FACTORS THAT INFLUENCE SPORTS-RELATED CONCUSSION MEASURES IN CONTACT, NON-CONTACT SPORTS AND NON-ATHLETES

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DEDICATION

To all my family, friends, faculty, patients, athletes and others who have helped me on my academic journey, I am personally and professionally thankful.

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ABSTRACT

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FACTORS THAT INFLUENCE SPORTS-RELATED CONCUSSION MEASURES IN CONTACT, NON-CONTACT SPORTS AND NON-ATHLETES

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The purpose of this two-study dissertation was to determine how concussion history, career status, cumulative years of football exposure (Study 1), and activity status (Study 2) affect performance on sports-related concussion measures in healthy, elite athletes and non-athletes.

Elite, American football players (Study 1), and elite athletes from all sports and non-athletes (Study 2), between the ages of 18 – 45 years were invited to voluntarily participate. Individuals were excluded if they had a diagnosed concussion within the past 30 days, if they were currently experiencing symptoms preventing return to play/sport or if they were pregnant. Both studies followed a cross-sectional design. Each participant underwent a single session where demographic data, as well as data from a symptom evaluation, neurocognitive testing, and balance testing (Study 1) and additional data from the Vestibular/Ocular-Motor Screening tool (VOMS) and dual-task tandem gait (DT TG) testing (Study 2), were collected.

Data was analyzed utilizing regression modeling, alpha was set to .05, a priori. Results revealed symptom reports from the symptom evaluation and the VOMS were affected by concussion history, activity status, age, and career status. Balance was affected by both concussion history and age. Neurocognitive performance and DT TG were measures not significantly impacted by the outlined factors: concussion history, career status, cumulative years of football exposure, and activity status. Additionally, cumulative years of football exposure was not a significant factor.

Therefore, clinicians should take concussion history, career status, and activity status into consideration when analyzing symptom reports and balance scores, for all patient examinations regardless of their referral diagnosis, secondary to the long-term implications of these factors. Although our studies did not reach the point of significance with contact sports influencing neurocognitive performance and DT performance, we believe further research is needed to explore these relationships to better understand long-term implications associated with concussive and sub-concussive exposure. Thus, a longitudinal study is recommended to explore the long-term effects of contact sports and their effect on neurocognition, balance, and DT TG. Our studies provide foundations for future studies by identifying factors that influence common sports-related concussion measures.

Keywords: concussion, assessment, symptoms, neurocognition, balance, vestibular, ocular motor, dual-task, football, contact athletes, non-contact athletes, non-athletes

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

While carrying several different definitions across the literature, it is widely accepted that a concussion is a mild traumatic brain injury involving biomechanical forces that stimulate a chemical cascade within the brain ultimately leading to a change in homeostatic function (Center for Disease Control and Prevention, 2019; Choe, 2016; Langlois et al., 2006). Sports-related concussions (SRCs) represent a national public health problem, with a reported annual incidence of 1.6 to 3.8 million in the United States alone (Giza & Kutcher, 2014; Merchant-Borna et al., 2016).

Although concussion research has greatly evolved within the last decade, there remains significant gaps in the literature regarding the impact of concussion history and exposure related factors on longer term sequela including symptoms, symptom severity, neurocognitive performance, and balance. Thus, a two-study design was created to address these areas. Study 1 explored the effects of concussion history, career status, and cumulative years of contact football exposure on symptoms, balance, and neurocognitive performance in elite football players. Study 2 explored the same outcome measures as Study 1 and two additional measures: dual-task tandem gait (DT TG) and the Vestibular/Ocular-Motor Screening tool (VOMS), in contact athletes, non-contact athletes, and a non-athlete control group.

While reviewing the literature, nearly every sport has a risk of concussion (Clay et al., 2013). Athletes who compete in contact sports are at a greater risk for sustaining a concussion (Noble & Hesdorffer, 2013). Out of all contact sports, football has the highest incidence of concussions (Clay et al., 2013). Player-to-player contact is the primary mechanism for concussion in football (Daneshvar et al., 2011). Concussions sustained during elite football careers have been associated with acute and chronic neurologic impairment. However, how cumulative sub-concussive impacts contribute to this impairment requires further exploration (Gysland et al., 2012). A sub-concussive impact, blow, or hit is when an impact does not present with concussive "hallmark" symptoms at the time of the impact (Choe, 2016). There is growing concern that sub-concussive impacts may be as equally important as concussive hits. Football participation contributes to possibly thousands of sub-concussive head impacts for a singular player over the course of a season and subsequently a career (Slobounov et al., 2017). Sports-related sub-concussive blows, like concussive blows, have been correlated with alterations in brain function including short-term cognitive deficits (McAllister et al., 2012), decreased brain volume in the thalamus and caudate nucleus (Bernick et al., 2015), and enduring cognitive deficits (Stamm et al., 2015). We believe our studies contribute to this line of inquiry in two ways, first in the elite football athlete, we accounted for career status, cumulative years of football exposure, and concussion history. Second, we included participants who through their sport would regularly experience sub-concussive blows as well as those who would not. Comparing these subgroups provides additional insight into the potential role of sub-concussive blows and how they may influence concussion related symptoms, neurocognitive performance, and balance.

Many studies are exploring neurocognitive differences in athletes with a history of multiple concussions (2+ concussions; Baugh et al., 2015; Guskiewicz et al., 2005; Manley et al., 2017; Mez et al., 2015). Findings suggest that multiple concussions are a risk factor for cognitive neurological degeneration with associated adverse effects in some football players (Guskiewicz et al., 2005; Manley et al., 2017) and there is an association between repetitive brain injuries in contact sports and presenting with motor, cognitive and/or mood disturbances years after injury (Choe, 2016; Mez et al., 2015). Further, pilot data we collected in preparation for the first study suggested that multiple concussion history had an impact on long-term outcomes of football athletes. Thus, in both studies' concussion history was included in the modeling of the data.

Giza and Kutcher (2014) suggested, the presence of chronic neurocognitive impairment is a sequela found particularly in professional athletes with longer exposure to contact sports. There were two thoughts that arose after reading these findings: (1) are these findings due to the high level of play or (2) are they due to longer exposure? Whilst these questions cannot be answered within one research study, one of our studies was designed to expand upon their findings. Specifically, we explored neurocognitive performance within different football career statuses and cumulative years of contact football exposure, and additionally explore symptom reports and balance performance.

The Sport Concussion Assessment Tool (SCAT) was originally designed for on-field examinations of suspected concussions; however, the SCAT has been shown to have further clinical utility, such as offering baseline information (Putukian, 2017), assisting in tracking recovery (McCrory et al., 2017), and patient education (Yengo-Kahn et al., 2016). The SCAT has several versions including the newest version, the fifth edition of the SCAT (SCAT-5). This dissertation involved both the third edition of the SCAT (SCAT-3; Study 1) and the SCAT-5 (Study 2). Both SCAT versions include validated components for assessing concussion related symptoms (both type and severity), neurocognitive performance assessment, and balance assessment. When reviewing the literature there were three studies that analyzed these SCAT component findings in athletes, one in professional hockey players (Hänninen et al., 2015), another in professional rugby players (Fuller et al., 2018), and one in collegiate football players (Shehata et al., 2009). To our knowledge, we are the first authors to examine factors influencing these measures in elite football players. Our second study is a pioneer research study as well, as we are the first to further explore factors influencing performance on these elements of the SCAT in contact athletes, non-contact athletes, and a non-athlete control group.

Sixty percent of individuals who have sustained a concussion present with vestibular and ocular motor impairments and report associated symptoms following a SRC (Kontos et al., 2017). Thus, suggesting the vestibular and ocular motor systems be examined as part of a concussion assessment. Within the literature, the VOMS has been explored in both healthy and concussed individuals within youth, adolescent and collegiate, athlete samples (Kontos et al., 2016; Kontos et al., 2017; Moran et al., 2018 Mucha et al., 2014; Russell-Giller et al., 2018; Worts et al., 2018). However, research exploring the use of the VOMS with elite contact athletes, non-contact athletes, and non-athletes, has not been published at this time. When comparing adolescent athletes who recently sustained a SRC to healthy controls, the VOMS was found to be a sensitive screen, with high internal consistency (Mucha et al., 2014). In samples of healthy, youth athletes and healthy, high school athletes the VOMS was found to have high internal consistency, a low false-positive rate, and high test-retest reliability (Moran et al., 2018). Another study exploring a sample of healthy collegiate athletes found the VOMS to have internal consistency and an acceptable false-positive rate (Worts et al., 2018). Study 2 was designed to explore the influence of activity status groups (contact athletes, non-contact athletes, and non-athletes) on VOMS performance, while adjusting for concussion history.

Impaired postural control and gait deviations are said to be cardinal symptoms post-concussion. When exploring the relationship between TG and concussion, TG has been proven to be an acceptable assessment of postural control following a concussion. Prior literature has found slower gait speeds during TG in concussed individuals (Oldham et al., 2018).

As investigators dive deeper into the effects concussions have on gait performance, the research question is evolving into: How do concurrent cognitive tasks influence gait performance in individuals that have sustained a concussion (Lee et al., 2012)? Normal daily activities and sport require simultaneous cognitive and physical demands (Buckley et al., 2018; Kleiner et al., 2018). A decline in gait performance has been present in individuals who have sustained a concussion during DT testing. Cognitive deficits were reported as still being present for as long as 5 – 12 months, and gait disturbances lasting up to 6 – 12 months post concussive episode (Kleiner et al., 2018). When comparing single task TG and DT TG, individuals who had sustained a concussion took significantly longer to complete the DT TG trials compared to the controls (Howell et al., 2017). Our second study was designed to examine the influence of sport (contact vs non-contact) on TG and DT performance while controlling for concussion history.

Statement of the Problem

There remains a significant gap in the literature regarding factors that may contribute to symptoms, impaired neurocognitive performance and balance deficits following concussion resolution. Factors may include concussion history, career status, and cumulative years of contact football exposure. In addition, it is unclear how the type of sport, contact or non-contact, will influence measures of SRC. It is also unclear if measures of SRC differ between individuals participating in sports and individuals who are not involved in sports.

Purpose of the Studies

The overarching purpose of this two-study dissertation was to fill the gaps within the literature regarding factors that influence SRC measurements in elite athletes and non-athletes. The purpose of the first study was to examine how specific factors of concussion history, career status, and cumulative years of football exposure affect symptoms, neurocognitive performance, and balance. Preliminary findings suggest concussion history and career status have varying degrees of association on symptoms, neurocognition, and balance in elite football players. These findings led to the second research study exploring these measures in all athletes and comparing them to non-athlete controls.

The purpose of the second study was to compare symptoms, neurocognition, balance, vestibular and ocular motor function, and DT performance in contact athletes, non-contact athletes, and non-athletes. Specifically, the SCAT-5 was used to assess symptoms, neurocognitive performance, and balance performance, the VOMS was used to assess vestibular and ocular motor performance, and the DT TG was used to assess dual-task performance.

Study 1

Research Questions

The first study addressed the following questions:

1. Does concussion history affect number of symptoms, symptom severity, neurocognitive performance and balance performance, in elite football players?
2. Does career status of elite football players influence number of symptoms, symptom severity, neurocognitive performance and balance performance?
3. Do cumulative years of contact football exposure influence number of symptoms, symptom severity, neurocognitive performance and balance performance?

Hypotheses

Within the scope of this research study, the following research hypotheses were examined:

1. Controlling for age, elite football players who have been diagnosed with multiple concussions (2+) will present with a greater number of symptoms, greater symptom severity, greater neurocognitive deficits, and greater balance deficits.
2. Controlling for concussion history and player position risk level, the retired professional football players will have a greater number of symptoms, greater symptom severity, greater neurocognitive deficits, and greater balance deficits compared to active professional football players and professional football draft prospects.
3. Controlling for concussion history and player position risk level, elite football players with a greater number of cumulative years of contact football exposure will present with a greater number of symptoms, greater symptom severity, greater neurocognitive deficits, and greater balance deficits.

Significance of the Study

SRCs are currently a subject of intense interest in American football. Despite this interest and changes in acute management, significant gaps remain in our understanding of the longer-term impact of concussions on symptoms, severity of symptoms, neurocognitive performance, and balance. Literature has explored these relationships in collegiate football and professional hockey players; however, our pilot study was the first to examine the impact of concussion history on the number of symptoms, symptom severity, neurocognitive performance, and balance in elite football players. In our preliminary findings ($N = 57$) we found elite football players with a concussion history reported greater symptoms, greater symptoms severity, and greater neurocognitive deficits (Cookinham & Swank, 2019). This study expanded on these findings by exploring the same research question with a greater sample size ($N = 102$) and controlling for age.

Our pilot study also explored the impact of the various levels of elite participation in football (career status) and their performance on elements of the SCAT-3. Findings revealed there was a significant difference between retired professionals and draft prospects with symptom reports, neurocognitive performance and balance performance (Cookinham & Swank, 2019). This study explored this research question in a greater capacity, by expanding the sample size, adding control variables (concussion history and player position risk level) and utilizing more robust statistical analyses.

This study also investigated the influence of cumulative years of contact football exposure. To our knowledge, this has not been studied in elite football players and it is critical to understand the role in the chronic neurocognitive impairments detected during a player's lifetime. Multiple studies support the presence of these chronic impairments, particularly in professional athletes with longer exposure to contact sports (Giza & Kutcher, 2014). Furthermore, research suggests football players sustain 1,000 sub-concussive hits per season (Slobounov et al., 2017); thus, this study investigated if the greater number of years one is exposed to football (individuals enduring greater sub-concussive hits), was related to performance on a SRC measure.

There are many diagnostic tools utilized to evaluate SRC, however no single modality has been sufficient as a stand-alone diagnostic tool. Literature suggests the diagnosis of a concussion be based on a battery of tests; however, the specific battery has not been outlined. Healthcare providers involved in SRC evaluations should understand factors that influence SRC evaluation findings (Dessy et al., 2017), especially since the final return to play decision relies heavily on their clinical judgment (McCrory et al., 2017). We believe the new knowledge generated by Study 1, will contribute to better clinical decision-making as the study will identify some of those factors that influence SRC assessment measures.

Study 2

Research Questions

The second study addressed the following questions:

1. Do symptoms, neurocognitive performance and balance performance differ between contact athletes, non-contact athletes, and non-athletes?
2. Does VOMS performance differ between contact athletes, non-contact athletes, and non-athletes?
3. Does DT TG performance differ between contact athletes, non-contact athletes, and non-athletes?

Hypotheses

Within the scope of this research study, the following research hypotheses were examined:

1. Controlling for concussion history, individuals who participate in contact sports, will have a greater number of symptoms, greater symptom severity, greater neurocognitive deficits and greater balance deficits compared to non-contact athletes, and non-athletes.

2. Controlling for concussion history, individuals who participate in contact sports, will have significantly worse VOMS scores compared to non-contact athletes, and non-athletes.
3. Controlling for concussion history, individuals who participate in contact sports, will have a greater number of cognitive errors, a greater number of physical errors and longer times with DT TG testing, compared to non-contact athletes, and non-athletes.

Significance of the Study

Study 2 was built upon our anticipated findings in Study 1 by addressing some known limitations, including the inclusion of solely elite football players, the lack of a comparison group, and the reliance on primarily subjective self-reported measures. Thus, Study 2 grew from these limitations. We, again, compared the number of symptoms, symptom severity, neurocognitive performance, and balance performance. Two additional measures were added: the VOMS and DT TG performance to assess the visual and vestibular systems, complimenting the Modified Balance Error Scoring System (mBESS) measure utilized in the SCAT. The recruited participants were represented by elite contact sport athletes, non-contact sport athletes, and non-athletes.

This study is important as it controlled for varying levels of exposure relative to concussion risk. The myriad of symptoms, balance disturbances, and cognitive deficits that are consistent with a concussion diagnosis are not exclusive to concussion alone. Many of the symptoms are considered everyday symptoms; thus, this study was able to compare the symptom checklist along with neurocognitive performance as well as the more objective measures of balance, VOMS, and DT TG performance within our groups.

Research exploring the relationship between VOMS testing in subjects comparable to our activity status groups, is not published at this time; however, there is a moderate level of evidence supporting the use of the VOMS within a concussion evaluation for youth athletes and college athletes (Kontos et al., 2016; Kontos et al., 2017; Moran et al., 2018). Upon further review of the literature, we also found a study that utilized similar activity status groups. Although the investigators compared fMRI activation during smooth pursuit eye movements amongst healthy, contact sport athletes, non-contact sport athletes, and non-athletes, they did not delineate any significant findings (Kellar et al., 2018). While, we did not use a fMRI, we believe our study expanded on these findings, as the VOMS not only includes a smooth pursuit assessment, it also includes saccades-horizontal, saccades-vertical, convergence, vestibular ocular reflex-horizontal, vestibular ocular reflex-vertical, and a visual motion sensitivity test, assessment. Thus, one of the second study's aims was to explore the relationship between VOMS and activity status, while controlling for concussion history.

As stated earlier, normal daily activities and sport require simultaneous cognitive and physical demands (Kleiner et al., 2018). Short-term declines in gait performance, specifically decreased gait velocity and increased medial-lateral displacement, was found during DT testing in individuals with a concussion (Kleiner et al., 2018). The long-term effects on gait performance have not been explored. Thus, we had chosen to explore DT

TG performance as well, within our activity status groups, while controlling for concussion history.

Study 2 extended upon the generalizability of the concussion history knowledge gained in Study 1 by testing it in different populations. By including a non-athlete control group, we were able to gain a better understanding of what the standard concussion measures represent. Further, we believe this study delineated the influence of sport participation on concussion measures. Inherently contributing to clinical practice, as an understanding of these additional factors will lead to better informed clinical decision making.

Operational Definitions

1. *Activity status groups* are defined as contact athletes, non-contact athletes, and non-athletes.
2. *Balance deficits* are defined by any errors noted on the mBESS or any composite score greater than zero.
3. *Career status groups* are comprised of elite, American, football players and characterized as professional draft prospects (an athlete who had an invitation to the NFL combine or professional athlete tryout event), active professional players, and retired professional players.
4. *Concussion* were self-reported by the participants. Participants were asked to report the number of concussions they have had diagnosed by medical professionals.

5. *Concussion history* (*Study 1*) used in the context of "high" or "low", is regarding the frequency of concussions reported within one's medical history. Low concussion history is the term used when 0 – 1 concussions were self-reported as part of one's medical history; High concussion history is the term used when 2 or more concussions were self-reported as part of one's medical history (Yumul & McKinlay, 2016).
6. *Concussion history* (*Study 2*) used in the context of "yes" or "no", is regarding whether or not a concussion has been reported within one's medical history. For participants that had "no" history of a concussion—they reported zero diagnosed concussions within their medical history. For participants that reported "yes" they had a history of concussion(s)—they reported 1 or more diagnosed concussion(s) within their medical history.
7. *Contact sport athletes* are considered "elite" if they are/were part of a professional or semi-professional athletic organization, if they had received invitations to work out with professional/semi-professional organizations, if they have competed at a National Governing Body sanctioned Olympic/National event or are considered a National Collegiate Athletic Association (NCAA) athlete. This individual specifically participates in a sport that involves physical contact with other players or has a high incidence of contact with physical structures/apparatuses. Contact sport athletes are considered a high risk for concussions. Examples include football, soccer, basketball, mixed martial arts, gymnastics, etc.

8. *Cumulative years of football exposure* is the number of years an individual has played contact football.
9. *Neurocognitive performance* was assessed utilizing the Standardized Assessment of Concussion (SAC), which is cumulative measure scoring between 0 – 30 (higher scores indicate better performance).
10. *Non-athletes* were individuals who did not play high school sports or only participated in non-contact high school sports and it had been at least five years since their participation.
11. *Non-contact sport athletes* are considered “elite” if they are/were part of a professional or semi-professional athletic organization, if they had received invitations to work out with professional/semi-professional organizations, if they have competed at a National Governing Body sanctioned Olympic/National event or are considered a NCAA athlete. “Elite” criteria also included: individuals with a qualifying time for a: major marathon (New York, Boston, or Chicago), triathlon (gold/silver level) or Ironman race. Non-contact sport athletes partake in a sport that does not require physical contact and the rules of the game do not require touching an opponent. Non-contact sport athletes are considered a low risk for concussions. Examples include running, triathlon, cycling, swimming, etc.
12. *Player position risk level* was categorized by football positions that had a high risk (tight ends, running backs, wide receivers, and corners backs/defensive

backs), and low risk (offensive lineman, defensive lineman, linebacker, and quarterbacks) of sustaining a SRC (Dai et al., 2018).

13. *Symptoms* were assessed using the SCAT and measured as a count score 0 – 22 (0 being no symptoms, 22 being all the symptoms).
14. *Symptom Severity* was measured using a Likert scale of severity for each of the 22 symptoms on the symptom's component of the SCAT. Scores could range from 0 – 132 with higher scores indicating greater symptom severity.

Assumptions and Limitations

Assumptions

The following assumptions apply to this study:

1. Participants truthfully reported their previous medical history including their concussion history.
2. Participants truthfully reported their current health status in order to ensure appropriateness to participate.
3. Participants truthfully reported their current symptoms and symptom severity in efforts to attain the most accurate results.
4. The mBESS is an accurate measure of balance.
5. The SAC effectively measures neurocognition.
6. The VOMS accurately measures the vestibular and ocular motor systems.
7. DT TG is an effective measure of gait performance.

Limitations

The following limitations were anticipated for this study:

1. The participants were recruited from a sample of convenience.
2. The cross-sectional single assessment design could potentially limit the generalizability and limit ability to draw conclusions about associations, not causation.
3. Participants may not have disclosed their concussion history, and the study relied on self-report for concussion history.
4. Self-reported previous medical history (specifically, prior diagnosed concussions) adds a greater degree of variability which adds to the difficulty in examining the factors.
5. The mBESS has an element of subjectivity, and observation via the human eye allows room for error.
6. The VOMS is primarily based on subjective report of symptoms.
7. DT TG was measured with a stopwatch and there is risk for human error when measuring time.
8. Age may have limited performance on certain testing procedures (including balance and cognitive measures) and been a confounding variable.
9. The SCAT-3 instrument evolved to the SCAT-5. Study 1 used the SCAT-3 and Study 2 used the SCAT-5 for data collection. However, the elements used from each SCAT version were identical with only small differences in the manner in which they are collected.

CHAPTER II

LITERATURE REVIEW

Sports-Related Concussions

Introduction

Concussions are a mild traumatic brain injury involving biomechanical forces, which induce a neurometabolic cascade within the brain, ultimately leading to alterations in homeostatic function (Choe, 2016; Langlois et al., 2006; Williams et al., 2015; Worley, 2019). SRCs have an incidence of 1.6 to 3.8 million athletes per year in the United States (McPherson et al., 2019). Concussions are an ongoing concern for health care practitioners (Mucha & Trbovich, 2019).

This literature review will begin with a discussion of concussions including the pathophysiology of concussions, incidence of SRC, evaluation of SRC, and long-term outcomes from concussions. The chapter will end with a discussion regarding identified gaps within the existing literature and how our research questions will address those gaps.

Pathophysiology

The rapid acceleration/deceleration experienced in the brain during a concussion causes a complex cascade of neurochemical and neuro-metabolic events including a stretch of the axonal membranes and neurons, causing physical membrane defects and an influx in ion channels (Signoretti et al., 2011). Excitatory proteins are released along with a multitude of neurotransmitters causing a change in neuron homeostasis, leading to neuronal depolarization and an increase in calcium and hyper-glycolysis (Chancellor et al., 2019; Seifert & Shipman, 2015). The imbalance between cellular ions causes mitochondrial calcium to overload and bombard cellular membrane permeability, inherently causing malfunction and swelling (Moy, 2013; Signoretti et al., 2011). The net effects cause a decrease in cerebral blood flow and an increase in energy demand (Moy, 2013), with persistent deficits until brain glucose utilization is restored (Choe, 2016).

The term concussion is diversely defined across the scientific literature and within clinical practice (Chancellor et al., 2019). Thus, the definition that will be used for the purposes of this dissertation is as follows: a concussion is defined as a mild traumatic brain injury involving biomechanical forces that stimulates a chemical cascade within the brain ultimately leading to a change in homeostatic function (Center for Disease Control and Prevention, 2019; Choe, 2016; Langlois et al., 2006).

Epidemiology

Approximately 2.8 million traumatic brain injuries are documented within United States' emergency departments each year. Approximately 75% to 90% of the traumatic brain injuries were classified as concussions (mild traumatic brain injuries; Worley, 2019). Whereas, SRC have an incidence of 1.6 to 3.8 million athletes per year in the United States (McPherson et al., 2019; Wasserman et al., 2015), which accounted for 5 – 9% of all sport related injuries (Harmon et al., 2013). It is suggested that nearly 50% of SRC go unreported (Worley, 2019) for a myriad of reasons including difficulty in diagnosing, lack of sensitive diagnostic imaging, and inconsistent definitions (Choe, 2016). Additionally, the subjective nature of symptom reporting may interfere with the validity to the epidemiology of SRC (Yengo-Kahn et al., 2016).

Concussions occur in all sports (Harmon et al., 2013), with the highest incidence in football (Choe, 2016), female soccer, male soccer, wrestling, and female basketball (Clay et al., 2013). Females have been found to have a greater incidence compared to males, and youth athletes have a greater incidence compared to collegiate athletes. While, it is well established that, athletes that compete in contact sports are at a greater risk for sustaining concussions (Noble & Hesdorffer, 2013), the concussion risk levels within non-contact sport athlete and the non-athlete populations are not well established.

Professional football has become a focal point within SRC epidemiology and intervention (Nathanson et al., 2016). Within the National Football League (NFL) there is an average of 0.61-0.66 concussions per game (Nathanson et al., 2016; Thomson et al., 2020) and 645 SRC reported in a season (Teramoto et al., 2017). However, with the NFL underreporting concussions, those recorded SRC numbers are thought to be greater (Thomson et al., 2020).

All football players are at risk for a concussion and sub-concussive impacts; however, recent literature is exploring concussion risk based on position. NFL offensive skills players have a significantly greater risk of obtaining a SRC (Nathanson et al., 2016), specifically players involved in passing plays (Teramoto et al., 2017). Tight ends, running backs, wide receivers were considered high-risk positions and while corner backs are defensive players they were also listed as a high-risk position (Dai et al., 2018).

Approximately 61% of retired NFL players (*N* = 2552) reported having sustained at least one concussion during their professional football careers (Guskiewicz et al., 2007; Thomson et al., 2020), whereas, within Cookinham and Swank's (2019) pilot study, their sample of retired NFL players (*N* = 24) revealed 88% had sustained at least one concussion during their careers (Cookinham & Swank, 2019). In another sample of retired NFL players (*N* = 34), the average number of concussions sustained throughout their careers was 4.00 (Hart et al., 2013; Thomson et al., 2020); while other researchers found, on average, their retired NFL player sample (*N* = 24) had sustained 5.67 concussions throughout their careers (Cookinham & Swank, 2019). However, there is limited evidence exploring the lasting impacts of concussion within this population (Thomson et al., 2020).

Evaluation

While, there is no gold standard measurement to assess SRC, the literature does suggest a comprehensive concussion evaluation should include a battery of tests (Committee on Sports-Related Concussions in Youth, et al., 2014). Components of the battery should include: symptom scores (number of symptoms and symptom severity), evaluation of postural control (Hunt & Ferrara, 2009), neurocognitive functioning assessment (Broglio et al., 2007b), vestibular ocular motor testing (Kontos et al., 2016; Kontos et al., 2017; Moran et al., 2018; Mucha et al., 2014; Russell-Giller et al., 2018; Worts et al., 2018), and dual-task testing (Kleiner et al., 2018). Factors that influence these components of a SRC assessment battery are unclear.

The Sport Concussion Assessment Tool

The SCAT is a standardized tool for evaluating injured athletes for concussion and can be used in athletes aged 13 years and older (Sports Concussion Assessment Tool - 1st Edition, 2005). The SCAT is comprised of several components: the Glasgow Coma Scale, Maddocks Questions, background information on the athlete, a symptom evaluation, a cognitive assessment, a neck examination, a balance examination, a coordination examination, and the SAC Delayed Recall test. The third edition of the SCAT was published in 2013 (Sport Concussion Assessment Tool - 3rd Edition, 2013) and the fifth was published in 2017 (Sports Concussion Assessment Tool - 5th Edition, 2017). While, the SCAT was originally designed for on-field examinations of suspected concussions, the SCAT-5 now only distinguishes, one of the five sections as an "immediate or on-field assessment", and sections 2 – 5 are appropriate for "office or off-field assessment". The clinical utility of the SCAT includes baseline information (Putukian, 2017), assisting in tracking recovery (McCrory et al., 2017), and patient education (Yengo-Kahn et al., 2016).

Psychometric properties supporting the SCAT are scarce, secondary to the SCAT being a compilation of many tests. Studies exploring healthy and concussed collegiate athletes reported the SCAT, as a combined measure, to have good reliability (Mrazik et al., 2017a), 75.8 – 76.2% sensitivity, and 100% specificity in identifying acute (3 – 5 days post injury) concussions (Downey et al., 2018). Test-retest reliability measured within professional ice hockey players, was found to be moderate to high (Hänninen et al., 2020). Another author explored collegiate, collision sport athletes and found the SCAT to have good to moderate reliability (Intraclass Correlation Coefficient [ICC] = 0.66 – 0.94; Mrazik et al., 2017b). While, the SCAT is a reliable tool, factors that influence SCAT performance are not clear at this time. Having a better understanding of influential factors, specifically long-term effects of concussion history and sub-concussive exposure, will aide clinicians in interpreting baseline and post-injury findings, and making decisions during the recovery process.

Symptom Evaluation

The symptom evaluation is a component of the SCAT. It is comprised of 22 symptoms. The participant is asked to rate the severity of each symptom on a 0 – 6 scale (0 = *none*; 1 – 2 = *mild*; 3 – 4 = *moderate*; 5 – 6 = *severe*). It is important to note, there are some potential sources of error when collecting and interpreting the symptom evaluation. One possible complication to the symptom evaluation is that athletes may not disclose concussive events (Miyashita et al., 2014) and may not be truthful about their concussion-related symptoms in order to expedite return to play (Broglio et al., 2007a), thus, questioning the reliability of the symptom evaluation. Another complication with the symptom evaluation is that concussion-related symptoms are not specific to concussions. Symptoms such as headache, irritability, forgetfulness, and sleep disturbances can be attributed to everyday life (Polinder et al., 2018). Despite these complications, the literature has reported psychometric properties that still favor using the symptom evaluation clinically.

The SCAT symptom evaluation has demonstrated both face validity and content validity (McLeod & Leach, 2012). In a sample of both healthy and concussed athletes (15 high schools and 10 universities), the symptom evaluation was found to have excellent internal consistency (Cronbach's alpha = 0.93; Lovell et al., 2006). A study exploring healthy and concussed, collegiate, contact sport athletes found the symptom evaluation to have moderate reliability (Mrazik et al., 2017a). In a sample of healthy and concussed athletes from both the high school and college level, the authors found the minimal detectable change for the symptom score was 38.08 (24 hours post-concussion), 22.05 (8 days post-concussion), 10.94 (15 days post-concussion), and 6.58 (45 days post-concussion). This study also reported the test-retest reliability to be adequate (Chin et al., 2016). In another study exploring healthy and concussed, collegiate athletes, the authors found the symptom evaluation to have 47.4 – 72.2% sensitivity and 78.6 – 91.7% specificity (Downey et al., 2018). To our knowledge, the symptom evaluation component of the SCAT has only been researched in acute concussions, the long-term effects of concussions and sub-concussive exposure on the symptom evaluation are unclear at this time.

Standardized Assessment of Concussion

Though a component of the SCAT, the SAC can be used as a standalone concussion assessment. The SAC total (0 – 30) is a composite score that sums orientation (0 – 5), immediate memory (0 – 15), concentration (0 – 5), and delayed memory recall (0 – 5); the larger the score the better the neurocognitive performance (Sport concussion assessment tool - 3rd edition, 2013). New York University School of Medicine explored archived, neuropsychological test data within civil litigation patients. All subjects claimed cognitive impairments (psychiatric illness, cognitive disorder, neurological disorder and head injuries). Within this study, the SAC yielded adequate sensitivity (62% – 95%) and negative predictive power (0.93 – 0.97; Zottoli et al., 2015). In a study exploring healthy and concussed, high school and collegiate athletes, the authors found the SAC to have 76% specificity, 94% sensitivity, adequate test-retest reliability (ICC = 0.55), and excellent predictive validity (AUC = 0.939, SE = 0.021; Barr & McCrea, 2001). Another study exploring healthy and concussed, high school and collegiate athletes found a three-point change in a SAC score was considered the minimally clinically important difference, with a 90% confidence interval. However, discrimination between concussed and control athletes was considered poor (Chin et al., 2016). In a study exploring healthy and concussed, collegiate contact sport athletes, the SAC demonstrated good reliability (ICC = 0.83; Mrazik et al., 2017a). Thus, supporting the use of the SAC clinically, however factors that influence the SAC are unclear. Specifically, the long-term effects of concussions and sub-concussive exposure on the SAC, and how activity status groups influence performance on the SAC are unclear at this time.

Modified Balance Error Scoring System

The mBESS assesses static standing balance of individuals with concussion and includes three different stance positions (double, tandem, and single) on a firm surface.

The participant must hold their hands on their hips (iliac crest) for 20 seconds in each position with their eyes closed. One point is given per error (up to 10 errors per position), a perfect score is zero. An mBESS total score sums the errors for each testing position, and ranges from 0 – 30, the higher the score the worse the balance (Sport concussion assessment tool - 3rd edition, 2013).

In studies exploring collegiate student-athletes, both concussed and healthy subjects, the mBESS demonstrated good reliability (ICC = 0.88; Mrazik et al., 2017a), moderate sensitivity (47.4%), and moderate specificity (63.2%; Oldham et al., 2018). In another study, exploring concussed, collegiate, student-athletes, the authors found the mBESS to have moderate sensitivity (71.4%), when used as a diagnostic tool post-acute concussion (Buckley et al., 2018). Lastly, a study with healthy and concussed, high school and collegiate student-athletes found the mBESS to have adequate test-retest reliability, and adequate interrater reliability (Chin et al., 2016). While the mBESS is an acceptable tool to assess balance, the long-term effects of concussions, sub-concussive exposure, and activity status influences on the mBESS are unclear.

The Vestibular/Ocular-Motor Screening tool

The VOMS is a screening tool designed to detect ocular and vestibular impairments in individuals with concussion aged 9 to 40 years old (Mucha et al., 2014). The VOMS uses minimal equipment (tape measure, metronome, and target) to assess symptom provocation (headache, dizziness, nausea, fogginess) during tasks that challenge the visual and vestibular systems (smooth pursuits, saccades, convergence, vestibular ocular reflex, visual motion sensitivity). When comparing adolescent athletes who recently sustained a SRC to healthy controls, the VOMS was found to be a sensitive screen, with high internal consistency (Mucha et al., 2014). In samples of healthy youth athletes and healthy high school athletes the VOMS was found to have high internal consistency, a low false-positive rate, and high test-retest reliability (Moran et al., 2018; Worts et al., 2018). Clinically, VOMS can be used to identify patients with concussions with sensitivity, if they have a symptom score ≥ 2 and near point convergence ≥ 5 cm (Mucha et al., 2014). While the VOMS has statistical and clinical significance supporting its utility, factors that impact the VOMS such as long-term effects of concussions, sub-concussive exposure, and activity status, are currently unclear.

Dual-Task Tandem Gait

TG is deemed a practical tool to evaluate dynamic balance, coordination and speed. Regarding psychometric properties, TG has a published sensitivity of 63.2%, specificity of 60.5%, and an ICC of 0.97 (Oldham et al., 2018). Normative parameters of TG have been established in children, collegiate student-athletes, and professional athletes (Oldham et al., 2018); however, the effect of concussion on TG are still limited within the literature.

There has been a paradigm shift for testing balance performance to follow a DT model. DT methodology is an objective testing model that allows multiple systems to be evaluated concurrently; it requires a person to simultaneously perform a cognitive and motor task. More specifically, this model typically involves a mathematical task while performing a motor task (Broglio et al., 2005). Broglio et al. (2005) suggests DT methodology brings about systematic changes to reaction time in relation to increasing balance demands. Literature suggests deficits in postural control following the addition of a cognitive task (Broglio et al., 2005). Following a concussive episode literature suggests a further decline in gait performance during DT testing (Kleiner et al., 2018); this motor function impairment may or may not correlate to symptom reports (Quatman-Yates et al., 2020), which demonstrates the benefit of having an objective metric within a concussion assessment (Howell et al., 2017). Another study compared single task TG to DT TG and found individuals who had sustained a concussion took significantly longer to complete the DT TG trial compared to the controls (Howell et al., 2017). While, DT testing provides an objective measure of performance following a concussive event (Howell et al., 2017), further research is needed to explore the effects of DT TG.

Long-Term Outcomes

Concussion History

Much is unknown about the long-term impact of concussion on individuals. A history of previous concussions may be associated with a slower recovery of neurological function (Guskiewicz et al., 2003), decreased attention, a decline in memory performance (Martini et al., 2017), and depression (Thomson et al., 2020). Concussion history may raise the long-term risk for neurodegenerative disease, neurobehavioral changes, and neurocognitive decline (McAllister & McCrea, 2017). However, there remains a considerable gap in the research regarding long-term effects of concussion (Martini et al., 2017). For instance, will one concussion lead to the same long-term consequences as multiple concussions? Or is long-term exposure to sub-concussive impacts associated with collision and contact sports a greater risk for long-term effects? Consequently, further research is needed (McAllister & McCrea, 2017).

Concussion history effects on SRC assessment performance appears to have mixed findings. Concussion history did not impact baseline SCAT-3 performance in professional male ice hockey players (Hänninen et al., 2015). Controversially, concussion history did impact SCAT performance amongst elite football players (Cookinham & Swank, 2019), collegiate athletes (Shehata et al., 2009), high school athletes (Snedden et al., 2016; Valovich McLeod et al., 2012), and youth hockey players (Schneider et al., 2010). A pilot study exploring SCAT-3 performance, participants with multiple concussion (2+) history reported a greater number of symptoms, greater symptom severity, and lower neurocognitive scores (measured by the SAC), however, no differences were observed on the mBESS (Cookinham & Swank, 2019). A study exploring SCAT baseline scores within high school athletes found those with a prior concussion history had worse SCAT total scores, and greater total symptom scores (Valovich McLeod et al., 2012). Another study exploring SCAT preseason baseline scores in youth hockey players, found similar findings. Those with a concussion history presented with greater total symptom scores (Schneider et al., 2010). Lastly a study exploring SCAT-3 findings within high school athletes found those with a concussion history had a greater number of symptoms and greater symptom severity. However, SAC and mBESS scores were not significantly different. Thus, it is apparent concussion history affects SRC assessment performance, however, which components of the SCAT are affected, and to what extent are unclear.

Career Status

Literature exploring professional football draft prospects is scarce. One cohort study looked at 226 draft prospects over a 7-year period. They examined Wonderlic and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT®) scores compared to concussion history. The athletes were categorized into three groups: no concussion history, one prior concussion and two or more concussions in their history. They were able to conclude there was no correlation between concussion history and neurocognitive scores in the NFL draft prospects (Solomon & Kuhn, 2014).

Active professional players are also rarely researched. Kuhn et al. (2016) looked at National Hockey League players returning to play after sustaining a concussion and they noted no change in performance or style of play. Another study exploring SCAT performance in a professional hockey sample failed to find a significant relationship between performance and concussion history (Hänninen et al., 2015).

Retired professional football players are becoming a population of interest for research recruitment. Researchers have found evidence regarding age at first contact football exposure and later-life cognitive impairments (Stamm et al., 2015), and decreased executive and neuropsychiatric function (Alosco, Jarnagin et al., 2017). There is also an association between retired NFL players, concussion history and later-life neuropsychiatric dysfunction, depression, and impulsivity (Alosco, Jarnagin et al., 2017).

A pilot study exploring NFL draft prospects, active professional football players, and retired professional football players, found the retired professional player group presented with a greater number of symptoms, greater symptom severity, lower neurocognitive scores (SAC), and greater balance errors (mBESS). Further, there were significant differences when comparing draft prospects and retired professional players, and active professional players and retired professional players for all the SCAT elements (number of symptoms, symptom severity, SAC, and mBESS). However, there were no differences between draft prospects and active professionals (Cookinham & Swank, 2019). Perhaps true career status differences are demonstrated later in life, as described by Alosco, Jarnagin et al. (2017). Further research is recommended to explore the relationship between concussion history, career status, and performance on elements of the SCAT.

Sub-concussive Exposure

Multiple studies support the presence of chronic neurocognitive impairments, particularly in professional athletes with longer exposure to contact sports (Giza & Kutcher, 2014; Giza et al., 2013). This impairment may potentially be linked to repetitive sub-concussive head impacts. Research suggests football players sustain thousands of sub-concussive hits per season (Slobounov et al., 2017; Zonner et al., 2019). This exposure to repetitive sub-concussive head impacts has also been correlated with increased risk of developing long-term neurodegeneration (Kuo et al., 2018). In preliminary cross-sectional findings, Cookinham and Swank (2019) found participants with longer exposure to football (19+ seasons) demonstrated 6.87 times greater symptom severity compared to participants with <11 years of football exposure (Cookinham & Swank, 2019). With this in mind, further research is warranted to aid in a better understanding of how these measures may differ based on type of sport (contact vs. non-contact).

Literature Review Summary

Concussion is a mild traumatic brain injury involving biomechanical forces that stimulates a chemical cascade within the brain ultimately leading to changes in homeostatic function. SRCs have an incidence of 1.6 to 3.8 million athletes per year in the United States (McPherson et al., 2019). Concussions are a common sports-related injury that can lead to short-term neurological deficits (Kuo et al., 2018), however, long-term effects are still in question.

Concussions often go unreported or undiagnosed due to a myriad of reasons, but the primary reason is due to the subjective nature to concussion assessments. Thus, a multi-modal assessment that incorporates objective measures can be valuable (Paniccia et al., 2018). While, scattered across the literature we were able to compile a comprehensive concussion evaluation (Committee on Sports-Related Concussions in Youth, et al., 2014), including symptom scores (number of symptoms and symptom severity), evaluation of postural control (Hunt et al., 2009), neurocognitive functioning assessment (Broglio et al., 2007b), vestibular ocular motor testing (Kontos et al., 2016; Kontos et al., 2017; Moran et al., 2018; Mucha et al., 2014; Russell-Giller et al., 2018; Worts et al., 2018), and dual-task testing (Kleiner et al., 2018).

The SCAT is a compilation of symptom scores, neurocognitive functioning assessment and an evaluation of postural control. The SCAT has good (Mrazik et al., 2017a) to moderate reliability (Mrazik et al., 2017b), moderate sensitivity, high specificity (Downey et al., 2018), and moderate to high test-retest reliability (Hänninen et al., 2020). The VOMS is considered a sensitive screen with high internal consistency and a low false-positive rate (Kontos et al., 2016; Kontos et al., 2017; Moran et al., 2018; Mucha et al., 2014; Russell-Giller et al., 2018; Worts et al., 2018). DT TG is a dual-task test with moderate sensitivity, moderate specificity, and a high ICC. While the individual components of the SCAT, the VOMS, and DT TG are valid assessments of concussion, factors that influence these measures are unclear. Specifically, how long-term effects of concussions, sub-concussive exposure, and activity status influences performance on these SRC measures is unknown.

Concussions occur in all sports (Harmon et al., 2013). While contact athletes are said to be at a greater risk (Noble & Hesdorffer, 2013), there are very few comparison studies, comparing contact athletes to non-contact athletes, and even fewer comparing athletes to non-athletes. It is important to note how these individuals perform on SRC measures based on their sport classification (or lack of sport participation). If there are any differences in performance in healthy subjects (with varying sport classifications and non-athletes), researchers and clinicians can interpret their findings accordingly with patients that have acute concussions.

Concussion history affects SRC assessment performance, however, which components of the assessment are affected, and to what extent is unclear. Further, research suggests football players sustain thousands of sub-concussive hits per season (Slobounov et al., 2017; Zonner et al., 2019). Thus, questioning if concussion history or sub-concussive exposure has the greater impact on SRC assessment performance. However, the relationship between sub-concussive exposure and SRC assessment performance is currently lacking within the literature.

Cookinham and Swank are the first authors to analyze career status and its effects on SRC assessment performance with all three groups (NFL draft prospects, active professional football players, and retired professional football players). Their results revealed that the retired professional player group reported a greater number of symptoms, greater symptom severity, lower neurocognitive scores (SAC), and greater balance errors (mBESS). Other authors have explored career statuses as individual samples and found mixed results. NFL draft prospects demonstrated no difference between concussion history and neurocognitive performance (Solomon & Kuhn, 2014). Likewise, in professional hockey, concussion history did not affect SCAT performance or level of play on the ice (Hänninen et al., 2015). Whereas, retired professional football players with a concussion history demonstrated later-life neuropsychiatric dysfunction, depression, and impulsivity (Alosco, Jarnagin et al., 2017).

The first study within this dissertation explores the relationship of concussion history and its effects on concussion-related symptoms, symptom severity, neurocognitive performance, and balance within a sample of elite football players, as well as, the relationship between career status and cumulative years of contact football exposure. Our second study compared the same measures of concussion-related symptom scores, neurocognitive performance, and balance while adding VOMS and DT TG testing in a sample of elite athletes from contact sports, non-contact sports, and a control group of non-athletes.

CHAPTER III

STUDY 1

Concussion History, Career Status, and Football Exposure Effects on Sports-Related Concussion Assessment Measures

Abstract

Objective

To determine the effects of concussion history, career status, and cumulative years of contact football exposure on symptoms, balance, and neurocognitive performance in elite football players.

Methods

One hundred and two elite football players (age: $M = 27.75$, $SD = 6.95$ years) were evaluated utilizing symptom evaluation, neurocognitive testing, and balance testing (in accordance with the Sport Concussion Assessment Tool – 3rd edition guidelines), in an outpatient therapy setting. Negative binomial regression analyses were used to assess the influence of concussion, career status, and cumulative years of exposure to football on concussion-related symptoms and symptom severity. Multiple linear regression analyses were used to examine the influence of the same factors on neurocognitive performance and balance.

Results

Results revealed that participants with a high concussion history (2+ concussions) were expected to have a rate of symptoms 2.08 times higher (*IRR* = 2.0819 [1.14, 3.81], $p = .017$), and symptom severity 1.9 times higher (*IRR* = 1.895 [1.045, 3.435], $p = .035$) compared to participants with a low concussion history (0 – 1 concussions). Neurocognitive performance and balance performance were not significantly different amongst concussion history groups. When exploring the effects of career status, results revealed retired professional players were expected to have a rate of symptoms 3.59 times higher (*IRR* = 3.59 [1.60, 8.06], $p = .002$), symptom severity 3.95 times higher (*IRR* = 3.95 [1.88, 8.33], $p < .001$), and have an average of 3.41 more errors with balance testing (B = 3.41 [0.65, 6.17], $p = .016$), than draft prospects. Neurocognitive performance was not significantly different amongst the career status groups. When exploring the effects of cumulative years of contact football exposure, models for number of symptoms, symptom severity, neurocognitive performance, and balance performance were not significant.

Conclusion

Concussion history and career status produced significant associations to symptom reports. Career status also produced a significant association to balance performance. However, cumulative years of contact football exposure did not yield any significant findings. Since a cross-sectional design was used in the current study, examining cumulative year of contact football exposure in a longitudinal design is warranted. Longitudinal studies would allow exploration of these relationships throughout the lifespan.

Introduction

The term concussion is encompassed by a variety of definitions within the range of current literature, the overall consensus is that a concussion is a form of mild traumatic brain injury involving biomechanical forces, which induce a neurometabolic cascade within the brain, ultimately leading to alterations in homeostatic function (Choe, 2016; Langlois et al., 2006). SRCs represent a national public health problem, demonstrating an annual frequency of 1.6 to 3.8 million in the United States alone (Giza & Kutcher, 2014; Merchant-Borna et al., 2016). Significant variability in concussion risk has been established based on sport classification (Slobounov et al., 2017) and position played (Baugh et al., 2015; Clay et al., 2013; Harmon et al., 2013). Football consistently retains the highest incidence of concussions (Slobounov et al., 2017). The position played creates further risk for the football player. Specifically, tight ends, running backs, wide receivers, and corner backs/defensive backs are considered to be at a higher risk for sustaining a SRC (Dai et al., 2018).

While concussion assessments are variable within the literature, the Consensus Statement on Concussion in Sport encourages the use of the latest version of the SCAT (McCrory et al., 2017). Key elements of the SCAT that were included in this study were: the symptom evaluation, the mBESS examination and the SAC (Sport Concussion Assessment Tool - 3rd Edition, 2013). The long-term impact of a SRC, is not well understood despite most athletes appearing to recover enough to be cleared to return to play. A history of previous concussions may be associated with a slower recovery of neurological function (Guskiewicz et al., 2003), decreased attention, a decline in memory performance (Martini et al., 2017), and depression (Thomson et al., 2020). Concussion history may raise the long-term risk for neurodegenerative disease, neurobehavioral changes, and neurocognitive decline (McAllister & McCrea, 2017). Concussion history was significantly related to symptom reports amongst elite football players (Cookinham & Swank, 2019), collegiate athletes (Shehata et al., 2009), high school athletes (Snedden et al., 2016; Valovich McLeod et al., 2012), and youth hockey players (Schneider et al., 2010), though no such correlation was found in a sample of professional male ice hockey players (Hänninen et al., 2015). However, the effect of concussion history on neurocognitive performance and balance had mixed findings within the afore mentioned groups.

Literature exploring professional football draft prospects is scarce. One study explored the influence of concussion history on neurocognitive performance (via the Wonderlic and ImPACT®) in draft prospects. They found no correlation between concussion history and neurocognitive scores in the NFL draft prospects (Solomon & Kuhn, 2014). Literature involving active professional players is also rare. One study exploring professional male ice hockey players found no change in performance or style of play following concussion resolution (Kuhn et al., 2016). Another study exploring professional male ice hockey players failed to find a significant relationship between SCAT performance and concussion history (Hänninen et al., 2015). Lastly, retired professional football players are becoming a population of interest for research recruitment. There is some evidence linking the age at which one began participating in contact football and later-life cognitive impairments (Stamm et al., 2015), as well as the potential for decreased executive and neuropsychiatric function (Alosco, Kasimis et al., 2017). There is also an association between retired NFL players, concussion history, and later-life neuropsychiatric dysfunction, depression, and impulsivity (Alosco, Jarnagin et al., 2017). To our knowledge, there are no other authors exploring differences between elite athlete career statuses (draft prospect, active professional, retired professional).

There remains a considerable gap in the research regarding long-term effects of SRC (Martini et al., 2017). For instance, will one concussion lead to the same long-term consequences as multiple concussions? Is it the level of play that is associated with long-term consequences? Or is long-term exposure to sub-concussive impacts associated with collision and contact sports that has a greater risk for long-term effects? Consequently, further research is needed (McAllister & McCrea, 2017) to explore the effects of concussion history, career status, and cumulative years of contact football exposure.

Therefore, the primary aim of this study was to examine the influence of concussion history on symptom reports, neurocognitive performance, and balance performance in healthy elite football players. Further, the secondary aims in this study were to examine the influence of career status and the influence of cumulative years of contact football exposure, on symptom reports, neurocognitive performance, and balance performance in healthy, elite, football players.

Methods

This study was approved by Texas Woman's University Institutional Review Board. Prior to enrollment each participant was informed of the intent and methods of the study and completed an informed consent document. This study did not involve any commercial sponsors and was performed outside of any professional football teams or leagues.

All elite, American football players training at a sports performance facility were invited to voluntarily participate between 2017 and 2018. Participants were eligible if they were between the ages of 18 and 45. To qualify as elite, participants had to be draft prospects, active professional football players, or retired professional football players. Draft prospects were participants that had invitations to the NFL combine or professional athlete tryout events. Active professional players were currently in the NFL or Canadian Football League (CFL). Retired professionals were participants that had prior professional football experience in the NFL or CFL. Participants were excluded if they had sustained a concussion within the preceding 30 days.

Participant assessment included a symptom evaluation, neurocognitive testing, and balance testing by the same athletic trainer in a private treatment room. Testing was administered in accordance with published recommendations within the SCAT-3. The athletic trainer had 9 years of experience working with elite athletes. Additional information acquired included: medical background, football position played, previous concussion history, and cumulative number of years they had played contact football. The operational definition for cumulative years of participation was the total number of years of player participation from contact youth football, junior high football, high school football, college football through professional football.

Via interview, participants were brought through a 22-concussion symptom checklist and asked to report "yes" or "no" if they were currently experiencing that symptom. The total number of symptoms were tallied and entered as a composite score into the database. If the participant said "yes" to any of the symptoms, they were then asked to rate the severity of that symptom on a 0 – 6 Likert scale (0 = *none*; 1 – 2 = *mild*; 3 – 4 = *moderate*; 5 – 6 = *severe*). This study assessed symptom severity by summing the symptom Likert scales, ranging from 0 to 132, the higher the score indicated the greater severity of the symptoms. The SCAT symptom evaluation has demonstrated both face and content validity (McLeod & Leach, 2012), moderate sensitivity, moderate specificity (Downey et al., 2018), excellent internal consistency (Lovell et al., 2006), and adequate test-retest reliability (Chin et al., 2016).

Neurocognitive performance was measured utilizing the SAC components of the SCAT-3. The SAC composite score was a sum of orientation (0 – 5), immediate memory (0 – 15), concentration (0 – 5), and delayed memory recall (0 – 5). The SAC composite score, used in the data analyses, ranged from 0 to 30, the higher scores were reflective of better neurocognitive performance. In studies exploring healthy and concussed athletes, the SAC demonstrated good reliability (Mrazik et al., 2017a), moderate specificity, adequate test-retest reliability, excellent predictive validity, and excellent sensitivity (Barr & McCrea, 2001).

To assess balance, the mBESS within the SCAT-3 was utilized. The mBESS total score was calculated by summing the errors for each testing position (double, tandem, and single). The mBESS scores range from 0 – 30, with higher scores indicating poorer balance (Sport concussion assessment tool - 3rd edition, 2013). One study exploring concussed athletes, found the mBESS to have moderate sensitivity (Buckley et al., 2018). Other studies exploring both concussed and healthy athletes, found the mBESS to have moderate sensitivity, moderate specificity (Oldham et al., 2018), good reliability (ICC = 0.88; Mrazik et al., 2017a), adequate interrater reliability, and adequate test-retest reliability (Chin et al., 2016).

Statistical Analysis

The primary aim of this study was to examine the influence of concussion history on the number of symptoms, symptom severity, neurocognitive performance, and balance performance in healthy, elite, football players, while controlling for age. Concussion history was categorized by low concussion history (0 – 1 concussions) and high concussion history (2+ concussions; Cookinham & Swank, 2019). The reference category for all primary aim analyses were participants within the low concussion history group.

One secondary aim in this study was to examine the influence of career status on the number of symptoms, symptom severity, neurocognitive performance, and balance performance in healthy, elite, football players, while controlling for concussion history and player position risk level. Career status was categorized by professional draft prospects, active professional players, and retired professional players. Player position risk level was categorized by football positions that had a high risk (tight ends, running backs, wide receivers, and corners backs/defensive backs) and low risk (offensive lineman, defensive lineman, linebacker, and quarterbacks) of sustaining a SRC (Dai et al., 2018). The reference categories used within this secondary aim, were participants within the draft prospect group that had a low concussion history and played a low risk position.

Our last secondary aim in this study was to examine the influence of cumulative years of contact football exposure, on symptom reports, neurocognitive performance, and balance performance in healthy, elite, football players, while controlling for concussion history and player position risk level. The reference categories used in this secondary aim were participants who had a low concussion history and played a low risk position.

Analyses involving the outcomes of the number of symptoms and symptom severity utilized negative binomial regression analyses because the Poisson distributions typical of count data violated multiple regression normality assumptions. The outcome variables of neurocognitive performance and balance performance were modeled utilizing multiple linear regressions.

Results

Description of Sample

One hundred and two participants completed surveys regarding their football playing career and injury history. All participants completed a concussion-related symptoms inventory and underwent assessments of neurocognition and balance. Frequencies and percentages for categorical demographic variables for study participants are displayed in Table 1. Most participants indicated they had sustained a concussion within their playing careers ($\geq$1; 60.8%). The largest group of participants were active professional football players (46.1%). The average amount of time exposed to contact football was 15.92 years (*SD* = 4.66).

Table 1

Participant Characteristics

Variable	*n*	%	Age *M* (*SD*)
History of Concussions			
Low Concussion History (0 – 1)	63	61.8	24.83 (4.90)
High Concussion History (2+)	39	38.2	32.49 (7.20)
Career status			
Draft Prospects	31	30.4	21.97 (1.08)
Active Professionals	47	46.1	26.55 (3.79)
Retired Professionals	24	23.5	37.58 (5.73)

Note. *N* = 102; *M = mean; SD = standard deviation.*

Effect of Concussion History

Our primary aim assessed the relationship between concussion history and the number of symptoms, symptom severity, neurocognitive performance (measured by the SAC), and balance performance (measured with the mBESS), while controlling for age. Table 2 and Table 3 provide the descriptive statistics for the study participants.

Table 2

Concussion History Influence on Dependent Variables

	Low Concussion History	High Concussion History	All Participants
	Med (IQR)	*Med (IQR)*	*Med (IQR)*
Number of Symptoms	1 (0 – 2)	3 (0 – 10)	1 (0 – 4.25)
Symptom Severity	1 (0 – 4)	8 (0 – 26)	2 (0 – 9.25)

Note. *Med* = median; *IQR*= interquartile range; Low Concussion History = 0 – 1 concussions (*N* = 63); High Concussion History = 2+ concussions (*N* = 39). All participants, *N* = 102.

Table 3

Concussion History Influence on Dependent Variables

	Low Concussion History	High Concussion History	All Participants
	M (SD)	*M (SD)*	*M (SD)*
Neurocognitive Performance	25.89 (3.04)	24.18 (3.46)	25.24 (3.30)
Balance Performance	4.02 (3.83)	5.69 (5.06)	4.66 (4.39)

Note. *M* = mean; *SD* = standard deviation; Low Concussion History = 0 – 1 concussions (*N* = 63); High Concussion History = 2+ concussions (*N* = 39). All participants, *N* = 102.

The overall model to predict the number of symptoms based on concussion history, while controlling for age was significant, $\chi^2(2) = 64.122$, $p < .001$. Those with a high concussion history were expected to have a rate of symptoms 2.08 times greater compared to those with a low concussion history (*IRR* = 2.0819 [1.14, 3.81], $p = .017$). The regression model also revealed with every year increase in age, elite football individuals were expected to have 1.10 times greater number of symptoms (*IRR* = 1.096 [1.05, 1.14], $p < .001$).

Another negative binomial regression analysis was conducted to determine whether concussion history was predictive of symptom severity, while controlling for age. The overall model was significant, $\chi^2(2) = 97.704$, $p < .001$, suggesting those with a high concussion history were expected to have a symptom severity rate 1.90 times greater compared to those with a low concussion history (*IRR* = 1.895 [1.045, 3.435], $p = .035$). The regression model also revealed with every year increase in age, elite football individuals were expected to have 1.10 times greater severity of symptoms (*IRR* = 1.120 [1.07, 1.17], $p < .001$). Table 4 outlines the influence of concussion history on symptom reports.

Table 4

Concussion History Influence on Symptom Reports

Effect	*IRR*	95% CI		*p*
		LL	*UL*	
Number of Symptoms				
Intercept	0.118	0.038	0.365	< .001
Concussion History	2.081	1.137	3.807	.017
Age	1.096	1.051	1.144	< .001

Table 4 Continued

Concussion History Influence on Symptom Reports

Effect	*IRR*	95% CI		*p*
		LL	*UL*	
Total Symptom Severity				
Intercept	0.151	0.051	0.447	.001
Concussion History	1.895	1.045	3.435	.035
Age	1.120	1.074	1.169	< .001

Note. IRR = incident rate ratio; CI = confidence interval; *UL* = upper limit; *LL* = lower limit; Low Concussion History was the reference category.

Using a linear regression model, concussion history was used to predict neurocognitive performance, while controlling for age. The overall model was significant, $F(2, 99) = 6.56$, $p = .002$, and accounted for a 9.9% of variance (Adj. $R^2 = .099$). Within the model, concussion history was not found to be significant ($p = .344$); however, age was found to be a significant factor ($p = .017$). Suggesting age was inversely proportional to neurocognitive performance. Specifically, with every year increase in age, elite football individuals would have a decrease in neurocognitive performance by 0.13 points on the SAC measure.

Finally, multiple linear regression analyses were conducted to assess whether concussion history predicted balance performance, while controlling for age. The overall model was significant, $F(2, 99) = 8.475$, $p < .001$, and accounted for almost 13% of the variance (Adj. $R^2 = .129$). Within the model, concussion history was not significant ($p =$

.807); however, age was a significant factor (p = .001). These results suggest with every year increase in age of elite football, individuals would increase by 0.25 errors on the mBESS measure. By extension, every 10 years one can anticipate an increase by an average of 2.50 errors. Table 5 provides the regression coefficient results for the neurocognitive performance and balance performance models.

Table 5

Concussion History Influence on Neurocognitive Performance and Balance Performance

Variable	B	95% CI		*p*
		LL	*UL*	
Neurocognitive Performance				
Constant	29.10	26.367	31.832	< .001
Concussion History	-0.718	-2.219	0.782	.344
Age	-0.129	-0.235	-0.024	.017
Balance Performance				
Constant	-2.203	-5.786	1.379	.225
Concussion History	-0.243	-2.210	1.724	.807
Age	0.251	0.112	0.389	.001

Note. B = estimate; CI = confidence interval; *UL* = upper limit; *LL* = lower limit; *p* = p-value; Low Concussion History was the reference category.

Effect of Career Status

Our secondary aim assessed the relationship between career status (draft prospects, active professional players, and retired professional players) and the number of symptoms, symptom severity, neurocognitive performance, and balance performance, whilst controlling for concussion history and player position risk level. Table 6 and Table 7 provide the descriptive statistics outlined per career status group.

The influence of career status on the number of symptoms was assessed using a negative binomial regression analysis. The overall model to predict the number of symptoms based on career status, while controlling for concussion history and player position risk level was significant, $\chi^2(4) = 54.52$, $p < .001$. Retired professional players had a positive and significant association with total symptoms. Retired professional players were expected to have a symptom rate 3.59 times greater than that of draft prospects (*IRR* = 3.59 [1.60, 8.06], $p = .002$). The association between active professional players and the number of symptoms was similar to draft prospect rates ($p = .246$).

Table 6

Career Status Influence on Dependent Variables

Variable	Draft Prospects *Med (IQR)*	Active Professionals *Med (IQR)*	Retired Professionals *Med (IQR)*
Number of Symptoms	0 (0 – 2)	1 (0 – 3)	7.5 (3 – 11)
Symptom Severity	0 (0 – 4)	1 (0 – 5)	22.5 (8 – 28)

Note. Med = median; *IQR*= interquartile range; Draft Prospects *N* = 31; Active Professionals *N* = 47; Retired Professionals *N* = 24.

Table 7

Career Status Influence on Dependent Variables

Variable	Draft Prospects	Active Professionals	Retired Professionals
	M (SD)	*M (SD)*	*M (SD)*
Neurocognitive Performance	25.65 (2.97)	25.77 (3.31)	23.67 (3.29)
Balance Performance	3.16 (3.64)	4.53 (4.69)	6.83 (3.93)

Note. M = mean; *SD* = standard deviation; Draft Prospects *N* = 31; Active Professionals *N* = 47; Retired Professionals *N* = 24.

Another negative binomial regression analysis was conducted to determine whether career status predicted symptom severity, while controlling for concussion history and player position risk level. The overall model to predict symptom severity was also significant, $\chi^2(4) = 79.56$, $p < .001$. Results revealed that retired professionals had a positive and significant association with symptom severity. On average, the retired professional's symptom severity rate was 3.95 times greater than draft prospects (*IRR* = 3.95 [1.88, 8.33], $p < .001$). The association between active professionals and symptom severity was not significant when compared to draft prospects ($p = .103$). Table 8 outlines the influence of career status on symptom reports.

Table 8

Career Status Influence on Symptom Reports

Effect	IRR	95% CI		p
		LL	*UL*	
Total Symptoms				
Intercept	0.875	0.503	1.521	.635
Retired Professionals	3.587	1.596	8.062	.002
Active Professionals	1.449	0.774	2.711	.246
Concussion History	2.514	1.383	4.569	.002
Player Position Risk	1.202	0.731	1.978	.468
Total Symptom Severity				
Intercept	1.767	1.094	2.854	.020
Retired Professionals	3.953	1.876	8.332	< .001
Active Professionals	1.586	0.910	2.765	.2103
Concussion History	2.973	1.716	5.154	<.001
Player Position Risk	1.239	0.785	1.958	.357

Note. IRR = incident rate ratio; CI = confidence interval; *UL* = upper limit; *LL* = lower limit; Draft prospects, low concussion history and low player position risk level were the reference categories.

The remaining components to assess this secondary aim were analyzed using multiple linear regression analyses. The reference categories remained the draft prospect group, low concussion history, and low risk positions. Career status was used to predict neurocognitive performance, while controlling for concussion history and player position risk level. The overall model was significant, $F(4, 97) = 2.47$, $p = .050$. However, within the model, neither retired professional ($p = .303$) and active professional ($p = .576$)

groups were significant when compared to the draft prospect group. Finally, multiple linear regression analyses were conducted to assess whether career status predicted balance performance, while controlling for concussion history and player position risk level. The overall model was significant, $F(4, 97) = 2.80$, $p = .030$, and accounted for a small amount of variance (Adj. $R^2 = .067$). On average, retired professionals had 3.41 more balance errors on the mBESS compared to draft prospects (B = 3.41 [0.65, 6.17], $p = .016$); however, the difference between balance scores amongst active professionals and draft prospects was not significant ($p = .238$). Table 9 outlines the influence of career status on neurocognitive performance and balance performance.

Table 9

Career Status Influence on Neurocognitive Performance and Balance Performance

Variable	B	95% CI		*p*
		LL	*UL*	
Neurocognitive Performance				
Constant	25.660	24.330	26.990	<.001
Retired Professionals	-1.086	-3.169	0.996	.303
Active Professionals	0.432	-1.096	1.961	.576
Concussion History	-1.174	-2.735	0.386	.138
Player Position Risk	0.191	-1.094	1.476	.768

Table 9 Continued

Career Status Influence on Neurocognitive Performance and Balance Performance

Variable	B	95% CI		*p*
		LL	*UL*	
Balance Performance				
Constant	3.578	1.816	5.339	<.001
Retired Professionals	3.412	0.652	6.171	.016
Active Professionals	1.212	-0.814	3.237	.238
Concussion History	0.192	-1.875	2.260	.854
Player Position Risk	-0.843	-2.545	0.860	.328

Note. B = estimate; CI = confidence interval; *UL* = upper limit; *LL* = lower limit; *p* = p-value; Draft prospects, low concussion history, and low player position risk level were the reference categories.

Effect of Cumulative Years of Contact Football Exposure

Another secondary aim examined the relationship between cumulative years of contact football exposure and the number of symptoms, symptom severity, neurocognitive performance, and balance performance, whilst controlling for concussion history and player position risk level. Cumulative years of contact football exposure ranged from 1 – 25 years, with 15.92 years as the mean (*SD* = 4.66). Cumulative years of experience ranged within the career status groups as well: prospective athletes had an average of 13.58 years (*SD* = 3.44), active professional players had an average of 16.28 years (*SD* = 4.94), and retired professionals had an average of 18.25 years (*SD* = 4.23).

The first association exploring the number of symptoms and cumulative years of contact football exposure, while controlling for concussion history and player position risk level, was assessed using a negative binomial regression analysis. The overall model was significant, $\chi^2(3) = 44.07$, $p < .001$. However, within the model, years of contact football exposure ($p = .860$) was not significant, secondary to concussion history driving significance within the model.

Another negative binomial regression analysis was conducted to determine whether total years played predicted symptom severity, while controlling for concussion history and player position risk level. The overall model was significant, $\chi^2(3) = 66.55$, $p < .001$. However, within the model, years of contact football exposure ($p = .418$) was not significant. Again, concussion history affected significance within the model. Table 10 outlines the influence of cumulative years of contact football exposure on symptom reports.

Table 10

Cumulative Years of Contact Football Exposure Influence on Symptom Reports

Effect	*IRR*	95% CI		*p*
		LL	*UL*	
Number of Symptoms				
Intercept	1.179	0.468	2.969	.727
Cumulative Years	1.005	0.950	1.603	.860
Concussion History	4.699	2.808	7.861	<.001
Player Position Risk	1.002	0.620	1.617	.995

Table 10 Continued

Cumulative Years of Contact Football Exposure Influence on Symptom Reports

Effect	*IRR*	95% CI		*p*
		LL	*UL*	
Total Symptom Severity				
Intercept	1.975	0.834	4.680	.122
Cumulative Years	1.022	0.970	1.077	.418
Concussion History	5.447	3.402	8.723	<.001
Player Position Risk	1.022	0.660	1.582	.922

Note. IRR = incident rate ratio; CI = confidence interval; *UL* = upper limit; *LL* = lower limit; Draft prospects, low concussion history, and low player position risk level were the reference categories.

The remaining components to assess this secondary aim, were analyzed using multiple linear regression analyses. Cumulative years of contact football exposure was used to predict neurocognitive performance, while controlling for concussion history and player position risk level. The overall model was not significant, $F(3, 98) = 2.338$, $p = .078$, suggesting cumulative years of contact football exposure was not predictive of neurocognitive performance. Finally, multiple linear regression analyses were conducted to assess whether cumulative years of playing experience was predictive of balance performance, while controlling for concussion history and player position risk level. The overall model was not significant, $F(3, 98) = 1.653$, $p = .182$, suggesting cumulative years played was not predictive of balance performance.

Discussion

We examined the impact of concussion history, career status, and cumulative years of contact football exposure on elements of the SCAT. Our pilot study explored similar research questions with a sample of 57 elite football players. When we doubled the sample size in this study ($N = 102$), we found similar findings to our pilot study, leading us to believe our sample is representative of the population.

Our primary aim explored the influence of concussion history on elements of the SCAT (symptom reports, neurocognitive performance, and balance performance). SCAT performance within elite athletes has been examined by two other authors with different samples (professional ice hockey players and professional rugby players). Further, only one of the authors explored concussion history influences on SCAT data. Hänninen et al. (2015) did not find a significant relationship between concussion history and SCAT performance within their professional ice hockey sample. In our pilot study ($N = 57$) we explored concussion history within an elite football player sample and found a significant relationship between the number of symptoms, symptom severity and neurocognitive performance, however there was no significant difference between concussion history groups and balance performance (Cookinham & Swank, 2019). When looking at the same research question, with a greater sample size ($N = 102$), and controlling for age, we found similar findings, those with multiple concussions had a greater number of symptoms, greater symptom severity, and greater balance errors. However, in this study we found when controlling for age, neurocognitive performance was no longer different between groups, indicating a potential relationship between age and SAC scores. In contrast, several studies suggest age does not affect SAC scores, however those studies explored this relationship in high school (Hunt et al., 2009) and collegiate football players (McCrea et al., 1998; Yengo-Kahn et al., 2016). Our elite football sample (18 – 45 years old) had a median age of 27.75 years (*SD* = 6.95), suggesting the need for a wider range in age to demonstrate the true impact of age on neurocognitive performance.

Our secondary aim explored career status and its relationship to symptom reports, neurocognitive performance, and balance performance. To our knowledge, we are the first authors to explore this relationship. In our pilot study, we found retired professional football players had a greater number of symptoms, greater symptom severity, decreased neurocognitive performance, and greater balance errors (Cookinham & Swank, 2019). In this study, we refined the secondary aim to include controls for concussion history and player position risk level. Results revealed retired professional players had a greater number of symptoms, greater symptom severity, and greater balance errors; however, career status was not associated with neurocognitive performance.

Lastly, we examined the impact of cumulative years of contact football exposure on elements of the SCAT-3, in elite football players. To our knowledge, there are only two similar studies looking at normative SCAT-3 data in professional rugby players (Fuller et al., 2018) and professional ice hockey players (Hänninen et al., 2015); however, they did not explore the relationship between cumulative years of contact sport exposure and performance on the SCAT. In our hypothesis, we proposed there would be an inverse relationship between cumulative years of football exposure and symptom reports, neurocognitive performance, and balance performance. While our hypothesis was refuted, results revealed, again, concussion history was a strong predictor for performance on these elements.

Our participants most frequently reported symptoms were fatigue, trouble falling asleep, difficulty remembering, and difficulty concentrating. As one would presume, these subjective complaints would adversely impact SAC performance. However, we were unable to find a significant association between SAC performance and concussion history, career status, and cumulative years of contact football exposure.

As one would naturally expect, balance declines with age. Research confirms a declining performance on the mBESS with increasing age (Iverson & Koehle, 2013). More specific to football, research exploring helmet-based impacts found a significant correlation between repetitive sub-concussive head impacts and white matter lesions (Merchant-Borna et al., 2016). Brain white matter lesions have been associated with impaired balance in older adults (Starr et al., 2003; Wang et al., 2016). Knowing this, one would suspect our participants who had greater football exposure would have demonstrated decreased balance performance, however, that was not the case in our sample, rather concussion history was the stronger predictor.

As previously stated, football retains the highest incidence of concussions among the collective entirety of contact sports. In addition to concussive impacts sustained during practice or competition, it must also be noted that a football athlete may undergo a high number of head impacts, both concussive and sub-concussive. With regard to the latter, it has been demonstrated that football participation contributes to possibly thousands of sub-concussive impacts for a singular player over the course of a season and subsequently a career (Slobounov et al., 2017). Furthermore, sport related sub-concussive blows have been correlated with alterations in brain function including short-term cognitive deficits (McAllister et al., 2012), decreased brain volume in the thalamus and caudate nucleus (Bernick et al., 2015), and enduring cognitive deficits (Stamm et al., 2015).

We understand this growing concern over how concussions and repetitive sub-concussive impacts incurred during football are associated with neurophysiological change (Breedlove et al., 2012), and may affect long-term cognitive function (Broglio et al., 2011). Hence, the main rationale for the cumulative years of exposure secondary aim, was to determine if years of exposure might serve as a proxy measure of the impact of sub-concussive blows on concussion-related symptoms, neurocognitive performance, or balance. Guskiewicz et al. (2005) looked at the association between cerebral concussions and late-life cognitive impairments in retired football players. Just like our study, the mean cumulative years of football exposure was 15 years (*SD* = 4.3). In their sample of 2552 athletes, the average participant age was 53.8 years (*SD* = 13.4), while the average age of our participants was 27.75 years (*SD* = 6.95). Their data suggested significant memory problems may be caused by the repetitive cerebral trauma while playing football (Guskiewicz et al., 2005). Thus, it is possible the abbreviated nature of our study or current age of the participants explains our lack of findings in the analyses of this secondary aim.

There are several important limitations to address in this study. While the awareness and diagnostic vigilance pertaining to concussion have been increasing significantly over the past decade, it has been proposed that 50% of concussions remain unreported (Merchant-Borna et al., 2016). Further, the degree of variability involved with subjective symptom reporting, as well as, the myriad of influencing factors involved with this process (such as an athlete withholding current symptoms in order to maintain an active playing status (Delaney et al., 2018) exert a negative influence on the validity of epidemiologic data pertaining to SRC. Furthermore, age could not be used as a control variable when exploring career status, secondary to suspected multicollinearity issues due to age inherently increasing with each increase in level of play. Finally, this study followed a cross-sectional observational methodology, a longitudinal design may be beneficial to note trends over time. Consequently, generalizability is limited, thus, our results should be viewed with caution.

Conclusion

On average, those with multiple concussions had a greater number of symptoms, greater symptom severity, and greater balance deficits, suggesting there are long-term, lingering effects from concussions, even after concussion resolution. Clinicians should consider concussion history and career status effects on symptom reports and balance performance within their clinical decision making. While, cumulative years of contact football exposure did not have a significant impact on our findings, we suggest this research question be explored further, perhaps with a greater sample size and studied across the lifespan. This study lays the foundation for further research to explore concussion history effects in other sports and across the lifespan.

CHAPTER IV

STUDY 2

Activity Status Effects on Sports-Related Concussion Assessment Measures

Abstract

Objective

To determine the effects of activity status on concussion-related symptoms, balance, neurocognition, VOMS performance, and DT TG performance, in elite contact athletes, elite non-contact athletes, and non-athletes.

Methods

Ninety participants (age: $M = 28.48$, $SD = 6.19$ years) comprised of elite contact sport athletes ($N = 30$), elite non-contact sport athletes ($N = 30$), and non-athletes ($N = 30$), were evaluated utilizing, components of the Sport Concussion Assessment Tool – 5th edition (SCAT-5) (symptom evaluation, neurocognitive testing, and balance testing), the VOMS, and DT TG.

Results

Results revealed that participants within the non-contact athlete group were expected to have a rate of symptoms 1.94 times higher ($IRR = 1.94$ (1.06, 3.75), $p = .048$), and symptom severity 2.18 times higher ($IRR = 2.18$ (1.18, 4.00), $p = .012$), than the non-athlete group. Contact athletes' symptoms and symptom severity were not significantly greater when compared to non-athletes. Next, the model analyzing activity status groups' ability to predict VOMS total symptom reports was significant. Results

revealed non-contact athletes and those with a high concussion history had greater headache scores and greater dizziness scores, but nausea and fogginess scores were not significantly different. Lastly, activity status was not significantly predictive of neurocognitive performance, balance performance, VOMS symptom severity reports, or DT TG performance.

Conclusion

Activity status and concussion history produced significant associations to symptom reports. Whereas, activity status did not have a significant impact on neurocognition, balance or DT TG performance. Secondary to the minimal findings within this cross-sectional design, longitudinal studies are recommended to further explore these relationships across the lifespan.

Introduction

Concussion, a form of mild traumatic brain injury, results from biomechanical forces that induce a neurometabolic cascade within the brain and ultimately alter homeostatic function (Choe, 2016; Langlois et al., 2006). In the United States alone, 1.6 to 3.8 million SRCs occur every year and have become a national public health problem (Giza & Kutcher, 2014; Merchant-Borna et al., 2016). Epidemiology regarding concussions within the general population is limited at this time. While awareness and diagnostic vigilance pertaining to concussion have increased significantly over the past decade potentially leading to an increase in the reported incidence of concussion, 50% of concussions continue to remain unreported (Merchant-Borna et al., 2016). Several key factors such as the lack of sensitive diagnostic imaging, a high degree of variability in the definition of SRC, and primary utilization of subjective symptom reporting all represent challenges in accurate identification and diagnosis of concussion (Merchant-Borna et al., 2016).

The type of sport played affects concussion risk, with athletes involved in contact sports demonstrating a greater risk of sustaining a concussion when compared to non-contact sports counterparts. In addition to concussive impacts sustained during practice or competition, some athletes in contact sports (i.e., Football) may undergo a high number of total head impacts, both concussive and sub-concussive, throughout a single season and subsequently a career (Slobounov et al., 2017). Sport related sub-concussive blows have been correlated with alterations in brain function including short-term cognitive deficits (McAllister et al., 2012), decreased brain volume in the thalamus and caudate nucleus

(Bernick et al., 2015), and long-term structural and functional deficits to one's neuroanatomy (Stamm et al., 2015). However, when considering the potential role of concussion exposure, the distinction between contact athletes and non-contact athletes is rarely explored in the literature. Thus, it was our intention to further explore this relationship through concussion evaluations with healthy participants that are elite contact athletes, non-contact athletes, and non-athletes.

While there is no standardized clinical assessment for concussions, the literature suggests a comprehensive concussion evaluation should include a battery of tests (Committee on Sports-Related Concussions in Youth, et al., 2014) such as symptom scores (total number of symptoms and symptom severity), evaluation of postural control (Hunt & Ferrara, 2009), neurocognitive functioning assessment (Broglio et al., 2007b), vestibular ocular motor testing (Kontos et al., 2016; Kontos et al., 2017; Moran et al., 2018; Mucha et al., 2014; Russell-Giller et al., 2018; Worts et al., 2018), and DT testing (Kleiner et al., 2018). However, a gold standard concussion battery has not been established for clinical use, at this time. Thus, performance on a symptom evaluation, neurocognitive testing (via the SAC), balance testing (via the mBESS), the VOMS, and DT TG testing, was explored within elite contact athletes, non-contact athletes, and non-athletes, as we believe this compilation of measures is the most encompassing of the above criteria.

This study is important as it controlled for varying levels of exposure relative to concussion risk. The myriad of symptoms, balance disturbances, and cognitive deficits that are consistent with a concussion diagnosis are not exclusive to concussion alone.

Post-concussion affects can include prolonged fatigue, headaches, slower cognitive processing times, poor concentration, irritability, and sleep disturbances (Polinder et al., 2018). However, many of these concussion-related symptoms are considered "everyday symptoms" and are common in the otherwise healthy, non-concussed population, including those who do and do not participate in sports (Polinder et al., 2018). Further, fatigue, irritability, more emotional, difficulty with sleep, and difficulty with concentration are all common symptoms experienced by athletes as a result of overtraining (Ma, 2011). Thus, this study was designed to compare a concussion-related symptom checklist along with neurocognitive performance as well as the more objective measures of balance, VOMS, and DT performance within three different groups of individuals with varying levels of concussion exposure risk and sports participation.

Current literature suggests 60% of individuals who have sustained a concussion will present with vestibular and ocular-motor impairments and report symptoms following a SRC that can last up to two months (Kontos et al., 2017). However, due to the lack of research exploring the relationship between VOMS testing in individuals comparable to our activity status groups (contact athletes, non-contact athletes, and non-athletes), our study is the first to report this relationship.

Normal daily activities and sport require simultaneous cognitive and physical demands (Kleiner et al., 2018). One study suggested a decline in gait performance is present in individuals who have sustained a concussion and is most obvious during DT testing (Kleiner et al., 2018). Another study that compared single task TG to DT TG found that, individuals who had sustained a concussion took significantly longer to complete the DT TG trial compared to the controls (Howell et al., 2017). While, research is exploring a DT assessment, a gold standard has not been established at this time. Further, the long-term effects of gait deterioration have not been explored. Thus, a secondary aim of this study was to compare cognitive and motor performance between contact athletes, non-contact athletes, and non-athletes utilizing DT TG protocols, whilst controlling for concussion history.

By including a non-athlete control group, we were able to gain a better understanding of what standard concussion measures represent. Further, we believe this study was able to delineate the influence of sport participation on concussion measures. Inherently contributing to clinical practice, as an understanding of these additional factors should lead to better informed clinical decision making.

Thus, the primary purpose of this study was to examine if there are differences between healthy contact athletes, non-contact athletes, and non-athletes (activity status) and symptom reports, neurocognitive performance, and balance performance. The secondary purpose of this study was to determine if activity status is a factor involved with VOMS performance and DT TG performance.

Methods

This study was approved by Texas Woman's University Institutional Review Board. Prior to enrollment, each participant was informed of the intent and methods of the study and asked to complete an informed consent document. Contact athletes from any sport, non-contact athletes from any sport and non-athletes were invited to participate. Participants were between the ages of 18 and 45. To be eligible to participate, contact athletes had to participate in a professional or semi-professional athletic organization, or have received invitations to work out with professional/semi-professional organizations or have competed at a National Governing Body sanctioned Olympic/National event. Eligible non-contact athletes were currently participating in or had previously participated in a major competition for their sport. For example, athletes who qualified for a major marathon (New York, Boston, or Chicago), triathlon (gold/silver level) or Ironman. Non-athlete controls were individuals who did not play high school sports or only participated in non-contact high school sports and it had been at least five years since their participation. Individuals were excluded if they had a diagnosed concussion within the past 30 days, if they were currently experiencing symptoms preventing return to play/sport, or if they were pregnant.

The study followed a cross-sectional design. Participants underwent a single session involving the collection of demographic data (sport position played, previous concussion history, and cumulative number of years they have participated in their sport). Additional data collected included concussion symptom evaluation, neurocognitive, and balance assessments from the SCAT-5 concussion battery as well as VOMS and DT TG testing.

The symptom evaluation, neurocognitive performance, and balance assessments were administered in accordance with the SCAT-5 recommended guidelines (see Appendix A). Total symptoms were evaluated using the 22-concussion symptom scale from the SCAT-5. The participant rated the severity of each symptom on a 0 – 6 scale (0 = *none*; 1 – 2 = *mild*; 3 – 4 = *moderate*; 5 – 6 = *severe*). The study assessed total symptoms by adding the total number of symptoms reported and symptom severity was measured by summing the symptom Likert scales. The SCAT symptom evaluation has demonstrated both face and content validity (McLeod & Leach, 2012), adequate test-retest reliability (Chin et al., 2016), excellent internal consistency (Lovell et al., 2006), moderate sensitivity, and moderate specificity (Downey et al., 2018).

Neurocognitive performance was measured using the SAC components of the SCAT-5. The SAC composite score (0 – 30) was a sum of orientation (0 – 5), immediate memory (0 – 15), concentration (0 – 5), and delayed memory recall (0 – 5). The lower scores are reflective of poorer neurocognitive performance. The composite score was used in the data analyses. In studies exploring healthy and concussed athletes, the SAC demonstrated moderate specificity, excellent sensitivity, adequate test-retest reliability, excellent predictive validity (Barr & McCrea, 2001), and good reliability (Mrazik et al., 2017a).

The mBESS was used to measure balance. The mBESS total score was calculated by summing the errors for each testing position (double, tandem, and single). The mBESS scores can range from 0 – 30, with higher scores indicating poorer balance (Sport concussion assessment tool - 3rd edition, 2013). In studies exploring both concussed and healthy athletes, the mBESS demonstrated good reliability (ICC = 0.88; Mrazik et al., 2017a), moderate sensitivity, moderate specificity (Oldham et al., 2018), adequate test-retest reliability, and adequate interrater reliability (Chin et al., 2016). In another study with concussed athletes, the mBESS exhibited moderate sensitivity (Buckley et al., 2018).

VOMS testing was implemented according to the standardized procedures (see Appendix B). However, scores were calculated and analyzed two different ways, one method was the standard VOMS symptom severity calculation and the other method, described below, was simply a count of symptoms without calculating the severity component of the symptom. The VOMS total symptom score was the difference of the total number of symptoms reported during the 7 testing measures and the baseline reported total number of symptoms. Performance scores could range between 0 – 28 and baseline scores could range between 0 – 4. A higher score indicates a greater impairment. The VOMS symptom severity score was the calculated difference of the total severity rating during testing and the baseline severity. The performance severity ranged between 0 – 280. The baseline severity ranged between 0 – 40. A higher score indicates a greater severity of impairment. The VOMS has demonstrated high internal consistency (Moran et al., 2018), a low false-positive rate (2 – 11%; Mucha & Trbovich, 2019), and high sensitivity in identifying athletes who have experienced a concussive episode (Mucha et al., 2014). The VOMS measures aspects of ocular motor and vestibular function other than those tested by mBESS, with good reliability (Mucha & Trbovich, 2019).

For DT TG, participants were instructed to tandem walk as quickly and accurately as possible, without footwear, along a 38mm wide and 3-meter-long tape. At the end of the tape they completed a 180-degree turn and returned to the starting position (Sport Concussion Assessment Tool - 3rd Edition, 2013; see Appendix C). Participants completed one trial under each of the following conditions in random order. The single task TG trial followed the instructions above and the number of physical errors and time to complete the task were recorded. Physical errors included stepping off the line, loss of TG, or touching the examiner or an object (Sport Concussion Assessment Tool - 3rd Edition, 2013). For the single task cognitive trial: the individuals were instructed to stand and complete "serial 7's". They were instructed to count backwards from 100 by 7's until they reached the number 51. The examiner counted the cognitive errors (incorrect numbers spoken). For the combination trial /DT trial, the individual followed the TG instructions above, while simultaneously completing "serial 7's" as described in the single-task cognitive trial. The length of time and errors (both physical and cognitive) were recorded for this trial.

Differential scores for each trial were utilized in our data analyses. Specifically, single task time was subtracted from DT time to create a differential score. Similar procedures were followed for cognitive and physical errors. Single task cognitive errors were subtracted from the DT physical errors. Single task physical errors were subtracted from the DT physical errors.

Tandem gait is considered clinically feasibly, highly reliable (ICC = 0.97), has moderate sensitivity and moderate specificity (Oldham et al., 2018), and has a high test-retest reliability in both the single-task and dual-task testing conditions (Howell et al., 2019). Specific recommendations for DT testing to assess individuals following SRC in a clinic setting have not been determined to date (Oldham et al., 2018).

Statistical Analysis

All statistical analyses were performed using SPSS Version 26 and included descriptive statistics, as well as, multifactorial regression modeling. Data screening was conducted to ensure the validity of the data and tested for assumptions. Our primary aim was to determine how the sport classification (contact, non-contact, or none) influences concussion measures including the number of symptoms, symptoms severity, neurocognitive performance, and balance, while controlling for concussion history. Thus, participants were grouped by their activity status category. Regression models were developed for each of the outcome variables (number of symptoms, total symptom severity, SAC composite scores, mBESS composite scores, VOMS total symptom differential scores, VOMS symptom severity differential scores, and DT TG cognitive differential scores, DT TG physical differential scores and DT TG differential time values). In each model, activity status was the independent variable and concussion history was used as a covariate. The alpha level was set a priori at 0.05.

For our primary aim, negative binomial regression models were used for analyses involving count variables (number of symptoms and symptom severity), secondary to normality violation concerns with the displayed Poisson distributions. Analyses involving neurocognitive performance and balance performance were assessed utilizing multiple linear regression modeling. The reference category for all primary aim analyses were participants within the non-athlete group with no reported history of concussion.

Our secondary aims were to analyze (1) how VOMS performance compared amongst contact sport athletes, non-contact sport athletes, and non-athletes while controlling for concussion history and (2) how DT TG performance compared amongst contact sport athletes, non-contact sport athletes, and non-athletes, while controlling for concussion history. To examine these secondary aims, multiple linear regression models were used. VOMS and DT TG were the outcome measures in these models, with activity status and concussion history serving as the independent variable and covariate respectively. The reference categories used within these secondary aims, were participants within the non-athlete group, that had a low concussion history.

An a priori power analysis was conducted using G*Power 3.1 to determine the sample size required to find significance. The desired level of power was set to .80 and an alpha-level was set to 0.05. Based on previous symptom and symptom severity findings (Downey et al., 2018), a large effect size was predicted to be .80 (Cohen's d). Assuming a linear multiple regression with 3 groups, G*Power suggested a minimum of 73 participants, however 10% was added for suspected abnormal distributions. Thus, we sought 81 participants with 27 participants per group.

Results

Description of Sample

Ninety participants completed surveys regarding their activity status and injury history. Baseline characteristics per activity status group can be found in Table 11. Many participants denied having a history of concussions (77.8%). For activity status groups, participants were classified as contact athletes, non-contact athletes, and non-athletes. Frequency of sports played by participants within the contact athlete and non-contact athlete groups can be found in Table 12.

Table 11

Baseline Characteristics per Activity Status Group

	Contact Athletes	Non-Contact Athletes	Non-Athletes	*p*
Age in years (*M* (*SD*))	25.43 (5.06)	29.23 (6.14)	30.77 (6.21)	.002
Gender (Male / Female)	26 / 4	9 / 21	11 / 19	< .001
Concussion History (Yes / No)	11 / 19	5 / 25	4 / 26	.063
Single Task Tandem Gait time (in seconds) (*M* (*SD*))	15.50 (3.99)	16.16 (3.99)	18.00 (7.82)	.223
Single Task Cognitive errors (*M* (*SD*))	0.57 (1.04)	0.33 (0.55)	0.33 (0.92)	.361
Single Task Physical Errors (*M* (*SD*))	0.07 (.37)	0 (0)	0.20 (0.55)	.177

Note. *M* = mean; *SD* = standard deviation; *p* = p-value; VOMS = Vestibular/Ocular-Motor Screening tool; Contact Athletes *N* = 30; Non-Contact Athletes *N* = 30; Non-Athletes, *N* = 30.

Table 12

Frequency of Participants per Sport

Sport	Frequency
Contact Athletes	
Football	14
Softball	2
Taekwondo	4
Gymnastics	3

Table 12 Continued

Frequency of Participants per Sport

Sport	Frequency
Figure skating	3
Baseball	3
Basketball	1
Non-Contact Athletes	
Running	27
Triathlon	1
Golf	2

Note. Contact Athletes $N = 30$; Non-Contact Athletes $N = 30$.

Primary Analysis

Our primary aim assessed the relationship between activity status groups (contact sport athletes, non-contact sport athletes, and non-athletes) and the number of symptoms, symptom severity, neurocognitive performance (measured by the SAC), and balance performance (measured by the mBESS), while controlling for concussion history. Table 13 and Table 14 depict the activity status influence on the dependent variables. The overall model to predict the number of symptoms based on activity status was significant, $\chi^2(3) = 16.77$, $p = .001$. These results revealed that participants within the non-contact athlete group were expected to have a rate of symptoms 1.94 times higher compared to the non-athlete group (*IRR* = 1.94 (1.06, 3.75), $p = .048$). However, being contact athlete did not predict the number of symptoms when compared to non-athletes ($p = .672$). With symptom severity, the overall model was significant, $\chi2(3) = 37.04$, $p < .001$. These results revealed non-contact athletes were expected to have a symptom severity rate 2.18 times higher compared to non-athletes (*IRR* = 2.18 (1.18, 4.00), $p = .012$). However, being a contact athlete did not predict symptom severity when compared to non-athletes ($p = .134$). The influence of activity status on the number of symptoms is presented in Table 15.

Table 13

Activity Status Influence on Dependent Variables

	Contact Athletes *Mdn (IQR)*	Non-Contact Athletes *Mdn (IQR)*	Non-Athletes *Mdn (IQR)*
Number of Symptoms	0 (0 – 3)	1 (0 – 4)	0 (0 – 1.25)
Symptom Severity	0 (0 – 4)	2 (0 – 8)	0 (0 – 2)

Note. *Mdn* = median; *IQR* = interquartile range; Contact Athletes *N* = 30*;* Non-Contact Athletes *N* = 30; Non-Athletes, *N* = 30.

Table 14

Activity Status Influence on Dependent Variables

	Contact Athletes *M (SD)*	Non-Contact Athletes *M (SD)*	Non-Athletes *M (SD)*
Neurocognitive Performance	25.30 (3.47)	26.63 (2.15)	27.36 (2.38)
Balance Performance	2.57 (2.45)	3.40 (2.54)	4.50 (3.92)

Note. M = mean; SD = standard deviation; Contact athletes, *N* = 30; Non-contact athletes *N* = 30; Non-athletes, *N* = 30; Balance performance was measured using the mBESS; Neurocognitive performance was measured using the SAC.

Table 15

Activity Status Influence on Symptom Reports

Effect	*IRR*	95% CI		*p*
		LL	*UL*	
Number of Symptoms				
Intercept	0.996	0.602	1.649	.989
Contact Athletes	1.166	0.573	2.371	.672
Non-Contact Athletes	1.942	1.006	3.748	.048
Concussion History	3.067	1.599	5.881	.001
Symptom Severity				
Intercept	1.501	0.948	2.378	.083
Contact Athletes	1.657	0.856	3.208	.134
Non-Contact Athletes	2.175	1.183	3.998	.012
Concussion History	4.073	2.184	7.597	<.001

Note. IRR = incident rate ratio; CI = confidence interval; *UL* = upper limit; *LL* = lower limit; Non-athletes and no concussion history were used were the reference categories.

Activity status was used to predict neurocognitive performance; however, the overall model was not significant, $F(3, 86) = 0.981$, $p = .406$, suggesting activity status did not predict neurocognitive performance. Last, activity status was used to predict balance performance, however the overall model was not significant $F(3, 86) = 2.66$, $p = .053$, suggesting activity status did not predict balance performance.

Secondary Analysis

One of our secondary aims assessed the relationship between activity status groups and VOMS symptom severity (headache severity, nausea severity, dizziness severity, fogginess severity), while controlling for concussion history. Table 16 depicts activity status influence on VOMS symptom severity reports. The overall models to predict severity of: headache, $F(3, 86) = 1.04$, $p = .378$, dizziness, $F(3, 86) = 2.04$, $p = .114$, nausea, $F(3, 86) = 0.86$, $p = .463$, and fogginess, $F(3, 86) = 1.38$, $p = .254$, based on activity status were not significant. These results suggest activity status did not predict VOMS symptom severity reports.

Table 16

Activity Status Influence on Vestibular/Ocular-Motor Screening Tool Symptom Severity

VOMS Variable	Contact Athletes	Non-Contact Athletes	Non-Athletes
	M (SD)	*M (SD)*	*M (SD)*
Headache Total	1.8 (6.00)	2.88 (6.35)	0.67 (2.09)
Dizziness Total	2.70 (6.28)	1.60 (2.58)	0.82 (2.81)
Nausea Total	0.533 (2.29)	0 (0)	0.133 (0.73)
Fogginess Total	1.33 (4.40)	1.6 (3.50)	0 (0)

Note. $N = 90$; M = mean; SD = standard deviation; Contact Athletes $N = 30$; Non-Contact Athletes $N = 30$; Non-Athletes $N = 30$; VOMS = Vestibular/Ocular-Motor Screening Tool.

This secondary aim also assessed the relationship between activity status and VOMS total symptom reports (headache total, nausea total, dizziness total, fogginess total), while controlling for concussion history. The overall model to predict the total number of times a headache was reported with testing, based on activity status was significant, $F(3, 86) = 4.879$, $p = .004$ with an adjusted R^2 of 0.116, suggesting a predictive relationship between VOMS total symptom reporting and activity status. Results revealed non-contact athletes ($p = .046$) and those with a high concussion history ($p = .010$) had higher headache total scores.

The overall model to predict the number of times dizziness was reported with testing, based on activity status was significant, $F(3, 86) = 13.780$, $p < .001$, and accounted for a moderate amount of the variance (Adj. $R^2 = 0.301$). Within the model, results revealed contact athletes had 1.22 more counts of dizziness reports compared to non-athletes ($p = .004$), non-contact athletes had 0.87 more reports of dizziness compared to non-athletes ($p = .035$), and those with a high concussion history had 2.01 higher reports of dizziness ($p < .001$).

The overall model to predict the total number of times nausea was reported with testing, based on activity status was significant, $F(3, 86) = 4.793$, $p = .004$, with a model variance of 11.3%. Within the model, being a contact athletes or non-contact athlete did not predict the number of nausea reports (ps < .05), however concussion history was a significant predictor ($p = .006$).

The overall model to predict the total number of times fogginess was reported with testing, based on activity status was not significant, $F(3, 86) = 2.296$, $p = .083$. The influence of activity status on VOMS for headache, dizziness, and nausea total symptoms are presented in Table 17.

Table 17

Activity Status Influences Vestibular/Ocular-Motor Screening Tool Total Symptoms

Variable	B	95% CI		*p*
		LL	*UL*	
Headache Total				
Constant	-0.168	-0.845	0.508	.622
Contact Athletes	0.939	-0.027	1.904	.057
Non-Contact Athletes	0.958	0.018	1.898	.046
Concussion History	1.263	0.310	2.215	.010
Dizziness Total				
Constant	-0.268	-0.847	0.311	.361
Contact Athletes	1.215	0.388	2.041	.004
Non-Contact Athletes	0.866	0.061	1.671	.035
Concussion History	2.008	1.193	2.823	< .001
Nausea Total				
Constant	-0.052	-0.248	0.143	.598
Contact Athletes	0.209	-0.070	0.488	.140
Non-Contact Athletes	-0.013	-0.285	0.259	.924
Concussion History	0.390	0.115	0.666	.006

Note. B = estimate; CI = confidence interval; *UL* = upper limit; *LL* = lower limit; *p* = p-value; Non-athletes and no concussion history were the reference categories.

Our last secondary aim assessed the relationship between activity status groups and DT TG performance, while controlling for concussion history. Table 18 provides the descriptive statistics outlined per activity status group. The overall model to predict DT TG time (measured in seconds) on activity status was not significant, $F(3, 86) = 0.296$, $p = .828$. When examining cognitive performance (measured in errors) and DT TG, the overall model was not significant, $F(3, 86) = 0.144$, $p = .933$. Lastly, the overall model to predict DT TG physical performance (measured in errors) was not significant, $F(3, 86) = 0.624$, $p = .624$, suggesting activity status was not predictive of performance on any of the DT TG measures.

Table 18

Activity Status Influence on Dual-Task Tandem Gait Performance (Differential Scores)

Dual-Task Tandem Gait Variable	Contact Athlete	Non-Contact Athletes	Non-Athletes
	M (SD)	*M (SD)*	*M (SD)*
Time (measured in seconds)	4.57 (2.75)	5.66 (4.90)	5.89 (9.84)
Cognitive Errors	-0.07 (0.365)	-0.13 (.43)	-0.10 (0.66)
Physical Errors	0.03 (0.18)	0 (0)	0.03 (1.83)

Note. *M* = mean; *SD* = standard deviation; Contact Athletes *N* = 30; Non-Contact Athletes *N* = 30; Non-Athletes, *N* = 30.

Discussion

Our primary aim was to examine the difference between contact athletes, non-contact athletes, and non-athletes and their symptom reports, neurocognitive performance and balance performance, while controlling for concussion history. Results yielded non-contact athletes had greater symptoms and greater symptom severity compared to non-athletes. Whereas, contact athletes were not significantly different from non-athletes. Thus, refuting our hypothesis of contact athletes having the greatest number of symptoms and greater symptom severity.

Similarly, one study exploring varsity, female, rugby players and non-contact age matched controls (female, varsity rowers and swimmers) found non-contact athletes had on average more symptoms and a greater symptom severity compared to contact athletes, with both in-season and off-season testing (Manning et al., 2020). Another study exploring collegiate athletes also found that contact sport athletes had better symptom scores compared to non-contact athletes (Katz et al., 2018).

There are a few factors that can possibly contribute to these findings. The first factor to consider, is concussion symptom checklists are not specific to concussions. Elite endurance athletes can have symptoms of overtraining such as: fatigue, irritability, anxiety, more emotional, difficulty with sleep, and difficulty with concentration (Ma, 2011), which are all symptoms on the checklist. Regarding gender, our contact athlete group was comprised of approximately 87% males, whereas, our non-contact athlete group was comprised of approximately 70% females, and the non-athlete group was comprised of approximately 63% females. Literature suggests females are more likely to report symptoms (Wallace et al., 2017), take baseline testing more seriously and exert greater effort compared to their male counterparts (Cottle et al., 2017). Another factor to consider, is that symptom checklists are based solely on subjective report. Perhaps non-contact athletes were more truthful with their symptom reporting compared to contact athletes. Literature suggests athletes may not be truthful about their symptoms following a concussive injury (Broglio et al., 2007a); while not explored in the research, perhaps this is true with baseline testing in healthy subjects, as well.

Within this study, concussion history was the most consistent factor associated with the modeled outcome variables. While concussion history did not impact symptom scores in professional, male, ice hockey players (Hänninen et al., 2015), symptom scores amongst elite football players (Cookinham & Swank, 2019), collegiate athletes (Shehata et al., 2009), high school athletes (Snedden et al., 2016; Valovich McLeod et al., 2012), and youth hockey players (Schneider et al., 2010) were all impacted by concussion history. In our pilot study, elite football players with a history of multiple concussions (2+) reported a greater number of symptoms and greater symptom severity. Similarly, studies exploring high school athletes found those with a prior concussion history had a greater number of symptoms (Valovich McLeod et al., 2012) and greater symptom severity (Snedden et al., 2016). Another study exploring youth hockey players, found similar findings, those with a concussion history presented with a greater number of symptoms (Schneider et al., 2010).

When analyzing activity status group differences within neurocognitive performance, no significant results were yielded. In a study exploring NCAA student-athletes, researchers found that contact sport athletes had better symptom scores (SCAT-3), better visual and verbal memory (ImPACT®), but slower reaction times (ImPACT®) and worse neurocognitive scores (SAC), when compared to non-contact athletes (Katz et al., 2018). Similarly, another study comparing collegiate, collision, contact, and non-contact athletes found significant differences between sport classifications with neurocognitive scores, though it was through a different testing platform (ImPACT®); (Benedict & Parker, 2014). Another study exploring diffusor tensor imaging in contact (female, varsity, rugby players) and non-contact athletes (female, varsity rowers and swimmers) found significant diffusion changes along the brain stem, corpus callosum, cingulum, inferior occipital fasciculi, and superior longitudinal white matter tract amongst the contact athletes, when compared to the non-contact athletes (Manning et al., 2020). With these studies in mind (Katz et al., 2018; Manning et al., 2020), we hypothesized that contact athletes in our study would have significantly different neurocognitive scores when compared to non-contact athletes; however, our hypothesis was refuted.

A possible explanation for our outcome is perhaps the age and concussion history report within our sample. The average age of our participants was 28 years old, and only 22% of our participants had reported a prior concussion. Whereas, a sample of 2,552 retired professional football players (M = 53 years), 85% of which sustained at least one concussion during their careers, had significant neurocognitive impairments (Guskiewicz et al., 2005). A sample of retired elite rugby players, recreational rugby players, and non-contact sport athletes (M = 43 years) found those who had played rugby or had a history of a concussion had moderate neurocognitive deficits (Hume et al., 2016). Perhaps, neurocognitive deficits associated with concussive and sub-concussive impacts from contact sports are more pronounced later in life. Further research is indicated to explore the long-term effects on neurocognition following contact and non-contact sports.

Lastly, our primary aim also explored activity status group differences on balance performance, again no significant results were yielded. A similar study exploring high school and collegiate athletes from collision, contact, and non-contact sports found no between-group differences over the course of four seasons with balance testing (Eckner et al., 2019). Long-term balance impairments amongst contact sport athletes, and non-contact sport athletes remains unclear, indicating further research, perhaps with a different balance assessment that is specific and sensitive enough to be responsive to chronic impairments.

One of our secondary aims assessed the relationship between activity status and VOMS performance by looking at total symptom scores (headache total, nausea total, dizziness total, fogginess total), while controlling for concussion history. When looking at total symptom scores within the VOMS, there were some differences amongst the activity status groups (headache and dizziness), however, the primary factor (most significant predictor) impacting the regression models remained concussion history. Those with a high concussion history had higher headache, dizziness, and nausea total symptom scores. Literature exploring VOMS total symptoms in healthy athletes and non-athletes is not available that this time.

When exploring the association between VOMS symptom severity reports and activity status, the regression models did not reveal any significant findings, refuting our hypothesis that contact athletes would have greater symptom severity. Further concussion history was not a significant factor within these models. Likewise, in a sample of healthy, collegiate athletes, concussion history was not a factor associated with VOMS symptom severity (Kontos et al., 2016). Similarly, another study with a sample of healthy, adolescent students, found concussion history did not impact VOMS symptom severity (Yorke et al., 2017).

The VOMS is a relatively new measurement tool (Bliss & Carr, 2020), thus, factors that impact findings are still elementary within the literature. To our knowledge, the influence of concussion history and VOMS performance amongst elite contact-athletes, non-contact athletes, and non-athletes has not been previously established.

Our last secondary aim explored the difference between DT TG performance amongst contact athletes, non-contact athletes, and non-athletes. Our hypothesis of contact athletes having greater cognitive errors, physical errors and longer times, was refuted. We believe our study design, specifically our inclusion/exclusion criteria (i.e., individuals were excluded if they had a diagnosed concussion within the past 30 days, and if they were currently experiencing symptoms preventing return to play/sport) may be the reason our hypothesis was refuted.

In contrast, Berkner et al. (2017) found that even after concussion symptoms had resolved, there were still dual-task gait alterations such as: slower gait speeds, smaller cadences, and shorter stride lengths (Berkner et al., 2017). Multiple authors have explored concussion history effects on TG and DT TG, and they all found decreased gait velocities in those with a concussion history (Berkner et al., 2017; Howell et al., 2017;

Lynall et al., 2019). Thus, suggesting a cumulative effect of concussions can contribute to deteriorating dual-task dynamic motor function (Howell et al., 2017) and long-term deficits in executive functions (Tapper et al., 2017), even after the concussion symptoms have resolved (Howell et al., 2017). Controversially, a study exploring healthy, collegiate, collision/contact sport and non-contact sport athletes found no differences when comparing activity status groups or concussion history. However, this study solely explored single task TG and there were no non-athlete controls. Further, the participants performed four trials, thus, a practice effect cannot be ruled out (Oldham et al., 2018). Our results were equivocal to these findings, however there is a need for further research to elucidate the impact of concussion history on DT TG performance.

There are several limitations that need to be addressed. First, concussion history is control variable utilized in all our research aims, however, 50% of concussions can go un-reported for a myriad of reasons (Merchant-Borna et al., 2016). Thus, interfering with the validity of our control variable. Another limitation being the symptom evaluation. The symptom evaluation relies solely on the participants' subjective report and it includes everyday symptoms not specific to concussions, questioning the reliability. However, the literature has reported psychometric properties that still favor using the symptom evaluation clinically. The mBESS and DT TG rely on the human eye to count the amount of physical errors, leaving room for error. However, our study only utilized one examiner to minimize this risk. DT TG also requires a stopwatch, which has room for human error as well. Furthermore, our power analysis was performed based on previous findings for number of symptoms and symptom severity, perhaps a greater sample size was required to have significant findings with neurocognition, balance, and DT TG testing. Next, when looking at the cognitive errors portion of the DT TG there appears to be a learning effect with the "serial 7's". While the trials were randomized, the "serial 7's" followed the strict procedure of 100 minus 7, until 51; thus, if patients started with single task cognition trial, they were able to improve upon their cognitive errors with the DT trial. Therefore, randomizing the starting point with "serial 7's" or utilizing a different cognitive task, such as the Stroop Color and Word Test, may be beneficial for future research. Lastly, this study followed a cross-sectional observational methodology, a longitudinal design may be beneficial to note trends over time. With these limitations in mind, our results should be viewed with caution.

Conclusion

Activity status appears to moderately influence the number of symptoms, symptom severity, and VOMS total symptom reports, however greater factors may be at play, such as gender and overtraining symptoms. Whereas, concussion history was the most significant variable within our findings, suggesting clinicians should consider concussion history in their clinical decision making. Lastly, a longitudinal study is recommended to explore the long-term effects of contact sports and their effect on neurocognition, balance, and DT TG, secondary to the lack of findings within this cross-sectional design.

CHAPTER V

CONCLUSION

Purpose

The purpose of this dissertation was to fill the gaps within the literature regarding factors that influence SRC measurements in elite athletes and non-athletes. Specifically, long-term implications of concussion history, career status, cumulative years of contact football exposure, and activity status, are currently lacking within the literature. Thus, the purpose of the first study was to examine how specific factors (concussion history, career status, and cumulative years of football exposure) affect symptoms, neurocognitive performance, and balance in elite football players. The second study then analyzed those variables, in addition to analyzing vestibular and ocular-motor function, and DT performance in contact athletes, non-contact athletes, and non-athletes.

Methods

Elite, American football players between the ages of 18 – 45 years old were invited to voluntarily participate in Study 1. Elite athletes from any sport and non-athletes, between the ages of 18 – 45 years old, were invited to participate in Study 2. Individuals were excluded from both studies if they had a diagnosed concussion within the past 30 days, if they were currently experiencing symptoms preventing return to play/sport, or if they were pregnant.

Both studies followed a cross-sectional design. Each participant underwent a single testing session where demographic data was collected (sport position played, previous concussion history and cumulative number of years they have participated in their sport), as well as a concussion-related symptom evaluation, a neurocognitive performance measure, and a balance assessment in Study 1 with the addition VOMS and DT TG testing collected in Study 2.

Summary of Findings

Number of symptoms and symptom severity from the SCAT symptom evaluation and total symptoms and symptom severity from the VOMs were all affected by concussion history. Concussion history appears to be a factor that was consistently significant throughout both studies and our various research questions, leading us to conclude, even when concussions have resolved, there are long-term implications. Clinicians should take into consideration that concussion history can have long-term impact on symptoms common to many other diagnoses. Thus, despite a patient's medical diagnosis, concussion history should be part of a clinician's intake, and taken into consideration when analyzing a patient's reported symptoms. Other factors identified in our studies with a similar impact on symptoms include activity status, age, and career status. These results suggest clinicians should also take these factors into consideration when developing a treatment plan and prognosis for the patient.

Except for being correlated with age, neurocognitive performance measured by the SAC was not significant within our samples. While, there is value in the SAC when evaluating acute concussions, it may not have the same utility for measuring long-term implications for those who have recovered from a concussion. It may also not be a sensitive enough measure to identify changes related to sub-concussive blows. Other measures of neurocognitive performance should be tested or developed that are responsive to aging and neurocognitive performance as one progresses through their athletic careers, and through one's lifespan.

Balance was affected by both concussion history and age. Indicating that an older patient with a concussion history will likely have greater balance deficits, compared to a similarly aged patient without a concussion history. When clinicians are clinically analyzing their patient's balance performance, no matter their referral diagnosis, they should take concussion history into consideration within their clinical decision making.

Dual-task tandem gait has been proven to be a valuable measure in acute concussions, however, the factors tested in our study did not have an impact on this outcome measure. We postulate that DT TG as applied in our study was not responsive enough to measure differences in athletes who have recovered from SRC.

Clinical Relevance

Clinicians should take activity status, concussion history and age into consideration when analyzing their evaluation findings for all clients, regardless of the referral diagnosis. Especially, when evaluating symptom reports and balance performance. These performance tests were impacted by several variables, thus impacting one's interpretation of their referral diagnosis performance.

Future Research

The main area of improvement involves the study design. Further research involving longitudinal studies determining how contact sport exposure, concussion history, and aging influence each other is recommended. Concussion history was the variable that had the greatest impact on our studies. However, our participants ranged from 18 – 45 years old, thus, no conclusions regarding lifetime effects can be made. Therefore, future studies should study lifetime effects. In addition, valid assessments that allow assessment of athletes across their career and lifetime need to be identified or developed.

Conclusion

Concussion history, career status, and activity status should be taken into consideration when analyzing the number of symptoms, symptom severity, and balance scores, for all patients despite their referral diagnosis. While, cumulative years of contact football exposure did not have a significant impact on our findings, we suggest this research question be explored further, perhaps with a greater sample size and studied across the lifespan. Lastly, a longitudinal study is recommended to explore the long-term effects of contact sports and their effect on neurocognition, balance, and DT TG. Despite the cross-sectional design limitation, our studies did provide foundations for future research by identifying the factors that influence common measures of concussion.

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APPENDIX A

Sport Concussion Assessment Tool – 5th Edition

BJSM Online First, published on April 26, 2017 as 10.1136/bjsports-2017-097506SCAT5

To download a clean version of the SCAT tools please visit the journal online (http://dx.doi.org/10.1136/bjsports-2017-097506SCAT5)

SCAT5©

SPORT CONCUSSION ASSESSMENT TOOL — 5TH EDITION
DEVELOPED BY THE CONCUSSION IN SPORT GROUP
FOR USE BY MEDICAL PROFESSIONALS ONLY

supported by

Patient details

Name: ______________________________

DOB: ______________________________

Address: ______________________________

ID number: ______________________________

Examiner: ______________________________

Date of Injury: ____________________ Time: ____________________

WHAT IS THE SCAT5?

The SCAT5 is a standardized tool for evaluating concussions designed for use by physicians and licensed healthcare professionals[1]. The SCAT5 cannot be performed correctly in less than 10 minutes.

If you are not a physician or licensed healthcare professional, please use the Concussion Recognition Tool 5 (CRT5). The SCAT5 is to be used for evaluating athletes aged 13 years and older. For children aged 12 years or younger, please use the Child SCAT5.

Preseason SCAT5 baseline testing can be useful for interpreting post-injury test scores, but is not required for that purpose.Detailed instructions for use of the SCAT5 are provided on page 7. Please read through these instructions carefully before testing the athlete. Brief verbal instructions for each test are given in italics. The only equipment required for the tester is a watch or timer.

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Recognise and Remove

A head impact by either a direct blow or indirect transmission of force can be associated with a serious and potentially fatal brain injury. If there are significant concerns, including any of the red flags listed in Box 1, then activation of emergency procedures and urgent transport to the nearest hospital should be arranged.

Key points

- Any athlete with suspected concussion should be REMOVED FROM PLAY, medically assessed and monitored for deterioration. No athlete diagnosed with concussion should be returned to play on the day of injury.
- If an athlete is suspected of having a concussion and medical personnel are not immediately available, the athlete should be referred to a medical facility for urgent assessment.
- Athletes with suspected concussion should not drink alcohol, use recreational drugs and should not drive a motor vehicle until cleared to do so by a medical professional.
- Concussion signs and symptoms evolve over time and it is important to consider repeat evaluation in the assessment of concussion.
- The diagnosis of a concussion is a clinical judgment, made by a medical professional. The SCAT5 should NOT be used by itself to make, or exclude, the diagnosis of concussion. An athlete may have a concussion even if their SCAT5 is "normal".

Remember:

- The basic principles of first aid (danger, response, airway, breathing, circulation) should be followed.
- Do not attempt to move the athlete (other than that required for airway management) unless trained to do so.
- Assessment for a spinal cord injury is a critical part of the initial on-field assessment.
- Do not remove a helmet or any other equipment unless trained to do so safely.

1

Name: ______________________

DOB: ______________________

Address: ______________________

ID number: ______________________

Examiner: ______________________

Date: ______________________

IMMEDIATE OR ON-FIELD ASSESSMENT

The following elements should be assessed for all athletes who are suspected of having a concussion prior to proceeding to the neurocognitive assessment and ideally should be done on-field after the first first aid / emergency care priorities are completed.

If any of the "Red Flags" or observable signs are noted after a direct or indirect blow to the head, the athlete should be immediately and safely removed from participation and evaluated by a physician or licensed healthcare professional.

Consideration of transportation to a medical facility should be at the discretion of the physician or licensed healthcare professional.

The GCS is important as a standard measure for all patients and can be done serially if necessary in the event of deterioration in conscious state. The Maddocks questions and cervical spine exam are critical steps of the immediate assessment; however, these do not need to be done serially.

STEP 1: RED FLAGS

RED FLAGS:

- Neck pain or tenderness
- Double vision
- Weakness or tingling/ burning in arms or legs
- Severe or increasing headache
- Seizure or convulsion
- Loss of consciousness
- Deteriorating conscious state
- Vomiting
- Increasingly restless, agitated or combative

STEP 2: OBSERVABLE SIGNS

Witnessed ☐ Observed on Video ☐

Lying motionless on the playing surface	Y	N
Balance / gait difficulties / motor incoordination: stumbling, slow / laboured movements	Y	N
Disorientation or confusion, or an inability to respond appropriately to questions	Y	N
Blank or vacant look	Y	N
Facial injury after head trauma	Y	N

STEP 3: MEMORY ASSESSMENT MADDOCKS QUESTIONS[2]

"I am going to ask you a few questions, please listen carefully and give your best effort. First, tell me what happened?"

____

____

Mark Y for correct answer / N for incorrect		
What venue are we at today?	Y	N
Which half is it now?	Y	N
Who scored last in this match?	Y	N
What team did you play last week / game?	Y	N
Did your team win the last game?	Y	N

Note: Appropriate sport-specific questions may be substituted.

STEP 4: EXAMINATION GLASGOW COMA SCALE (GCS)[3]

Time of assessment			
Date of assessment			
Best eye response (E)			
No eye opening	1	1	1
Eye opening in response to pain	2	2	2
Eye opening to speech	3	3	3
Eyes opening spontaneously	4	4	4
Best verbal response (V)			
No verbal response	1	1	1
Incomprehensible sounds	2	2	2
Inappropriate words	3	3	3
Confused	4	4	4
Oriented	5	5	5
Best motor response (M)			
No motor response	1	1	1
Extension to pain	2	2	2
Abnormal flexion to pain	3	3	3
Flexion / Withdrawal to pain	4	4	4
Localizes to pain	5	5	5
Obeys commands	6	6	6
Glasgow Coma score (E + V + M)			

CERVICAL SPINE ASSESSMENT

Does the athlete report that their neck is pain free at rest?	Y	N
If there is NO neck pain at rest, does the athlete have a full range of ACTIVE pain free movement?	Y	N
Is the limb strength and sensation normal?	Y	N

In a patient who is not lucid or fully conscious, a cervical spine injury should be assumed until proven otherwise.

OFFICE OR OFF-FIELD ASSESSMENT

Please note that the neurocognitive assessment should be done in a distraction-free environment with the athlete in a resting state.

STEP 1: ATHLETE BACKGROUND

Sport / team / school: ______________________

Date / time of injury: ______________________

Years of education completed: ______________________

Age: ______________________

Gender: M / F / Other

Dominant hand: left / neither / right

How many diagnosed concussions has the athlete had in the past?: ______________________

When was the most recent concussion?: ______________________

How long was the recovery (time to being cleared to play) from the most recent concussion?: ______________________ (days)

Has the athlete ever been:

Hospitalized for a head injury?	Yes	No
Diagnosed / treated for headache disorder or migraines?	Yes	No
Diagnosed with a learning disability / dyslexia?	Yes	No
Diagnosed with ADD / ADHD?	Yes	No
Diagnosed with depression, anxiety or other psychiatric disorder?	Yes	No

Current medications? If yes, please list:

____

____

____

____

____

____

Name: ______________________

DOB: ______________________

Address: ______________________

ID number: ______________________

Examiner: ______________________

Date: ______________________

2

STEP 2: SYMPTOM EVALUATION

The athlete should be given the symptom form and asked to read this instruction paragraph out loud then complete the symptom scale. For the baseline assessment, the athlete should rate his/her symptoms based on how he/she typically feels and for the post injury assessment the athlete should rate their symptoms at this point in time.

Please Check: ☐ Baseline ☐ Post-Injury

Please hand the form to the athlete

	none	mild		moderate		severe	
Headache	0	1	2	3	4	5	6
"Pressure in 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
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
Trouble falling asleep (if applicable)	0	1	2	3	4	5	6

Total number of symptoms:	of 22
Symptom severity score:	of 132
Do your symptoms get worse with physical activity?	Y N
Do your symptoms get worse with mental activity?	Y N
If 100% is feeling perfectly normal, what percent of normal do you feel?	

If not 100%, why?

____

____

____

Please hand form back to examiner

3

STEP 3: COGNITIVE SCREENING

Standardised Assessment of Concussion (SAC)[4]

Name: ___

DOB: ___

Address: ___

ID number: ___

Examiner: ___

Date: ___

ORIENTATION

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

IMMEDIATE MEMORY

The Immediate Memory component can be completed using the traditional 5-word per trial list or optionally using 10-words per trial to minimise any ceiling effect. All 3 trials must be administered irrespective of the number correct on the first trial. Administer at the rate of one word per second.

Please choose EITHER the 5 or 10 word list groups and circle the specific word list chosen for this test.

I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order. For Trials 2 & 3: I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before.

List	Alternate 5 word lists					Score (of 5) Trial 1	Trial 2	Trial 3
A	Finger	Penny	Blanket	Lemon	Insect			
B	Candle	Paper	Sugar	Sandwich	Wagon			
C	Baby	Monkey	Perfume	Sunset	Iron			
D	Elbow	Apple	Carpet	Saddle	Bubble			
E	Jacket	Arrow	Pepper	Cotton	Movie			
F	Dollar	Honey	Mirror	Saddle	Anchor			
					Immediate Memory Score	of 15		
					Time that last trial was completed			

List	Alternate 10 word lists					Score (of 10) Trial 1	Trial 2	Trial 3
G	Finger	Penny	Blanket	Lemon	Insect			
	Candle	Paper	Sugar	Sandwich	Wagon			
H	Baby	Monkey	Perfume	Sunset	Iron			
	Elbow	Apple	Carpet	Saddle	Bubble			
I	Jacket	Arrow	Pepper	Cotton	Movie			
	Dollar	Honey	Mirror	Saddle	Anchor			
					Immediate Memory Score	of 30		
					Time that last trial was completed			

CONCENTRATION

DIGITS BACKWARDS

Please circle the Digit list chosen (A, B, C, D, E, F). Administer at the rate of one digit per second reading DOWN the selected column.

I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.

Concentration Number Lists (circle one)					
List A	List B	List C			
4-9-3	5-2-6	1-4-2	Y	N	0
6-2-9	4-1-5	6-5-8	Y	N	1
3-8-1-4	1-7-9-5	6-8-3-1	Y	N	0
3-2-7-9	4-9-6-8	3-4-8-1	Y	N	1
6-2-9-7-1	4-8-5-2-7	4-9-1-5-3	Y	N	0
1-5-2-8-6	6-1-8-4-3	6-8-2-5-1	Y	N	1
7-1-8-4-6-2	8-3-1-9-6-4	3-7-6-5-1-9	Y	N	0
5-3-9-1-4-8	7-2-4-8-5-6	9-2-6-5-1-4	Y	N	1
List D	List E	List F			
7-8-2	3-8-2	2-7-1	Y	N	0
9-2-6	5-1-8	4-7-9	Y	N	1
4-1-8-3	2-7-9-3	1-6-8-3	Y	N	0
9-7-2-3	2-1-6-9	3-9-2-4	Y	N	1
1-7-9-2-6	4-1-8-6-9	2-4-7-5-8	Y	N	0
4-1-7-5-2	9-4-1-7-5	8-3-9-6-4	Y	N	1
2-6-4-8-1-7	6-9-7-3-8-2	5-8-6-2-4-9	Y	N	0
8-4-1-9-3-5	4-2-7-9-3-8	3-1-7-8-2-6	Y	N	1
		Digits Score:			of 4

MONTHS IN REVERSE ORDER

Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November. Go ahead.

Dec - Nov - Oct - Sept - Aug - Jul - Jun - May - Apr - Mar - Feb - Jan	0 1
Months Score	of 1
Concentration Total Score (Digits + Months)	of 5

4

STEP 4: NEUROLOGICAL SCREEN

See the instruction sheet (page 7) for details of test administration and scoring of the tests.

Can the patient read aloud (e.g. symptom check-list) and follow instructions without difficulty?	Y	N
Does the patient have a full range of pain-free PASSIVE cervical spine movement?	Y	N
Without moving their head or neck, can the patient look side-to-side and up-and-down without double vision?	Y	N
Can the patient perform the finger nose coordination test normally?	Y	N
Can the patient perform tandem gait normally?	Y	N

BALANCE EXAMINATION

Modified Balance Error Scoring System (mBESS) testing[5]

Which foot was tested (i.e. which is the non-dominant foot) ☐ Left ☐ Right

Testing surface (hard floor, field, etc.) ____________

Footwear (shoes, barefoot, braces, tape, etc.) ____________

Condition	Errors
Double leg stance	of 10
Single leg stance (non-dominant foot)	of 10
Tandem stance (non-dominant foot at the back)	of 10
Total Errors	of 30

Name: ____________

DOB: ____________

Address: ____________

ID number: ____________

Examiner: ____________

Date: ____________

5

STEP 5: DELAYED RECALL:

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section. Score 1 pt. for each correct response.

Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order.

Time Started ____________

Please record each word correctly recalled. Total score equals number of words recalled.

____

____

____

Total number of words recalled accurately: of 5 or of 10

6

STEP 6: DECISION

Domain	Date & time of assessment:		
Symptom number (of 22)			
Symptom severity score (of 132)			
Orientation (of 5)			
Immediate memory	of 15 of 30	of 15 of 30	of 15 of 30
Concentration (of 5)			
Neuro exam	Normal Abnormal	Normal Abnormal	Normal Abnormal
Balance errors (of 30)			
Delayed Recall	of 5 of 10	of 5 of 10	of 5 of 10

Date and time of injury: ____________

If the athlete is known to you prior to their injury, are they different from their usual self?

☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**

(If different, describe why in the clinical notes section)

Concussion Diagnosed?

☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**

If re-testing, has the athlete improved?

☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**

I am a physician or licensed healthcare professional and I have personally administered or supervised the administration of this SCAT5.

Signature: ____________

Name: ____________

Title: ____________

Registration number (if applicable): ____________

Date: ____________

SCORING ON THE SCAT5 SHOULD NOT BE USED AS A STAND-ALONE METHOD TO DIAGNOSE CONCUSSION, MEASURE RECOVERY OR MAKE DECISIONS ABOUT AN ATHLETE'S READINESS TO RETURN TO COMPETITION AFTER CONCUSSION.

Davis GA, *et al. Br J Sports Med* 2017;**0**:1–8. doi:10.1136/bjsports-2017-097506SCAT5

CLINICAL NOTES:

Name:
DOB:
Address:
ID number:
Examiner:
Date:

CONCUSSION INJURY ADVICE

(To be given to the person monitoring the concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. Recovery time is variable across individuals and the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, worsening headache, double vision or excessive drowsiness, please telephone your doctor or the nearest hospital emergency department immediately.

Other important points:

Initial rest: Limit physical activity to routine daily activities (avoid exercise, training, sports) and limit activities such as school, work, and screen time to a level that does not worsen symptoms.

1) Avoid alcohol

2) Avoid prescription or non-prescription drugs without medical supervision. Specifically:

   a) Avoid sleeping tablets

   b) Do not use aspirin, anti-inflammatory medication or stronger pain medications such as narcotics

3) Do not drive until cleared by a healthcare professional.

4) Return to play/sport requires clearance by a healthcare professional.

Clinic phone number:

Patient's name:

Date / time of injury:

Date / time of medical review:

Healthcare Provider:

Contact details or stamp

INSTRUCTIONS

Words in *Italics* throughout the SCAT5 are the instructions given to the athlete by the clinician

Symptom Scale

The time frame for symptoms should be based on the type of test being administered. At baseline it is advantageous to assess how an athlete "typically" feels whereas during the acute/post-acute stage it is best to ask how the athlete feels at the time of testing.

The symptom scale should be completed by the athlete, not by the examiner. In situations where the symptom scale is being completed after exercise, it should be done in a resting state, generally by approximating his/her resting heart rate.

For total number of symptoms, maximum possible is 22 except immediately post injury, if sleep item is omitted, which then creates a maximum of 21.

For Symptom severity score, add all scores in table, maximum possible is 22 x 6 = 132, except immediately post injury if sleep item is omitted, which then creates a maximum of 21x6=126.

Immediate Memory

The Immediate Memory component can be completed using the traditional 5-word per trial list or, optionally, using 10-words per trial. The literature suggests that the Immediate Memory has a notable ceiling effect when a 5-word list is used. In settings where this ceiling is prominent, the examiner may wish to make the task more difficult by incorporating two 5–word groups for a total of 10 words per trial. In this case, the maximum score per trial is 10 with a total trial maximum of 30.

Choose one of the word lists (either 5 or 10). Then perform 3 trials of immediate memory using this list.

Complete all 3 trials regardless of score on previous trials.

"I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order." The words must be read at a rate of one word per second.

Trials 2 & 3 MUST be completed regardless of score on trial 1 & 2.

Trials 2 & 3:

"I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before."

Score 1 pt. for each correct response. Total score equals sum across all 3 trials. Do NOT inform the athlete that delayed recall will be tested.

Concentration

Digits backward

Choose one column of digits from lists A, B, C, D, E or F and administer those digits as follows:

Say: *"I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7."*

Begin with first 3 digit string.

If correct, circle "Y" for correct and go to next string length. If incorrect, circle "N" for the first string length and read trial 2 in the same string length. One point possible for each string length. Stop after incorrect on both trials (2 N's) in a string length. The digits should be read at the rate of one per second.

Months in reverse order

"Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November ... Go ahead"

1 pt. for entire sequence correct

Delayed Recall

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section.

"Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order."

Score 1 pt. for each correct response

Modified Balance Error Scoring System (mBESS)[5] testing

This balance testing is based on a modified version of the Balance Error Scoring System (BESS)[5]. A timing device is required for this testing.

Each of 20-second trial/stance is scored by counting the number of errors. The examiner will begin counting errors only after the athlete has assumed the proper start position. The modified BESS is calculated by adding one error point for each error during the three 20-second tests. The maximum number of errors for any single condition is 10. If the athlete commits multiple errors simultaneously, only one error is recorded but the athlete should quickly return to the testing position, and counting should resume once the athlete is set. Athletes that are unable to maintain the testing procedure for a minimum of five seconds at the start are assigned the highest possible score, ten, for that testing condition.

OPTION: For further assessment, the same 3 stances can be performed on a surface of medium density foam (e.g., approximately 50cm x 40cm x 6cm).

Balance testing – types of errors

1. Hands lifted off iliac crest
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into > 30 degrees abduction
5. Lifting forefoot or heel
6. Remaining out of test position > 5 sec

"I am now going to test your balance. Please take your shoes off (if applicable), roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable). This test will consist of three twenty second tests with different stances."

(a) Double leg stance:

"The first stance is standing with your feet together with your hands on your hips and with your eyes closed. You should try to maintain stability in that position for 20 seconds. I will be counting the number of times you move out of this position. I will start timing when you are set and have closed your eyes."

(b) Single leg stance:

"If you were to kick a ball, which foot would you use? [This will be the dominant foot] *Now stand on your non-dominant foot. The dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."*

(c) Tandem stance:

"Now stand heel-to-toe with your non-dominant foot in back. Your weight should be evenly distributed across both feet. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

Tandem Gait

Participants are instructed to stand with their feet together behind a starting line (the test is best done with footwear removed). Then, they walk in a forward direction as quickly and as accurately as possible along a 38mm wide (sports tape), 3 metre line with an alternate foot heel-to-toe gait ensuring that they approximate their heel and toe on each step. Once they cross the end of the 3m line, they turn 180 degrees and return to the starting point using the same gait. Athletes fail the test if they step off the line, have a separation between their heel and toe, or if they touch or grab the examiner or an object.

Finger to Nose

"I am going to test your coordination now. Please sit comfortably on the chair with your eyes open and your arm (either right or left) outstretched (shoulder flexed to 90 degrees and elbow and fingers extended), pointing in front of you. When I give a start signal, I would like you to perform five successive finger to nose repetitions using your index finger to touch the tip of the nose, and then return to the starting position, as quickly and as accurately as possible."

References

1. McCrory et al. Consensus Statement On Concussion In Sport – The 5th International Conference On Concussion In Sport Held In Berlin, October 2016. British Journal of Sports Medicine 2017 (available at www.bjsm.bmj.com)
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3. Jennett, B., Bond, M. Assessment of outcome after severe brain damage: a practical scale. Lancet 1975; i: 480-484
4. McCrea M. Standardized mental status testing of acute concussion. Clinical Journal of Sport Medicine. 2001; 11: 176-181
5. Guskiewicz KM. Assessment of postural stability following sport-related concussion. Current Sports Medicine Reports. 2003; 2: 24-30

CONCUSSION INFORMATION

Any athlete suspected of having a concussion should be removed from play and seek medical evaluation.

Signs to watch for

Problems could arise over the first 24-48 hours. The athlete should not be left alone and must go to a hospital at once if they experience:

- Worsening headache
- Drowsiness or inability to be awakened
- Inability to recognize people or places
- Repeated vomiting
- Unusual behaviour or confusion or irritable
- Seizures (arms and legs jerk uncontrollably)
- Weakness or numbness in arms or legs
- Unsteadiness on their feet.
- Slurred speech

Consult your physician or licensed healthcare professional after a suspected concussion. Remember, it is better to be safe.

Rest & Rehabilitation

After a concussion, the athlete should have physical rest and relative cognitive rest for a few days to allow their symptoms to improve. In most cases, after no more than a few days of rest, the athlete should gradually increase their daily activity level as long as their symptoms do not worsen. Once the athlete is able to complete their usual daily activities without concussion-related symptoms, the second step of the return to play/sport progression can be started. The athlete should not return to play/sport until their concussion-related symptoms have resolved and the athlete has successfully returned to full school/learning activities.

When returning to play/sport, the athlete should follow a stepwise, **medically managed exercise progression, with increasing amounts of exercise.** For example:

Graduated Return to Sport Strategy

Exercise step	Functional exercise at each step	Goal of each step
1. Symptom-limited activity	Daily activities that do not provoke symptoms.	Gradual reintroduction of work/school activities.
2. Light aerobic exercise	Walking or stationary cycling at slow to medium pace. No resistance training.	Increase heart rate.
3. Sport-specific exercise	Running or skating drills. No head impact activities.	Add movement.
4. Non-contact training drills	Harder training drills, e.g., passing drills. May start progressive resistance training.	Exercise, coordination, and increased thinking.
5. Full contact practice	Following medical clearance, participate in normal training activities.	Restore confidence and assess functional skills by coaching staff.
6. Return to play/sport	Normal game play.	

In this example, it would be typical to have 24 hours (or longer) for each step of the progression. If any symptoms worsen while exercising, the athlete should go back to the previous step. Resistance training should be added only in the later stages (Stage 3 or 4 at the earliest).

Written clearance should be provided by a healthcare professional before return to play/sport as directed by local laws and regulations.

Graduated Return to School Strategy

Concussion may affect the ability to learn at school. The athlete may need to miss a few days of school after a concussion. When going back to school, some athletes may need to go back gradually and may need to have some changes made to their schedule so that concussion symptoms do not get worse. If a particular activity makes symptoms worse, then the athlete should stop that activity and rest until symptoms get better. To make sure that the athlete can get back to school without problems, it is important that the healthcare provider, parents, caregivers and teachers talk to each other so that everyone knows what the plan is for the athlete to go back to school.

Note: If mental activity does not cause any symptoms, the athlete may be able to skip step 2 and return to school part-time before doing school activities at home first.

Mental Activity	Activity at each step	Goal of each step
1. Daily activities that do not give the athlete symptoms	Typical activities that the athlete does during the day as long as they do not increase symptoms (e.g. reading, texting, screen time). Start with 5-15 minutes at a time and gradually build up.	Gradual return to typical activities.
2. School activities	Homework, reading or other cognitive activities outside of the classroom.	Increase tolerance to cognitive work.
3. Return to school part-time	Gradual introduction of schoolwork. May need to start with a partial school day or with increased breaks during the day.	Increase academic activities.
4. Return to school full-time	Gradually progress school activities until a full day can be tolerated.	Return to full academic activities and catch up on missed work.

If the athlete continues to have symptoms with mental activity, some other accomodations that can help with return to school may include:

- Starting school later, only going for half days, or going only to certain classes
- More time to finish assignments/tests
- Quiet room to finish assignments/tests
- Not going to noisy areas like the cafeteria, assembly halls, sporting events, music class, shop class, etc.
- Taking lots of breaks during class, homework, tests
- No more than one exam/day
- Shorter assignments
- Repetition/memory cues
- Use of a student helper/tutor
- Reassurance from teachers that the child will be supported while getting better

The athlete should not go back to sports until they are back to school/learning, without symptoms getting significantly worse and no longer needing any changes to their schedule.

APPENDIX B

Vestibular/Ocular-Motor Screening (VOMS) for Concussions

Vestibular/Ocular-Motor Screening (VOMS) for Concussion

Vestibular/Ocular Motor Test:	Not Tested	Headache 0-10	Dizziness 0-10	Nausea 0-10	Fogginess 0-10	Comments
BASELINE SYMPTOMS:	N/A					
Smooth Pursuits						
Saccades – Horizontal						
Saccades – Vertical						
Convergence (Near Point)						**Near Point (in cm):** Measure 1: _____ Measure 2:______ Measure 3:______
VOR – Horizontal						
VOR – Vertical						
Visual Motion Sensitivity Test						

Instructions:

Interpretation: This test is designed for use with subjects ages 9-40. When used with patients outside this age range, interpretation may vary**.** Abnormal findings or provocation of symptoms with any test may indicate dysfunction – and should trigger a referral to the appropriate health care professional for more detailed assessment and management.
Equipment: Tape measure (cm); Metronome; Target w/ 14-point font print.

Baseline Symptoms – Record: Headache, Dizziness, Nausea & Fogginess on 0-10 scale prior to beginning screening

- **Smooth Pursuits -** Test the ability to follow a slowly moving target. The patient and the examiner are seated. The examiner holds a fingertip at a distance of 3 ft. from the patient. The patient is instructed to maintain focus on the target as the examiner moves the target smoothly in the horizontal direction 1.5 ft. to the right and 1.5 ft. to the left of midline. One repetition is complete when the target moves back and forth to the starting position, and 2 repetitions are performed. The target should be moved at a rate requiring approximately 2 seconds to go fully from left to right and 2 seconds to go fully from right to left. The test is repeated with the examiner moving the target smoothly and slowly in the vertical direction 1.5 ft. above and 1.5 ft. below midline for 2 complete repetitions up and down. Again, the target should be moved at a rate requiring approximately 2 seconds to move the eyes fully upward and 2 seconds to move fully downward. Record: Headache, Dizziness, Nausea & Fogginess ratings after the test. (Figure 1)

- **Saccades** – Test the ability of the eyes to move quickly between targets. The patient and the examiner are seated.
    - **Horizontal Saccades**: The examiner holds two single points (fingertips) horizontally at a distance of 3 ft. from the patient, and 1.5 ft. to the right and 1.5 ft. to the left of midline so that the patient must gaze 30 degrees to left and 30 degrees to the right. Instruct the patient to move their eyes as quickly as possible from point to point. One repetition is complete when the eyes move back and forth to the starting position, and 10 repetitions are performed. Record: Headache, Dizziness, Nausea & Fogginess ratings after the test. (Figure 2)
    - **Vertical Saccades**: Repeat the test with 2 points held vertically at a distance of 3 ft. from the patient, and 1.5 feet above and 1.5 feet below midline so that the patient must gaze 30 degrees upward and 30 degrees downward. Instruct the patient to move their eyes as quickly as possible from point to point. One repetition is complete when the eyes move up and down to the starting position, and 10 repetitions are performed. Record: Headache, Dizziness, Nausea & Fogginess ratings after the test. (Figure 3)

- **Convergence** – Measure the ability to view a near target without double vision. The patient is seated and wearing corrective lenses (if needed). The examiner is seated front of the patient and observes their eye movement during this test. The patient focuses on a small target (approximately 14-point font size) at arm’s length and slowly brings it toward the tip of their nose. The patient is instructed to stop moving the target when they see two distinct images or when the examiner observes an outward deviation of one eye. Blurring of the image is ignored. The distance in cm. between target and the tip of nose is measured and recorded. This is repeated a total of 3 times with measures recorded each time. Record: Headache, Dizziness, Nausea & Fogginess ratings after the test. Abnormal: Near Point of convergence $\geq$ 6 cm from the tip of the nose. (Figure 4)

- **Vestibular-Ocular Reflex (VOR) Test** – Assess the ability to stabilize vision as the head moves. The patient and the examiner are seated. The examiner holds a target of approximately 14-point font size in front of the patient in midline at a distance of 3 ft.
    - **Horizontal VOR Test**: The patient is asked to rotate their head horizontally while maintaining focus on the target. The head is moved at an amplitude of 20 degrees to each side and a metronome is used to ensure the speed of rotation is maintained at 180 beats/minute (one beat in each direction). One repetition is complete when the head moves back and forth to the starting position, and 10 repetitions are performed. Record: Headache, Dizziness, Nausea and Fogginess ratings 10 sec after the test is completed. (Figure 5)
    - **Vertical VOR Test**: The test is repeated with the patient moving their head vertically. The head is moved in an amplitude of 20 degrees up and 20 degrees down and a metronome is used to ensure the speed of movement is maintained at 180 beats/minute (one beat in each direction). One repetition is complete when the head moves up and down to the starting position, and 10 repetitions are performed. Record: Headache, Dizziness, Nausea and Fogginess ratings after the test.
- **Visual Motion Sensitivity (VMS) Test –** Test visual motion sensitivity and the ability to inhibit vestibular-induced eye movements using vision. The patient stands with feet shoulder width apart, facing a busy area of the clinic. The examiner stands next to and slightly behind the patient, so that the patient is guarded but the movement can be performed freely. The patient holds arm outstretched and focuses on their thumb. Maintaining focus on their thumb, the patient rotates, together as a unit, their head, eyes and trunk at an amplitude of 80 degrees to the right and 80 degrees to the left. A metronome is used to ensure the speed of rotation is maintained at 50 beats/min (one beat in each direction). One repetition is complete when the trunk rotates back and forth to the starting position, and 5 repetitions are performed. Record: Headache, Dizziness, Nausea & Fogginess ratings after the test. (Figure 6)

Figure 1. Smooth pursuits.

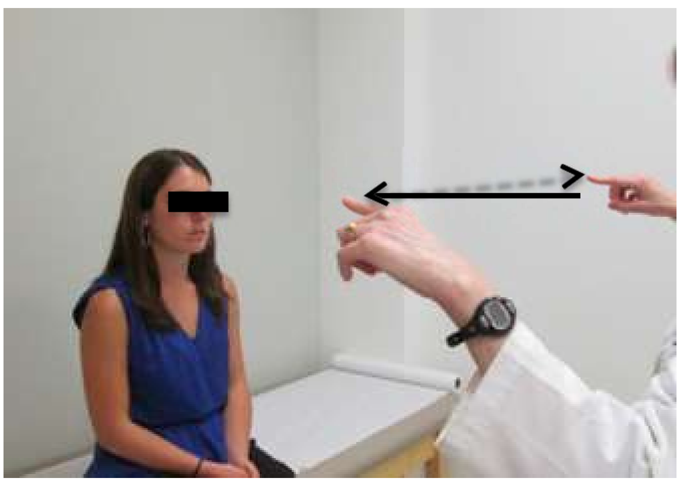

Figure 2. Horizontal saccades.

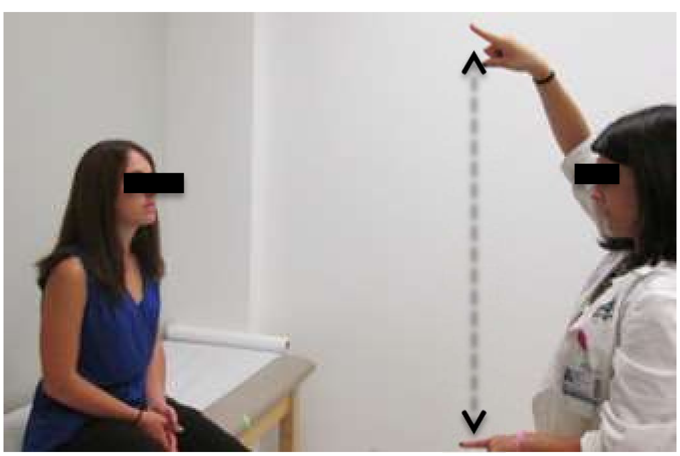

Figure 3. Vertical saccades.

Figure 4. Convergence

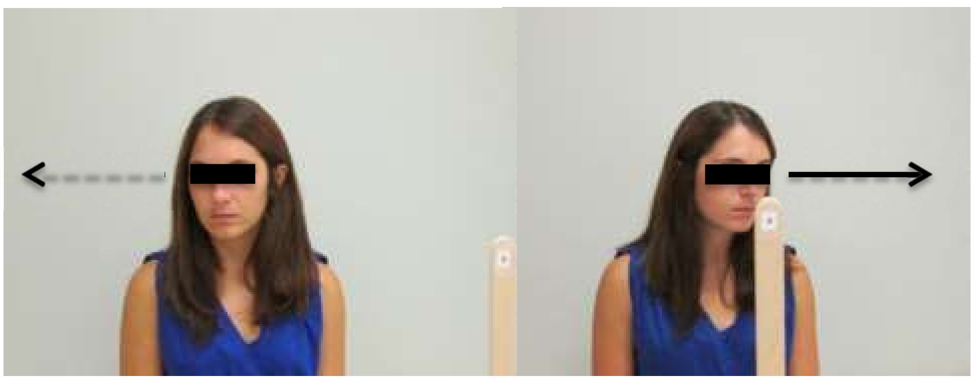

Figure 5. Horizontal VOR.

Figure 6. VMS.

APPENDIX C

Sport Concussion Assessment Tool – 3rd Edition

SCAT3™

Sport Concussion Assessment Tool – 3rd Edition

For use by medical professionals only

Name

Date/Time of Injury:
Date of Assessment:

Examiner:

What is the SCAT3?[1]

The SCAT3 is a standardized tool for evaluating injured athletes for concussion and can be used in athletes aged from 13 years and older. It supersedes the original SCAT and the SCAT2 published in 2005 and 2009, respectively[2]. For younger persons, ages 12 and under, please use the Child SCAT3. The SCAT3 is designed for use by medical professionals. If you are not qualified, please use the Sport Concussion Recognition Tool[1]. Preseason baseline testing with the SCAT3 can be helpful for interpreting post-injury test scores.

Specific instructions for use of the SCAT3 are provided on page 3. If you are not familiar with the SCAT3, please read through these instructions carefully. This tool may be freely copied in its current form for distribution to individuals, teams, groups and organizations. Any revision or any reproduction in a digital form requires approval by the Concussion in Sport Group.

NOTE: The diagnosis of a concussion is a clinical judgment, ideally made by a medical professional. The SCAT3 should not be used solely to make, or exclude, the diagnosis of concussion in the absence of clinical judgement. An athlete may have a concussion even if their SCAT3 is "normal".

What is a concussion?

A concussion is a disturbance in brain function caused by a direct or indirect force to the head. It results in a variety of non-specific signs and/or symptoms (some examples listed below) and most often does not involve loss of consciousness. Concussion should be suspected in the presence of **any one or more** of the following:

- Symptoms (e.g., headache), or
- Physical signs (e.g., unsteadiness), or
- Impaired brain function (e.g. confusion) or
- Abnormal behaviour (e.g., change in personality).

SIDELINE ASSESSMENT

Indications for Emergency Management

NOTE: A hit to the head can sometimes be associated with a more serious brain injury. Any of the following warrants consideration of activating emergency procedures and urgent transportation to the nearest hospital:

- Glasgow Coma score less than 15
- Deteriorating mental status
- Potential spinal injury
- Progressive, worsening symptoms or new neurologic signs

Potential signs of concussion?

If any of the following signs are observed after a direct or indirect blow to the head, the athlete should stop participation, be evaluated by a medical professional and **should not be permitted to return to sport the same day** if a concussion is suspected.

Any loss of consciousness?	Y	N
"If so, how long?"		
Balance or motor incoordination (stumbles, slow/laboured movements, etc.)?	Y	N
Disorientation or confusion (inability to respond appropriately to questions)?	Y	N
Loss of memory:	Y	N
"If so, how long?"		
"Before or after the injury?"		
Blank or vacant look:	Y	N
Visible facial injury in combination with any of the above:	Y	N

1 Glasgow coma scale (GCS)

Best eye response (E)	
No eye opening	1
Eye opening in response to pain	2
Eye opening to speech	3
Eyes opening spontaneously	4
Best verbal response (V)	
No verbal response	1
Incomprehensible sounds	2
Inappropriate words	3
Confused	4
Oriented	5
Best motor response (M)	
No motor response	1
Extension to pain	2
Abnormal flexion to pain	3
Flexion/Withdrawal to pain	4
Localizes to pain	5
Obeys commands	6
Glasgow Coma score (E + V + M)	of 15

GCS should be recorded for all athletes in case of subsequent deterioration.

2 Maddocks Score[3]

"I am going to ask you a few questions, please listen carefully and give your best effort."

Modified Maddocks questions (1 point for each correct answer)

What venue are we at today?	0	1
Which half is it now?	0	1
Who scored last in this match?	0	1
What team did you play last week/game?	0	1
Did your team win the last game?	0	1
Maddocks score		of 5

Maddocks score is validated for sideline diagnosis of concussion only and is not used for serial testing.

Notes: Mechanism of Injury ("tell me what happened"?):

Any athlete with a suspected concussion should be REMOVED FROM PLAY, medically assessed, monitored for deterioration (i.e., should not be left alone) and should not drive a motor vehicle until cleared to do so by a medical professional. No athlete diagnosed with concussion should be returned to sports participation on the day of Injury.

BACKGROUND

Name: ______ Date: ______
Examiner: ______
Sport/team/school: ______ Date/time of injury: ______
Age: ______ Gender: M F
Years of education completed: ______
Dominant hand: right left neither
How many concussions do you think you have had in the past? ______
When was the most recent concussion? ______
How long was your recovery from the most recent concussion? ______
Have you ever been hospitalized or had medical imaging done for a head injury? Y N
Have you ever been diagnosed with headaches or migraines? Y N
Do you have a learning disability, dyslexia, ADD/ADHD? Y N
Have you ever been diagnosed with depression, anxiety or other psychiatric disorder? Y N
Has anyone in your family ever been diagnosed with any of these problems? Y N
Are you on any medications? If yes, please list: Y N

SCAT3 to be done in resting state. Best done 10 or more minutes post excercise.

SYMPTOM EVALUATION

3 How do you feel?

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

	none	mild		moderate		severe	
Headache	0	1	2	3	4	5	6
"Pressure in 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)

Do the symptoms get worse with physical activity? Y N
Do the symptoms get worse with mental activity? Y N

self rated — self rated and clinician monitored
clinician interview — self rated with parent input

Overall rating: If you know the athlete well prior to the injury, how different is the athlete acting compared to his/her usual self?

Please circle one response:

no different | very different | unsure | N/A

Scoring on the SCAT3 should not be used as a stand-alone method to diagnose concussion, measure recovery or make decisions about an athlete's readiness to return to competition after concussion. Since signs and symptoms may evolve over time, it is important to consider repeat evaluation in the acute assessment of concussion.

COGNITIVE & PHYSICAL EVALUATION

4 Cognitive assessment

Standardized Assessment of Concussion (SAC)[4]

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

Immediate memory

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
Total									

Immediate memory score total — of 15

Concentration: Digits Backward

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

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

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

Concentration score — of 5

5 Neck Examination:

Range of motion — Tenderness — Upper and lower limb sensation & strength
Findings: ______

6 Balance examination

Do one or both of the following tests.
Footwear (shoes, barefoot, braces, tape, etc.) ______

Modified Balance Error Scoring System (BESS) testing[5]
Which foot was tested (i.e. which is the **non-dominant** foot) Left Right
Testing surface (hard floor, field, etc.) ______
Condition
Double leg stance: Errors
Single leg stance (non-dominant foot): Errors
Tandem stance (non-dominant foot at back): Errors

And/Or

Tandem gait[6,7]
Time (best of 4 trials): ______ seconds

7 Coordination examination

Upper limb coordination
Which arm was tested: Left Right
Coordination score — of 1

8 SAC Delayed Recall[4]

Delayed recall score — of 5

INSTRUCTIONS

Words in *Italics* throughout the SCAT3 are the instructions given to the athlete by the tester.

Symptom Scale

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

To be completed by the athlete. In situations where the symptom scale is being completed after exercise, it should still be done in a resting state, at least 10 minutes post exercise.

For total number of symptoms, maximum possible is 22.

For Symptom severity score, add all scores in table, maximum possible is 22 x 6 = 132.

SAC[4]

Immediate Memory

"I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order."

Trials 2 & 3:

"I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before."

Complete all 3 trials regardless of score on trial 1 & 2. Read the words at a rate of one per second. **Score 1 pt. for each correct response.** Total score equals sum across all 3 trials. Do not inform the athlete that delayed recall will be tested.

Concentration

Digits backward

"I am going to read you a string of numbers and when I am done, you repeat them back to me backwards, in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7."

If correct, go to next string length. If incorrect, read trial 2. **One point possible for each string length.** Stop after incorrect on both trials. The digits should be read at the rate of one per second.

Months in reverse order

"Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November ... Go ahead"

1 pt. for entire sequence correct

Delayed Recall

The delayed recall should be performed after completion of the Balance and Coordination Examination.

"Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order."

Score 1 pt. for each correct response

Balance Examination

Modified Balance Error Scoring System (BESS) testing[5]

This balance testing is based on a modified version of the Balance Error Scoring System (BESS)[5]. A stopwatch or watch with a second hand is required for this testing.

"I am now going to test your balance. Please take your shoes off, roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable). This test will consist of three twenty second tests with different stances."

(a) Double leg stance:

"The first stance is standing with your feet together with your hands on your hips and with your eyes closed. You should try to maintain stability in that position for 20 seconds. I will be counting the number of times you move out of this position. I will start timing when you are set and have closed your eyes."

(b) Single leg stance:

"If you were to kick a ball, which foot would you use? [This will be the dominant foot] Now stand on your non-dominant foot. The dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

(c) Tandem stance:

"Now stand heel-to-toe with your non-dominant foot in back. Your weight should be evenly distributed across both feet. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

Balance testing – types of errors

1. Hands lifted off iliac crest
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into > 30 degrees abduction
5. Lifting forefoot or heel
6. Remaining out of test position > 5 sec

Each of the 20-second trials is scored by counting the errors, or deviations from the proper stance, accumulated by the athlete. The examiner will begin counting errors only after the individual has assumed the proper start position. **The modified BESS is calculated by adding one error point for each error during the three 20-second tests. The maximum total number of errors for any single condition is 10.** If a athlete commits multiple errors simultaneously, only one error is recorded but the athlete should quickly return to the testing position, and counting should resume once subject is set. Subjects that are unable to maintain the testing procedure for a minimum of **five seconds** at the start are assigned the highest possible score, ten, for that testing condition.

OPTION: For further assessment, the same 3 stances can be performed on a surface of medium density foam (e.g., approximately 50 cm x 40 cm x 6 cm).

Tandem Gait[6,7]

Participants are instructed to stand with their feet together behind a starting line (the test is best done with footwear removed). Then, they walk in a forward direction as quickly and as accurately as possible along a 38mm wide (sports tape), 3 meter line with an alternate foot heel-to-toe gait ensuring that they approximate their heel and toe on each step. Once they cross the end of the 3m line, they turn 180 degrees and return to the starting point using the same gait. A total of 4 trials are done and the best time is retained. Athletes should complete the test in 14 seconds. Athletes fail the test if they step off the line, have a separation between their heel and toe, or if they touch or grab the examiner or an object. In this case, the time is not recorded and the trial repeated, if appropriate.

Coordination Examination

Upper limb coordination

Finger-to-nose (FTN) task:

"I am going to test your coordination now. Please sit comfortably on the chair with your eyes open and your arm (either right or left) outstretched (shoulder flexed to 90 degrees and elbow and fingers extended), pointing in front of you. When I give a start signal, I would like you to perform five successive finger to nose repetitions using your index finger to touch the tip of the nose, and then return to the starting position, as quickly and as accurately as possible."

Scoring: 5 correct repetitions in < 4 seconds = 1

Note for testers: Athletes fail the test if they do not touch their nose, do not fully extend their elbow or do not perform five repetitions. **Failure should be scored as 0.**

References & Footnotes

1. This tool has been developed by a group of international experts at the 4th International Consensus meeting on Concussion in Sport held in Zurich, Switzerland in November 2012. The full details of the conference outcomes and the authors of the tool are published in The BJSM Injury Prevention and Health Protection, 2013, Volume 47, Issue 5. The outcome paper will also be simultaneously co-published in other leading biomedical journals with the copyright held by the Concussion in Sport Group, to allow unrestricted distribution, providing no alterations are made.

2. McCrory P et al., Consensus Statement on Concussion in Sport – the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. British Journal of Sports Medicine 2009; 43: i76-89.

3. Maddocks, DL; Dicker, GD; Saling, MM. The assessment of orientation following concussion in athletes. Clinical Journal of Sport Medicine. 1995; 5(1): 32–3.

4. McCrea M. Standardized mental status testing of acute concussion. Clinical Journal of Sport Medicine. 2001; 11: 176–181.

5. Guskiewicz KM. Assessment of postural stability following sport-related concussion. Current Sports Medicine Reports. 2003; 2: 24–30.

6. Schneiders, A.G., Sullivan, S.J., Gray, A., Hammond-Tooke, G. & McCrory, P. Normative values for 16-37 year old subjects for three clinical measures of motor performance used in the assessment of sports concussions. Journal of Science and Medicine in Sport. 2010; 13(2): 196–201.

7. Schneiders, A.G., Sullivan, S.J., Kvarnstrom. J.K., Olsson, M., Yden. T. & Marshall, S.W. The effect of footwear and sports-surface on dynamic neurological screening in sport-related concussion. Journal of Science and Medicine in Sport. 2010; 13(4): 382–386

ATHLETE INFORMATION

Any athlete suspected of having a concussion should be removed from play, and then seek medical evaluation.

Signs to watch for

Problems could arise over the first 24–48 hours. The athlete should not be left alone and must go to a hospital at once if they:

- Have a headache that gets worse
- Are very drowsy or can't be awakened
- Can't recognize people or places
- Have repeated vomiting
- Behave unusually or seem confused; are very irritable
- Have seizures (arms and legs jerk uncontrollably)
- Have weak or numb arms or legs
- Are unsteady on their feet; have slurred speech

Remember, it is better to be safe.
Consult your doctor after a suspected concussion.

Return to play

Athletes should not be returned to play the same day of injury.
When returning athletes to play, they should be **medically cleared and then follow a stepwise supervised program,** with stages of progression.

For example:

Rehabilitation stage	Functional exercise at each stage of rehabilitation	Objective of each stage
No activity	Physical and cognitive rest	Recovery
Light aerobic exercise	Walking, swimming or stationary cycling keeping intensity, 70% maximum predicted heart rate. No resistance training	Increase heart rate
Sport-specific exercise	Skating drills in ice hockey, running drills in soccer. No head impact activities	Add movement
Non-contact training drills	Progression to more complex training drills, eg passing drills in football and ice hockey. May start progressive resistance training	Exercise, coordination, and cognitive load
Full contact practice	Following medical clearance participate in normal training activities	Restore confidence and assess functional skills by coaching staff
Return to play	Normal game play	

There should be at least 24 hours (or longer) for each stage and if symptoms recur the athlete should rest until they resolve once again and then resume the program at the previous asymptomatic stage. Resistance training should only be added in the later stages.

If the athlete is symptomatic for more than 10 days, then consultation by a medical practitioner who is expert in the management of concussion, is recommended.

Medical clearance should be given before return to play.

Scoring Summary:

Test Domain	Score		
	Date:	Date:	Date:
Number of Symptoms of 22			
Symptom Severity Score of 132			
Orientation of 5			
Immediate Memory of 15			
Concentration of 5			
Delayed Recall of 5			
SAC Total			
BESS (total errors)			
Tandem Gait (seconds)			
Coordination of 1			

Notes:

CONCUSSION INJURY ADVICE

(To be given to the **person monitoring** the concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. Recovery time is variable across individuals and the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, dizziness, worsening headache, double vision or excessive drowsiness, please contact your doctor or the nearest hospital emergency department immediately.

Other important points:

- Rest (physically and mentally), including training or playing sports until symptoms resolve and you are medically cleared
- No alcohol
- No prescription or non-prescription drugs without medical supervision. Specifically:
  - No sleeping tablets
  - Do not use aspirin, anti-inflammatory medication or sedating pain killers
- Do not drive until medically cleared
- Do not train or play sport until medically cleared

Clinic phone number

Patient's name

Date/time of injury

Date/time of medical review

Treatingphysician

Contact details or stamp