use by medical professionals only

I. Symptom Evaluation (S3SE)

Instructions: "You should score yourself on the following symptoms, based on how you feel now".

Symptom	None	Mild		Moderate		Severe	
Headache	0	1	2	3	4	5	6
"Pressure in the head"	0	1	2	3	4	5	6
Neck pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or anxious	0	1	2	3	4	5	6

Total number of symptoms (Maximum possible 22): ________
Symptom severity score (Maximum possible 132): ________

II. Standardized Concussion Assessment (SAC)

A. Orientation (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1

Orientation Score: ________ (of 5)

B. Immediate Memory Recall

List	Trial 1		Trial 2		Trial 3		Alternative word list		
elbow	0	1	0	1	0	1	candle	baby	finger
apple	0	1	0	1	0	1	paper	monkey	penny
carpet	0	1	0	1	0	1	sugar	perfume	blanket
saddle	0	1	0	1	0	1	sandwich	sunset	lemon
bubble	0	1	0	1	0	1	wagon	iron	insect

Immediate Memory Score Total: ________ (of 15)

C. Concentration

Digits Backward

List	Trial 1		Alternative digit list		
4-9-3	0	1	5-2-6	6-2-9	4-1-5
3-8-1-4	0	1	3-2-7-9	1-7-9-5	4-9-6-8
6-2-9-7-1	0	1	3-8-5-2-7	1-5-2-8-6	6-1-8-4-3
7-1-8-4-6-2	0	1	8-3-1-9-6-4	5-3-9-1-4-8	7-2-4-8-5-6

Total: ________ (of 4)

Month in Reverse Order (1 pt. for entire sequence correct)

Dec-Nov-Oct-Sept-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan	0	1

Total: ________ (of 1)

Concentration Score: ________ (out of 5)

D. Delayed Memory Recall

Delayed Memory Recall Score: ________ (out of 5)

SAC Total Score: ________ (out of 30)

ACTIVE REHAB

Brief Symptom Inventory 18 (BSI-18)

0a. Date assessment completed: ______ /_______/_________ Participant ID: ___________________

0b. Clinician initials: _______________

0c. Form completed: ☐ Online (1) ☐ On Paper (2)

If on paper:
0d. Initials of person completing data entry: ____________

0e. Data entry date: ________/ _______/ _____________

BSI-18

Below is a list of problems people sometimes have. Read each one carefully and mark the number that best describes HOW MUCH THAT PROBLEM HAS DISTRESSED OR BOTHERED YOU DURING THE PAST 7 DAYS INCLUDING TODAY.
Do not skip any items.

How much were you distressed by:	Not at all	A little bit	Moderately	Quite a bit	Extremely
1. Faintness or dizziness	0	1	2	3	4
2. Feeling no interest in things	0	1	2	3	4
3. Nervousness or shakiness inside	0	1	2	3	4
4. Pains in the heart or chest	0	1	2	3	4
5. Feeling lonely	0	1	2	3	4
6. Feeling tense or keyed up	0	1	2	3	4
7. Nausea or upset stomach	0	1	2	3	4
8. Feeling blue	0	1	2	3	4
9. Suddenly scared for no reason	0	1	2	3	4
10. Trouble getting your breath	0	1	2	3	4
11. Feeling of worthlessness	0	1	2	3	4
12. Spells of terror or panic	0	1	2	3	4
13. Numbness or tingling in parts of your body	0	1	2	3	4
14. Feeling hopelessness about the future	0	1	2	3	4
15. Feeling so restless you couldn't sit still	0	1	2	3	4
16. Feeling weak in parts of your body	0	1	2	3	4
17. Thoughts of ending your life	0	1	2	3	4
18. Feeling fearful	0	1	2	3	4

Appendix B: Consent Form

Consent to Participate in a Research Study

Title of Study: Role of Rehabilitation in Concussion Management: A Randomized, Controlled Trial
Principal Investigator: Johna Register-Mihalik, University of North Carolina

Co-Investigators: Kevin Guskiewicz, Mike McCrea, Steve Marshall, Karen McCulloch, Jason Mihalik
Canadian Site-Investigators: Dr. Martin Mrazik, Dr. Dhiren Naidu, University of Alberta
Funding Source and/or Sponsor: National Football League (NFL) Foundation

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<u>What is the purpose of this study?</u>
The potential benefit of introducing a program of active rehabilitation *during* symptom recovery following has been proposed as a new method for injury management, but there have been no studies that help us understand how this might help with recovery and function after concussion. The purpose of this study is to understand what types of activities improve outcomes following a concussion. You are being asked to be in the study because you are currently an active collegiate athlete.

<u>Are there any reasons you should not be in this study?</u> As long as you are an athlete on a team, there is no reason you should not be in the study.

<u>How many people will take part in this study?</u> Approximately 6,600 participants from high schools, colleges/universities, and professional organizations (Canadian Football League) will participate in this study.

<u>How long will your part in this study last?</u> If you only complete the baseline assessment, your time will only last the 1 hour and 30 minutes it takes to complete the baseline assessment. Should you complete the post-injury assessments and either set of study rehabilitation activities (graded exertion only OR multidimensional), your participation would include this baseline assessment and would last until 1-month following the concussion that triggered your entrance into the rehabilitation activities.

<u>What will happen if you take part in the study?</u> This is a randomized control trial and your team may either be randomized to the multidimensional rehabilitation group (MDR) or enhanced graded exertion (EGE) group.

You will complete the following as part of the study:

- Pre-season baseline tests (many that are similar to previous baseline medical evaluations) of your thinking/memory, symptoms, balance, coordination, vision, quality of life, demographics, and medical history.
- If you are concussed and complete the post-injury activities, you would also complete these same measures (except medical history) more detailed demographics and a timed gait/memory task 24-48 hours post-concussion, when you no longer have symptoms, and 1-month after your concussion.
- At the 1-month assessment, you will also complete some questions about your experience in the study and the care you received.
- From 24-48 hours after the injury you *along with your Athletic Therapist,* will also be asked to track your activities (physical and cognitive) and your symptoms each day until 7 days after you have fully returned to participating in your sport. The study team *from the University of Alberta* will also track your care over the period of your concussion recovery.

- Rehab exercises, supervised by a medical provider *(team physicians and Athletic Therapists)* at your site, that work on your thinking, balance, vision, and general well-being four times per week until you have fully returned to play in your sport.
- Once you no longer have symptoms, you will continue to be progressed through the graded exertion protocol (per above), while continuing your rehabilitation (graded exertion or multidimensional) exercises, supervised by *your team physician and Athletic Therapist* at your site, until you fully return to play.

What are the possible benefits from being in this study? Research is designed to benefit society by gaining new knowledge. You may benefit from the exercises during the rehabilitation post-injury paradigm.

What are the possible risks or discomforts involved from being in this study? Your risk of experiencing discomfort or issues as a result of the assessments is minimal. However, when participating in the graded exertion or the multidimensional activities (should you be in this group), you may experience increases in symptoms or other unknown discomforts. You should report these to the researchers and/or medical professionals from *your team*. *Your team physician* will decide if you need to stop exercises or activities during an assessment or exercise session. In addition, should you feel you need to stop, you may do so at any time. The research staff and medical professionals at your school will help you get follow-up care if needed. There may be uncommon or previously unknown risks and you should report any problems to the researcher listed at the back.

If you choose not to be in the study, what other treatment options do you have? You do not have to be in this research study in order to receive treatment. You should reach out to *your team physician and/or team Athletic Therapist* for additional treatment options.

What if we learn about new findings or information during the study? You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

How will information about you be protected? You will be assessed and if you complete post-injury exercise activities, these will occur in your normal athletic training environment. No study-specific data about you will be shared outside the research team or the data center. Data sent to UNC-Chapel Hill will not have personal information. Every participant is given a research identification number that removes personal information. Only the Canadian site investigators will have a master list. You will not be mentioned individually in publications or presentations and all study data will be stored in a secure location.

Participants will not be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies (for example, the FDA) for purposes such as quality control or safety.

What will happen if you are injured by this research? If you become ill or injured as a result of being in this study, you will receive necessary medical treatment, at no additional cost to you. By signing this consent form you are not releasing the investigator(s), institution(s) and/or sponsor(s) from their legal and professional responsibilities. The University of Alberta will provide you medical care.

What if you want to stop before your part in the study is complete? You can withdraw from this study at any time, without penalty. The investigators have the right to stop your participation at any time because you have had an unexpected reaction, failed to follow instructions, or because the entire study has been stopped.

Will you receive anything for being in this study? No compensation is provided for completing this study.

Will it cost you anything to be in this study? It will not cost you anything to be in this study.

Who is sponsoring this study? This research is funded by the National Football League Foundation. This means that the research team is being paid by the sponsor for doing the study.

What if you have questions about this study? You have the right to ask, and have answered, any questions you may have about this research. If you have questions about the study (including payments), complaints, concerns, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form. A description of this clinical trial will be available on www.clinicaltrials.gov, as required by U.S. Law. This website will not include information that can identify you. At most, the website will include a summary of the results. You can search this website at any time.

What if you have questions about your rights as a research participant? All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject, or if you would like to obtain information or offer input, you may contact the Institutional Review Board at the University of Alberta Research Ethics Office at 780-492-2615 or by email to *the University of Alberta (reo@ualberta.ca)*. The study's principle investigator (Johna Register-Mihalik) can be reached at (919) 962-2702 (johnakay@email.unc.edu) and the Canadian Investigator (Martin Mrazik) 780-492-8052 (mrazik@ualberta.ca)

Participant's Agreement: I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

_______________________________________ ________________
Signature of Research Participant Date

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Printed Name of Research Participant

_______________________________________ ________________
Signature of Research Team Member Obtaining Consent Date

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Printed Name of Research Team Member Obtaining Consent