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Combined Effects of Depression and Sport-Related Concussion on Neuropsychological Test Performance

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Abstract

Title: Combined Effects of Depression and Sport-Related Concussion on Neuropsychological Test Performance

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The goal of this study was to gain a deeper understanding of the ways in which the combination of depression and sport-related concussion (SRC) impact cognitive functioning and recovery time. Neuropsychological test-score differences between concussed athletes with and without pre-existing or post-concussive depression were examined. Participants included 2238 collegiate athletes who completed baseline testing between 2015 and 2019. Of those participants, 152 sustained concussions and were further investigated. The Patient Health Questionnaire (PHQ-9) was used to screen for depression at both baseline and post-concussion. Total scores of 5 or greater on the PHQ-9 resulted in classification as depressed. Cognitive functioning was compared between non-depressed and depressed athletes at baseline and post-concussion using Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT). At baseline, depressed athletes demonstrated slower Reaction-Time than non-depressed athletes. At post-concussion, depressed athletes performed poorer on the Verbal Memory Composite. Visual Motor Speed Composite scores were worse among depressed athletes at *both* baseline and post-concussion. Reaction time did not appear to be influenced by depression. Findings show support for the inclusion of a depression screening measure at baseline and post-concussion to provide a broader understanding of cognitive functioning and mental health.

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Chapter 1 Introduction

Background Review

A concussion is the mildest type of traumatic brain injury (TBI) caused by an impact or jolt to the head or by an impact to the body that makes the head and brain move back and forth (Daneshvar et al., 2011). Rapid movement of the brain can cause changes to the shape of brain tissue, which can subsequently stretch and damage brain cells (Giza et al., 2013). Chemical and metabolic changes within the brain cells also occur, effecting cell function and communication (Mullally, 2017). The 2017 Concussion in Sport Group (CISG) agreed in their consensus statement that sport-related concussions (SRC) are the most complex injuries encountered in sport medicine to diagnose, assess and manage (McCrory et al., 2017). Meanwhile, mild Traumatic Brain Injuries (mTBI) are among the most common neurological conditions in the general population (Polinder et al., 2018). According to a report by the Centers for Disease Control and Prevention (CDC, 2014a), approximately 2.87 million Americans present to a hospital emergency room with a TBI each year. The CDC also estimates that up to 3.8 million SRCs occur each year in the United States, but the exact number is unknown due to underreporting (CDC, 2014b; Yang, 2015). Markedly, in the 15-24-years old range, sport is the second leading cause of head injury next to motor vehicle accidents (Laker, 2011).

Medical professionals sometimes describe a concussion as a *mild* TBI since concussions are not typically life threatening. That said, the effects of a concussion can be serious and can have somatic, cognitive, and behavioral impacts (CDC, 2019). Loss of consciousness is relatively rare, occurring in less that 10% of individuals who experience a concussion, but indicates severe injury (Mullally, 2017). The absence of lost consciousness does not, however, indicate that the injury is not severe. Early identification of a concussion relies on the results of a comprehensive neuropsychological assessment, which includes patient self-report of concussion symptoms appearing after an injury, observational signs of concussion and tasks related to brain function (Baldwin et al., 2018). Neuroimaging of the brain using computed tomography (CT) and magnetic resonance imaging (MRI) scans do not detect the microscopic changes to the brain's tissue that occur (Mullally, 2017; CDC, 2020). For some athletes, cognitive deficits may persist after physical or somatic symptoms resolve (Jennings et al., 2021). Thus, neuropsychological assessment is the cornerstone of standardized and comprehensive post-concussion evaluation (McCrory et al., 2017).

Concussions can have significant detrimental effects on an athlete's cognition and balance within the first 24 hours and may develop a range of symptoms within the first week post-concussion (Mullally, 2017). The most common post-concussive symptom is headache, followed by problems with balance. Often, individuals report feeling like they are in a fog and have difficulty with memory, concentration, and attention. Figure 1 shows a list of the most common post-concussive symptoms.

Figure 1.

Most Common Post-Concussive Symptoms

Somatic	**Cognitive**	**Behavioral**
Headache	Mental “fogginess”	Mood lability
Dizziness	Memory difficulty	Irritability
Nausea	Difficulty concentrating	Hypersomnia
Light sensitivity	Aphasia	Insomnia
Noise sensitivity		Anxiety
Tinnitus		Depression
Blurred vision		Personality changes
Fatigue		
Loss of Smell		
Postural light-headedness		

Note. Adapted from Mullally, 2017

Behavioral and emotional symptoms are common post-concussion and are associated with quality of life and cognitive functioning and recovery after an injury (Kontos & Collins, 2018; Vargas et al., 2015). Mood-related changes including depression are among the more common post-concussive psychological outcomes (Kontos et al., 2012). According to Kontos et al. (2012), even when psychological symptoms occur concurrently with other post-concussive symptoms (e.g., cognitive, somatic), the psychological symptoms are often most distressing for student-athletes. Further, concurrent symptoms may be overlooked by athletes since the presentation of emotional and behavioral symptomology is more troubling.

Post-Concussion Depressive Symptomology

According to their 2015 study, Vargas and colleagues found that when compared with baseline, 1 in 5 student-athletes who suffered a concussion experienced an increase in depressive symptoms when compared to baseline, while only 1 in 20 non-concussed athletes demonstrated an increase in depression over a similar period of time. In 2012, Kontos et al. found that 29% of student-athletes experienced one or more psychological symptoms (e.g., sadness, increased emotionality, and irritability) following SRC. Additionally, they found that college athletes continued to show elevated levels of depression symptoms when retested 14 days following the injury. They posited that college-aged athletes may maintain or develop increased frustration with the injury and uncertainty surrounding recovery and return to sport. Moreover, Kontos and Collins (2018) suggest that the recommendation of cognitive/physical rest following concussion may exacerbate rumination, worry and frustration, which will then appear on depression screeners at follow-up. Polinder et al. (2018) also highlighted increasing concerns surrounding prolonged rest as treatment of concussion and prolonged symptomology. It has been recommended that concussed athletes rest within the first 24-48 hours, however, rest beyond that phase may interfere with symptom recovery time (Thomas et al, 2015). Rather, a graduated return to sport (RTS) strategy is recommended in which athletes slowly introduce more cognitive/physical activity as they progress through recovery (McCrory et al., 2017). At any point, if cognitive or physical exertion exacerbate or worsen symptoms, the athlete returns to a previous phase of the gradual exertion strategy, limiting activity to a level that can be tolerated.

Researchers have long been attempting to identify the cause of emotional symptomology that is often experienced following concussion. Matthews et al. (2011) suggested that post-concussion depressive symptoms are caused by functional and microstructural changes in the brain. They also found that post-concussion depression was more likely to be observed in individuals who lost consciousness at the time of injury. Similarly, Ruiter and colleagues (2020) demonstrated neurophysiological effects associated with the symptoms experienced by concussed adolescents. Alternatively, other researchers have suggested that the depressive symptoms associated with concussion are due to the initial trauma, functional limitations, frustration, anger, uncertainty, and the experience of loss that results from an injury (Cole & Bailie, 2016; Putukian, 2016). The overlap of symptoms makes it especially challenging to discriminate between depression symptoms caused by the concussion (Kontos & Collins, 2018). For instance, confusion, fatigue, difficulty concentrating, sleep disruption, memory difficulties and irritability are symptoms of both concussion and depression.

Though the data is mixed, and debate persists regarding etiology, pathophysiology, and prognosis, it is well established that concussion related depressive symptoms prolong and complicate recovery (Quinn et al., 2018; Iverson et al, 2017; Kontos & Collins, 2018). According to a systematic review conducted in 2017 by Iverson et al., slower concussion recovery time is most consistently predicted by the severity of an individual's initial symptoms. Iverson et al. (2017) also found that concussion recovery is more likely to be prolonged if subacute headaches or depression develop. The presence of subacute depression symptoms appears to place individuals at risk for persistence of post-concussive symptoms lasting more than one month. This aligns with a 2018 study by Polinder et al. in which they suggested that cognitive and emotional symptoms of concussion diminish slower than somatic symptoms. In individuals whose post-concussive symptoms persist longer than one-month, a mood disturbance or emotional distress often becomes the primary clinical concern (Corwin et al., 2014). If mood changes and psychological symptoms are not effectively treated, post-concussive symptoms can become chronic.

Typical Recovery from Concussion

After a concussion, most athletes notice symptoms subside within 1 to 2 weeks and recover fully within one month (Wasserman et al., 2016; McCrory et al., 2017). Some athletes, however, may experience persistent symptoms that last up to 6 months (Carroll et al., 2014). How quickly an individual recovers depends on various factors (Iverson et al., 2017). For instance, severity of the injury, age, overall health and well-being before the concussion, response to the injury and the behavioral management of symptoms all play a role in concussion recovery time (CDC, 2016). Recent research also shows that diagnosing concussions as soon as possible leads to improved management, shorter recovery time and prevention of a second, more serious injury (Deakin et al., 2021; CDC, 2014b). Guerriero et al. (2018) showed that females were more likely to take longer to recover from a concussion than males regardless of premorbid conditions. Their study also demonstrated that individuals under the age of 12 years old with a history of headaches or a migraine disorder recovered significantly slower than those without such a history, although no statistically significant differences in recovery time were found among individuals older than 12 years. Alternatively, Wasserman and colleagues (2016) found that college aged student-athletes recovered from concussion sooner than high school aged student-athletes, and that elite professional athletes recover sooner than both high school and college student-athletes. Furthermore, the study showed that previous concussion history was associated with more post-concussion symptoms when compared with athletes without a history of concussion. As mentioned, post-concussive depressive symptoms prolong recovery, but research shows that pre-concussion depression can also prolong recovery (Sandel et al., 2017; Yang, 2015).

Influence of Pre-Existing Depression on Concussion Recovery

The present study focuses on college varsity athletes, but it is important to note that depression is a common illness and affects more than 264 million individuals worldwide (World Health Organization [WHO], 2020). In the United State of America, major depression is one of the most common mental health disorders (The National Institute of Mental Health [NIMH], 2017). The 2017 National Survey on Drug Use and Health (NSDUH) showed that an estimated 17.3 million U.S. adults aged 18 or older had experienced at least on major depressive episode in the past year (Substance Abuse and Mental Health Services Administration [SAMHSA], 2018). That number represents 7.1% of all U.S. adults. 63.8% of those adults who reported having at least one major depressive episode in the past year described the episode as causing "severe impairment". Prevalence of depression was highest among adults aged 18-25 (13.1%) and was higher among females (8.7%) compared to males (5.3%). Further, the prevalence of a major depressive episode was highest among adults who identified as biracial (11.3%). Among 15–29-year-olds, suicide is the second leading cause of death and nearly 800,000 people die by suicide every year (WHO, 2020). For several years, college counselling centers have been reporting increases in students seeking services related to suicidal ideation, suicide attempts, self-injury and depression (Abrams, 2020). Considering the high prevalence of depression in the general population and with collegiate student-athletes in the age range of highest prevalence of death by suicide, examining depressive symptomology among college athletes is imperative.

Several studies have examined depression and mental health in college athletes specifically. In their 2019 International Olympic Committee consensus statement, Reardon et al. stated that based on current evidence, mental health symptom and disorder prevalence among male elite athletes varies from 5% for burnout and substance abuse to nearly 45% for depression and anxiety. Reported prevalence rates of mental health disorders among male and female collegiate athletes have ranged from 5% to 35% (Reardon et al., 2019). In a systematic review, Golding et al. (2020) analyzed peer-reviewed original research articles published between 1993 to 2018 that reported the prevalence of depression among high-performance athletes (including collegiate level athletes) ages 17 years and older and found that reported prevalence rates of depression amongst elite athletes ranged from 6.7% to 34%. Notably, the depression assessments used varied across studies. When the researchers pooled only from studies that used the Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977), a mean prevalence rate of 23.7% was revealed.

Various stressors and risk factors for depression specific to athletes have been identified (Tahtinen et al., 2021; Reardon et al., 2019; Wolanin et al., 2015). For instance, depression rates have been found to be higher among athletes who participate in individual sport (e.g., golf, boxing, tennis) versus team sports (Beable et al., 2017; Golding et al., 2020). Athletic injury has also been correlated with higher rates of depression among athletes (Junge & Feddermann-Demont, 2016; Reardon et al., 2019). Further, Hammond et al. (2013) showed a correlation between depression rates and level of competition, with higher level competitors experiencing greater depression symptoms and sport-related stressors. An association between depression and performance failure was also demonstrated by the study showing that among athletes who did not accomplish their competition goals, 80% met criteria for a major depressive episode after their performance failure (Hammond et al., 2013). Similarly, Doherty et al. (2016) found that public evaluation of performance increased depression among athletes and impacted athletic identity. Several studies found that when compared with male athletes, female athletes reported higher levels of depressive symptoms (Beable et al., 2017; Junge & Feddermann-Demont, 2016; Wolanin et al., 2015). In 2016, Prinz et al. found that among high-performance female soccer players, 32% reported a career prevalence of major depression at any time during their professional career, while 25% reported current mild to moderate depression. Moreover, athletes face pressure to appear strong and deny weakness or vulnerability, which Doherty et al. (2016) found to be a risk factor for depression among the athletes who participated in the study.

A history of depression introduces challenge in disentangling pre-existing symptoms from newly acquired, concussion-related symptoms since several mood and behavioral symptoms of depression and concussion overlap (Kontos & Collins, 2018). For instance, symptoms including sadness, irritability, increased emotionality, sleep disruption and fatigue are shared by depression and concussion. Thus, it is critical for concussion management programs to conduct depression screening at baseline to determine the degree to which these symptoms pre-exist (Kontos & Collins, 2018). Yang and colleagues (2015) found that depressive symptoms endorsed at baseline were the strongest predictor of post-concussion depression, and pre-existing depression also predicted post-concussion anxiety symptoms, while baseline trait anxiety did not consistently predict post-concussion anxiety symptoms. In other words, depression may lead to post-concussion state anxiety even in those do not typically experience anxiety. Vargas et al. (2015) found that 20% of collegiate athletes reported increased depressive symptoms following SRC and that pre-existing depression detected at baseline predicted development of exacerbated depression symptoms and prolonged recovery time with some athletes demonstrating chronic post-concussive symptoms. According to Cole and Bailie (2016), while acute depression symptoms impact concussion recovery time, post-concussion psychological symptomology may not be as important as preinjury history of depression in predicting concussion outcomes.

Contributing further to the difficulty of disentangling pre- and/or post-concussion depression from concussion symptoms is the overlap of cognitive deficits that are often present as symptoms of both depression and SRC (Kontos & Collins, 2018). For example, impairments in memory, concentration, attention, and executive function along with confusion are neuropsychological symptoms that are frequently endorsed on standardized self-report screeners for depression and on SRC symptom lists. Of course, self-report measures lend themselves to under- or over-reporting of symptoms, while comprehensive, standardized assessments that formally measure impairments may more accurately represent symptomology. Comprehensive cognitive assessments before and after injury are, therefore, crucial in distinguishing symptoms or impairments that may be related to another condition or that may predate the injury. When considering the combined effects of concussion and depression on neurocognitive performance, it is important to understand the individual impacts of depression on cognition in general.

Cognitive Deficits Associated with Depression

Impaired cognitive functioning is a common concern among individuals with Major Depressive Disorder (MDD; Tran et al., 2021). In fact, it has been estimated that approximately 67% of individuals with depression experience impaired cognition (Afridi et al., 2011). Diminished ability to think or concentrate, or indecisiveness and psychomotor slowing are included as criterion for Major Depressive Disorder as per the Diagnostic and Statistical Manual of Mental Disorders- Fifth Edition (DSM-5; American Psychological Association, 2013). Frequently, individuals diagnosed with MDD report that deficits in cognition are major barriers to daily functioning. (Tran et al., 2021).

Bora and colleagues (2012) found that when compared with healthy controls, patients with MDD demonstrated significantly poorer cognitive functioning, with striking differences shown in verbal memory, processing speed and executive functions including planning and problem-solving. Notably, these differences were found even among individuals who were not experiencing depressive episode and presented as euthymic at the time of testing. Similarly, Rock et al. (2013) investigated differences in cognitive functioning between patients with depression and non-depressed controls by conducting a systematic review and meta-analysis of studies that assessed patients using the Cambridge Neuropsychological Test Automated Battery (CANTAB). Included in their study were patients with active depressive episodes and patients in a remitted state, with results revealing that both patient groups perform significantly worse on tasks of executive function, memory, and attention.

More recently, Tran et al. studied cognitive deficits in a group of 111 patients diagnosed with MDD who were participating in cognitive remediation treatment. Patients' cognitive abilities were measured in reference to both normative comparison data and in reference to each individual's estimated premorbid functioning (within-subject). Results demonstrated that when using a normative approach to neuropsychological assessment, only 25% of patients met criteria for a cognitive impairment classification. On the other hand, when using within-subject comparisons, 62.2% of patients met criteria to be classified as cognitively impaired. Impairment was not significantly associated with depressive symptom severity. Consequently, studies that use traditional approaches using normative data may underestimate the prevalence of cognitive impairment among individuals with MDD.

Cognitive Test Performance after Concussion

Administration of a battery of neurocognitive assessments at baseline and again following injury for comparison is the typical protocol followed by collegiate athletics concussion management programs (Crook, 2018). Since concussions typically do not appear during neuroimaging and a clear biomarker has not yet been identified, evaluating an athlete's cognition along with their symptom profile and conducting an in-depth clinical interview is currently the standard diagnostic protocol (McCrory et al., 2017). Research has shown that cognitive deficits are often observed on one or several domains included on neuropsychological assessments, especially during the acute phase of SRC (Riegler et al., 2020). Post-concussion neurocognitive deficits can be seen in memory, reaction time, processing speed and attentional processes (Jennings et al., 2021; Echemendia et al., 2009).

A 2001 study conducted by Echemendia and colleagues found that when compared with healthy controls, concussed athletes showed significantly poorer performance on tasks of verbal memory, attention and concentration and verbal learning when assessed two hours post-concussion. When tested again 48-hours post-concussion, neuropsychological assessment scores of concussed athletes continued to worsen and demonstrate significant discrepancy in working memory, divided attention, verbal learning, verbal memory and attention and concentration when compared with controls. Shortly after, Belanger and Vanderploeg (2005) conducted a meta-analysis of concussion literature in athletics and overall results suggest that within the first 24 hours following SRC, neuropsychological function is affected across six domains (executive function, attention, orientation, memory acquisition, delayed memory, and global functioning), with the most severe deficits observed in memory acquisition, delayed memory, and global functioning. In 2008, Broglio and Puetz meta-analyzed neurocognitive effects of SRC and found that in the acute phase, SRC has a strong negative effect on neurocognitive performance. Two weeks following the injury, neurocognitive performance continued to be impacted negatively but to a lesser extent. Evidently, several domains of neurocognition are susceptible to impairment following SRC.

Chapter 2 Study Rationale

Depressive symptoms are common following concussion, but the precise cause remains unclear (Cole & Bailie, 2016). Greater understanding has been building surrounding the potential for a concussion to exacerbate pre-existing psychological problems or for concussion to produce newly occurring psychological distress (Iverson et al., 2017; Sandel et al., 2016). It appears that both pre-existing depression and depressive symptoms that develop following a concussion prolong recovery time (Cole & Bailie, 2016). Clinicians are challenged to determine whether the student-athlete's depression is a symptom of the concussion, was pre-existing prior to injury, or if the depression developed after injury but independently from it (Kontos & Collins, 2018). Considering the cognitive deficits associated with depression, it stands to reason that athletes with pre-existing depression or post-concussion depressive symptomology will experience significant adverse effects on cognitive functioning following SRC as well. Since the neuropsychological assessments administered post-concussion involve several cognitive domains including attention, memory, and concentration, it seems likely that performance on assessments of cognition will be poorer among athletes with post-concussive depressive symptoms when compared with non-depressed athletes. Subsequently, for athletes with pre-existing or post-concussion depression, returning to baseline may also take longer.

Understanding the relationship between concussion and depression and how this relationship impacts athletes' functioning is critical for professionals involved in concussion management. In their position paper, Bloom et al. (2020) suggested that understanding the scope of psychological responses to SRC is imperative for concussion management clinicians to make appropriate recommendations for treatment and return to play. There is a growing need for a more robust understanding of the emotional and behavioral outcomes of SRC, since guidelines available to clinicians for treating psychological factors after SRC are currently limited (Sandel et al., 2017). Included in the 2017 Berlin Concussion in Sport Group Consensus Statement as a current area of concussion research focus in team collision sports was relationships among psychological variables such as depression and post-concussion stress and concussion diagnosis, recovery from concussion and development of persistent symptoms (Patricios et al., 2018; McCrory et al., 2017).

To date, few studies have investigated the combined effects of depression and an SRC on student athletes' performance on cognitive assessments (Kontos et al., 2012; Riegler et al., 2020). Several studies have looked individually at either comparison of baseline depression with post-concussion depression or at comparison of baseline cognitive performance with post-concussion cognitive performance (Vargas et al. 2015; Yang et al., 2015). More recently, Riegler and Colleagues (2020) investigated the differences in performance on neuropsychological tests following an SRC in a group of depressed athletes compared with a group of nondepressed athletes. The researchers administered the BDI-FS post-concussion to determine if the athletes were experiencing depressive symptom severity that indicated clinically significant depression. Student-athletes who endorsed a score of 4 or greater, were placed in the depressed group and athletes who endorsed score less than 4 were placed in the nondepressed group. Cognition was assessed at baseline and post-concussion using a battery of both paper-and-pencil tests and a computerized test. At baseline, the depression screener was not administered. Results showed that when compared with the nondepressed group, depressed athletes performed significantly poorer on memory tasks post-concussion. Additionally, a greater proportion of cognitive impairment was observed in concussed athletes with depression versus nondepressed athletes with a concussion. This study provides further support that when significant post-concussion depressive symptomology is present, athletes show greater cognitive deficits than typically observed following an SRC.

Riegler et al.'s 2020 study examined the combined effects of depression symptoms and concussion on cognitive performance, however, a depression screener was only administered at post-concussion but not at baseline, eliminating opportunity for comparison. Thus, they were limited in their ability to make certain conclusions about the increase of depression symptoms following an SRC and could not examine the effects of pre-existing depression on post-concussion cognitive performance. The present research project included baseline depression screening for comparison with post-concussion depression and post-concussion cognitive performance.

Chapter 3 Aims and Hypotheses

Aim 1: To investigate differences in neuropsychological test performance among athletes who endorse depression at baseline compared with athletes who do not endorse depression at baseline.

Hypothesis 1: Athletes who endorsed PHQ-9 total scores of 5 or greater at baseline will score more poorly on the ImPACT Verbal Memory, Visual Memory, Visual Motor Speed, and Reaction Time Composites than athletes who endorsed PHQ-9 total scores of 4 or less at baseline.

Aim 2: To examine differences in neuropsychological test performance among concussed athletes who endorse depression at baseline and/or post-concussion compared with concussed athletes who do not endorse depression at baseline and/or post-concussion.

Hypothesis 2: Following a concussion, athletes with total scores of 5 or greater on the PHQ-9 at baseline and/or post-concussion will score more poorly on the ImPACT Verbal Memory, Visual Memory, Visual Motor Speed, and Reaction Time Composites than athletes whose total scores were 4 or less on the PHQ-9 at baseline or post-concussion.

Aim 3: To evaluate the relationship between depression and concussion recovery time.

Hypothesis 3: Recovery in athletes who endorse total scores of 5 or greater on the PHQ-9 at baseline or post-concussion will be prolonged when compared with athletes who endorse total scores of 4 or less on the PHQ-9 at baseline or post-concussion.

Aim 4: To investigate whether post-concussion classification of cognitive impairment is more predominant in concussed athletes who endorse total scores of 5 or greater on the PHQ-9 or in concussed athletes who do endorse total PHQ-9 scores of 4 or less.

Hypothesis 4: Cognitive impairment will be more predominant among concussed athletes who endorse PHQ-9 total scores of 5 or greater at post-concussion.

Chapter 4 Method and Procedures

The method and procedures involved in this study were approved by Florida Institute of Technology's Institutional Review Board.

Data Collection

Archival data collected by the Concussion Management Program (CMP) at Florida Institute of Technology (FIT) between 2015 and 2020 was used in this study. FIT is a National Collegiate Athletic Association (NCAA) Division II institution. All athletes involved in a varsity level sport are required to complete a pre-participation baseline evaluation. For the baseline evaluation, a depression screener is administered along with a computerized neuropsychological test (CNT) that assesses neurocognitive functioning. Following a known or suspected head injury, the athlete is referred by their athletic trainer for a post-concussion evaluation during which the depression screener and CNT are administered again. Results of the post-concussion evaluation are then compared to baseline results to determine a concussion diagnosis as indicated by development of concussive symptoms and/or significant decline in neurocognitive performance. If a concussion is diagnosed, it is recommended that the athletic trainer monitors symptoms, the athlete does not participate in sport activities or strenuous physical activity, and the athlete returns for a follow-up evaluation after 2 asymptomatic days. The process is repeated until the concussion is resolved, defined by neurocognitive performance returning to baseline and absence of concussive symptoms. Recovery time is measured by the number of days from the injury to the date of the final follow-up evaluation whereby the athlete is deemed to have recovered.

Measures

Patient Health Questionnaire- 9 item (PHQ-9)

The PHQ-9 (Kroenke et al., 2001) is a well-established and valid 9-item self-report depression screening tool. Items assess both the emotional and physiological symptoms associated with depression. Examples of items include, "Little interest or pleasure in doing things", "Feeling tired or having little energy", and "Poor appetite or overeating". The final item assesses for suicidal ideation and self-harm and reads, "Thoughts that you would be better off dead or of hurting yourself in some way". Each item is scored as 0 "not at all", 1 "several days", 2 "more than half the days", or 3 "nearly every day" to indicate symptom frequency. Finally, if any symptoms were endorsed, the patient is asked, "how difficult have these problems made it for you to do your work, take care of things at home, or get along with other people". The patient is given the following options: "Not difficult at all", "somewhat difficult", "very difficult" and "extremely difficult". The assessment can be completed in approximately 5 minutes. The maximum score an individual can report is 27 and scores are categorized for depression severity as, "minimal" (1–4), "mild" (5–9), "moderate" (10–14), "moderately severe" (15–19), and "severe" (20–27).

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)

The ImPACT (Lovell, 2016) is the most widely used computerized neuropsychological tests for diagnosing concussion in sport concussion management programs (Crook, 2018). The assessment includes demographics, a symptom inventory, and six neurocognitive modules from which four composite scores are calculated. The six modules evaluate visual working memory, verbal recognition memory, attentional processes, reaction time, visual processing speed, numerical sequencing ability and learning. After completion of all subtests, the following four core composite scores are generated: Verbal Memory, Visual Memory, Visual Motor Speed, and Reaction Time. Higher scores on the Verbal Memory, Visual Memory, and Visual Motor Speed Composites indicate better performance. Meanwhile, higher scores on the Reaction Time Composite indicates poorer performance. The assessment can be completed in approximately 30-minutes.

Participants

Participants included 2238 Florida Tech athletes who completed baseline testing with the Concussion Management Team between 2015 and 2019. Meanwhile, 152 of those participants (6.8%) sustained concussions and were further investigated. When making comparisons of baseline neuropsychological test performance, the participants were separated into two groups, 1) Athletes who endorsed PHQ-9 total scores of 5 or greater, indicating mild to severe depression and 2) Athletes who endorsed PHQ-9 total scores of 4 or less, indicating minimal or no depression. When analyzing hypothesis 2, the relationship between baseline and post-concussion neuropsychological test performance, the participants were divided into 4 groups, 1) Athletes who endorsed mild to severe depression at baseline only 2) Athletes who endorsed mild to severe depression post-concussion only 3) Athletes who endorsed mild to severe depression at *both* baseline and post-concussion and 4) Athletes who endorsed minimal or no depression symptoms at baseline and post-concussion.

Data Analysis

All statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS) version 27.0. Descriptive statistics and frequencies were computed to determine assessment score means and standard deviations as well as demographics of the sample. Independent *t*-tests were conducted to make comparisons between participant groups. The relationship between depressive symptomology and recovery time and depressive symptomology and cognitive performance was determined by conducting bivariate correlations and multiple regressions.

Chapter 5 Results

Aim 1:

Baseline data was available for 2238 Florida Tech athletes, with 1413 (63%) men and 825 (37%) women athletes. The mean PHQ-9 score for the overall sample was *M* = 1.31, *SD* = 2.08. A majority of the athletes (52%) endorsed zero symptoms on the PHQ-9. Independent samples t-tests were conducted to investigate gender but there were no statistically significant differences in the mean PHQ-9 scores. Of this sample, 158 (7%) athletes endorsed total scores of 5 or greater on the PHQ-9, with 94 (7%) of male athletes and 64 (8%) of female athletes in this depressed group. In this group of 158 athletes, there was a slightly higher proportion of female athletes who endorsed PHQ-9 total scores of 5 or greater, however, further analyses revealed that there were no statistically significant differences in the mean PHQ-9 scores endorsed by men (*M* = 6.99, *SD* = 2.18) compared to women (*M* = 7.27, *SD* = 3.41), $t(98) = -.57$, $p = .57$. The mean PHQ-9 score among the overall group of depressed athletes was *M* = 7.10, *SD* = 2.74. Scores ranged from 5-21 representing a range from mild to severe depression. The overwhelming majority of athletes (152, 96%) in the depressed group, however, endorsed scores in the mild to moderate range, with only 6 (4%) athletes endorsing scores representative of moderately severe or severe depression.

On ImPACT, the mean Verbal Memory Composite score for the overall baseline sample was *M* = 88.30, *SD* = 9.5. The overall sample mean Visual Memory Composite score was *M* = 80.24, *SD* = 11.77 at baseline. Meanwhile, the mean baseline Visual Motor Speed Composite score was *M* = 42.37, *SD* = 6.22. Finally, the mean Reaction Time Composite score was *M* = .59, *SD* = .08 at baseline. Statistically significant differences were found on two of the four ImPACT composites when comparing the ImPACT composite scores of the group of athletes who endorsed total scores of 5 or greater on the PHQ-9 to those who endorsed total scores of 4 or less. Specifically, the depressed group (*M* = 40.98, *SD* = 6.51) demonstrated poorer Visual Motor Speed Composite scores than the group without significant depressive symptoms (*M* = 42.47, *SD* = 6.20), $t(179) = 2.79$, $d = .24$. Additionally, Reaction Time Composite scores suggested slower performance among the participants who endorsed significant depressive symptoms (*M* = .62, *SD* = .10) than those who did not (*M* = .59, *SD* = .08), $t(172) = -2.03$, $d = -.21$. Bivariate correlations also aligned with this finding with lower Visual Motor Speed Composite scores as depression symptoms increased, $r = -.056$, $p = .008$. Similarly, Reaction Time Composite scores suggested faster performance when fewer depression symptoms were endorsed, $r = .074$, $p = <.001$. These findings partially support the hypothesis that athletes endorsing total scores of 5 or greater on the PHQ-9 would demonstrate poorer performance on all four composites. Poorer performance was only demonstrated by depressed athletes in the Visual Motor Speed and Reaction Time Composites.

Aim 2:

Post-concussion data was available for 152 athletes. The mean PHQ-9 score at baseline for this overall sample of 152 concussed athletes was *M* = 1.72, *SD* = 2.56, while the mean PHQ-9 score post-concussion was *M* = 4.32, *SD* = 4.35. Meanwhile, post-concussion PHQ-9 scores of 5 or greater were endorsed by 52 (34%) athletes with a mean score of *M* = 9.38, *SD* = 3.49. Comparatively, the mean post-concussion PHQ-9 score for those scoring 4 or less post-concussion was *M* = 1.67, *SD* = 1.37. A bivariate correlation to analyze the overall relationship between baseline and post-concussion PHQ-9 scores for all 152 concussed athletes was conducted. This analysis revealed a significant positive correlation between baseline and post-concussion PHQ-9 scores, $r = .32$, $p = <.01$.

At baseline, 21 (14%) of the 152 concussed athletes endorsed PHQ-9 total scores of 5 or greater. Of those 21 athletes, 5 of them endorsed total scores of 5 or greater on the PHQ-9 *only* at baseline and *not* post-concussion. The remaining 16 (76%) athletes in the group of 21 who endorsed baseline PHQ-9 total scores of 5 or greater also endorsed PHQ-9 scores of 5 or greater post-concussion. Of the 52 athletes who endorsed post-concussion PHQ-9 total scores of 5 or greater, 36 athletes had not endorsed PHQ-9 total scores of 5 or greater at baseline. Table 1 illustrates the number of athletes in each subgroup of athletes who endorsed PHQ-9 scores of 5 or greater.

Table 1.

Number of athletes who endorsed PHQ-9 total scores of ≥ 5

	n
Baseline Only	5
Baseline and Post-Concussion	16
Post-Concussion Only	36
Neither Baseline nor Post-Concussion	95
Total	152

Since there was so much variance in sample size across subgroups, feasibility of some statistical analyses was limited. For instance, an ANOVA to compare mean scores across all groups would have been inappropriate with such variance in sample sizes. Additionally, with a sample size of only 5, it would not have been possible to achieve strong enough statistical power to make conclusions about athletes who only endorsed

PHQ-9 scores of 5 or greater at baseline. Thus, analyses comparing this subgroup of 5 athletes with other subgroups were not conducted.

In consideration of the sample size variance, independent samples *t*-tests of unequal variance were conducted to analyze differences in post-concussion neuropsychological test performance between the athletes who endorsed post-concussion PHQ-9 total scores of 5 or greater (n =52) and those who endorsed scores of 4 or less (n= 100). There was statistically significant ImPACT composite score differences between the athletes who endorsed post-concussion total scores of 5 or greater on the PHQ-9 and those who endorsed post-concussion PHQ-9 total scores of 4 or less. Specifically, on the Verbal Memory Composite, the depressed group demonstrated poorer performance (M = 79.18, SD = 14.81) than the non-depressed group (M = 84.40, SD =11.87), $t(82) = 2.16$, $p = .034$, $d = .40$. Further, the group of athletes who endorsed PHQ-9 scores of 5 or greater (M = 36.68, SD = 8.03) showed poorer performance on the Visual Motor Speed Composite than the group scoring 4 or less on the PHQ-9 (M = 40.60, SD = 7.39), $t(92) = 2.88$, $p = .005$, $d = .52$. Meanwhile, no significant differences were observed between groups on the Visual Memory Composite, $t(102) = .75$, $p = .46$ or Reaction Time Composite, $t(85) = -1.42$, $p = .12$. Independent t-test analyses revealed that there were no statistically significant differences in PHQ-9 scores or ImPACT composite scores between male and female athletes. The hypothesis that athletes scoring 5 or greater on the PHQ-9 at post-concussion would perform poorer on all four ImPACT composite domains was, therefore, partially supported since poorer performance was only observed in the Visual Motor Speed and Verbal Memory Composites.

Aim 3:

The mean recovery time in days for the sample of athletes who sustained concussions (n = 152) was *M* = 17.03, *SD* = 11.85. A significant positive correlation was found between post-concussion PHQ-9 scores and recovery time after injury, $r = .219$, $p = .007$. This was, however, a weak correlation. Upon further investigation, an independent samples t-test did not yield a statistically significant difference in recovery time between athletes who endorsed PHQ-9 total scores of 5 or greater at post-concussion (n= 100, *M* = 20.52, *SD* = 18.61) and those who endorsed PHQ-9 post-concussion total scores of 4 or less (n= 52, *M* = 18.00, *SD* = 14.24), $t(83) = -.85$, $p = .40$). Further, there was not a correlation between baseline PHQ-9 scores and recovery time. This was further analyzed using an independent samples t-test, which confirmed that there were no significant differences in recovery time between athletes who endorsed baseline depression (n= 21, *M* = 18.29, *SD* = 16.76) and those who did not endorse depression (n= 13, *M* = 18.98, *SD* = 15.72) at baseline, $t(26) = .18$, $p = .43$. Thus, the hypothesis that recovery time would be longer in athletes who endorsed PHQ-9 total scores of 5 or greater at baseline or post-concussion was not supported.

Aim 4:

A computer-generated clinical summary report comparing baseline to post-concussion performance is available once an athlete completes post-concussion ImPACT testing. When an athlete's performance shows significant declines from their baseline performance based on a calculated reliable change index, the composite score is indicated in red. For the purpose of this study, athletes who had at least one composite score indicated in red were classified as impaired. Of the 152 athletes in the post-concussion sample, 108 (71%) showed impaired performance on ImPACT. A chi-square analysis in which athletes were dichotomously coded (impaired or not impaired) was conducted to determine whether athletes who endorsed significant post-concussion depressive symptoms were more likely than those who did not endorse significant depressive symptoms to show impaired performance on ImPACT. The chi-square results did not show an association between impaired ImPACT performance and endorsement of PHQ-9 total scores of 5 or greater, X^2 (1, *N* = 152) = 0.04, *p* = .84. These results, therefore, do not support the hypothesis that athletes who endorsed total scores of 5 or greater on the PHQ-9 would be more likely to demonstrate impaired neurocognitive function on ImPACT following a concussion.

Supplemental Analyses

Gender

When baseline ImPACT composite scores were analyzed by gender, there were statistically significant differences across all four composite scores. On the Verbal Memory Composite, female athletes (*M* = 89.54, *SD* = 8.97) performed slightly better than men (*M* = 87.58, *SD* = 9.74), *t*(1841) = - 4.83, *p* = <.001, *d* = 9.46. On the other hand, male athletes (*M* = 80.81, *SD* = 11.57) performed slightly better on the Visual Memory Composite than female athletes (*M* = 79.28, *SD* = 12.06), *t*(1667) = 2.94, *p* = .003, *d* =11.75. On the Visual Motor Speed Composite, slightly better performance was found among female athletes (*M* =42.73, *SD* = 6.13) compared to male athletes (*M* = 42.15, *SD* = 6.27), *t*(1757) = - 2.13, *p* = .033, *d* = 6.22. Finally, Reaction Time Composite scores suggested slightly slower performance in male athletes (*M* = .60, *SD* = .08) than female athletes (*M* = .59, *SD* = .08), *t*(1761) = 2.53, *p* = .012, *d* = .08. While the effect sizes are large, the mean score point-differences are relatively small.

Pre-existing Depression

Of the athletes who were depressed at baseline (n=21), 76% (n=16) were also depressed post-concussion. In that group, a statistically significant increase in mean PHQ-9 scores from baseline (*M* = 7.25, *SD* = 2.62) to post-concussion (*M* = 9.38, *SD* = 2.78) was revealed, *t*(15) = -2.81, *p* = 0.13 with a large effect size, *d* = 3.03. Scores from baseline to post-concussion increased by a mean of 2.13 points.

Chapter 6 Discussion

Existing research has demonstrated the effects of depression and sport-related concussion on neuropsychological test performance. Few studies, however, have investigated the combined effects of both depression and concussion on neuropsychological test performance. The purpose of this study was to investigate these potential combined effects. Baseline and post-concussion data from a sample of varsity collegiate athletes was analyzed. When comparing between-subject performance, at baseline, there were significant neuropsychological test performance differences between the athletes who endorsed total PHQ-9 scores of 5 or greater and the athletes who endorsed total PHQ-9 scores of 4 or less. Specifically, the individuals who endorsed significant depressive symptoms performed worse than their non-depressed counterparts. Similarly, post-concussion between-subject comparisons revealed poorer performance among athletes who endorsed post-concussive PHQ-9 total scores of 5 or greater.

The depressed group showed poorer performance on the Visual Motor Speed Composite at both baseline and post-concussion. Wallace and colleagues (2020) also found that baseline visual motor speed performance deficits were present in depressed college athletes when compared to their non-depressed counterparts. Similarly, Covassin et al. (2012) found that post-concussion visual motor speed was significantly slower in a group of depressed college and high school athletes when compared to healthy controls.

The current study revealed slower Reaction Time Composite scores among the depressed group at baseline. This is in agreement with a 2012 study by Kontos et al. that found a significant association between slower ImPACT Reaction Time Composite scores and depressive symptomology. Additionally, Keller and colleagues (2019) found that reaction time was slower in a group of depressed participants when compared to healthy controls. At post-concussion however, Reaction Time Composite scores were not slower among depressed athletes. Concussed athletes without significant post-concussion depressive symptoms performed similarly to those with significant depressive symptoms in terms of reaction time. This suggests that concussion may mimic the slowed reaction time seen in non-concussed athletes experiencing depression at baseline. Slowed reaction time is one of the more common cognitive deficits in concussed athletes (Eckner et al., 2014) and, as discussed, is also common among depressed individuals. The finding that reaction time appears worse among athletes with PHQ-9 total scores of 5 or greater at baseline, but not post-concussion further supports arguments that depression symptoms and concussion symptoms often overlap and are difficult to disentangle (Kontos & Collins, 2018).

Further, results of present study showed that the depressed group performed poorer on the Verbal Memory Composite at post-concussion. This aligns with findings by Riegler et al. (2020) that showed a reliable decrease in Verbal Memory Composite scores from baseline to post-concussion in depressed college athletes. On the other hand, the current study did not reveal poorer Verbal Memory Composite scores among depressed athletes at baseline. While this finding did not support the hypothesis 1, it is suggested that the combination of depression and concussion together produces pronounced deficits in the Verbal Memory Composite. However, it appeared that depression alone does not necessarily translate to poorer performance on tasks of verbal memory.

The effort hypothesis is one possible explanation for this finding. The effort hypothesis states that performance on tasks requiring effort is disproportionately worse in individuals with depression when compared to performance on automatic tasks (Gualtieri et al., 2006). It could be argued that the ImPACT tasks in the Verbal Memory Composite require relatively less effort than ImPACT tasks measuring reaction time and visual motor speed because some of the verbal memory tasks involve passive learning and recognition rather than spontaneous recall. When depression symptoms are compounded with concussion symptoms, however, the tasks may become more effortful than performing the tasks while dealing with depression symptoms alone. This would help to explain why at baseline, Verbal Memory Composite scores among depressed athletes were comparable to non-depressed athletes but were worse after sustaining a concussion.

Contrary to hypotheses 1 and 2, depressed athletes did not show worse performance than their non-depressed counterparts at either baseline or post-concussion in the Visual Memory Composite. The effort theory may also apply to this finding. Perhaps, the ImPACT Visual Memory Composite subtests require relatively less effort than the subtests included in other composites. Tasks measuring visual and verbal memory are often the least effortful subtests in neuropsychological test batteries that assess multiple domains of executive function since they typically rely on simple recognition (Gualtieri et al., 2006).

Surprisingly, there was only a weak correlation between recovery time and depression symptom endorsement. When investigated further, recovery time appeared independent of depression symptom endorsement. This contradicts previous research that pre-existing and/or post-concussive depression may prolong concussion recovery (Iverson et al., 2017; Vargas et al., 2015). This may be, however, be related to measurement of recovery time. Previous studies have measured recovery time as date of injury until return to sport date. In this study, recovery time was measured as the date of injury until follow-up evaluation, which requires at least two consecutive days free of symptoms. Both methods of recovery time measurement may be somewhat inaccurate representations of recovery time. Since the athlete may have technically recovered sooner than their next scheduled sport activity (e.g., practice, game) or follow-up evaluation due to scheduling delays.

When comparing within-subject baseline performance to post-concussion performance, depressed athletes were not more likely to show impaired ImPACT performance than non-depressed athletes. This suggests that the combination of concussion and depressive symptoms does not necessarily lead to more within-subject impaired functioning than if depression symptoms were not present. In other words, there was just as likely a chance that non-depressed athletes would show declines in their neuropsychological performance after sustaining a concussion than non-depressed athletes. It should be noted, however, that the reliable change index that determines whether the change from baseline to post-concussion is statistically significant does not operate on a severity scale but rather a minimum threshold. Any scores beyond the threshold of significance are highlighted and indicated in red. The depressed athletes may have had a higher degree of change/decline from baseline to concussion, but just as likely a chance to pass the minimum threshold of change. With this in mind, it is not altogether surprising then that cognitive impairment was found at similar rates between groups. In other words, even if an athlete is not endorsing depression symptoms, cognitive declines are common in concussion and athletes' scores are likely to be indicated in red.

Notably, 7% of the baseline sample (n=2238) endorsed significant depressive symptoms. This is in alignment with recent estimates that prevalence rates of mental health conditions in collegiate athletes are between 5 and 35 percent (Reardon et al., 2019). Depression in college athletes is not uncommon (Mast & Gentile, 2019). Additionally, it has been well studied that college athletes are less likely to seek treatment for mental health conditions than the general college population (Putukian, 2016).

Interestingly, while 7% of the overall sample at baseline (n = 2238) endorsed total scores of 5 or greater on the PHQ-9, 14% of the athletes in the post-concussion sample (n = 158) endorsed total scores of 5 or greater on the PHQ-9 at baseline. This may suggest that pre-existing depression is a risk factor for sustaining a concussion. Additionally, 76% of the athletes who were depressed at baseline were also depressed post-concussion. In that group, a statistically significant increase in mean PHQ-9 scores from baseline to post-concussion was revealed with a large effect size. This increase suggests that concussion exacerbates pre-existing depression symptoms.

Since over half of the athletes in the baseline sample endorsed zero symptoms on the PHQ-9, there was likely some degree of underreporting. Several possible explanations for this trend among college athletes have been posited such as, athletes attempting to portray themselves favorably, stigma in the athletic community about mental health, and fear of repercussions if depression is endorsed (Gulliver et al., 2012; Putukian, 2016; Sudano et al., 2017). Screening for pre-participation mental health conditions is, therefore, an important inclusion in baseline protocols. The results of the present study support previous research demonstrating that a higher proportion of female athletes experience depression than male athletes; however, based on statistical analyses, female and male athletes experienced similar degrees of symptom severity despite a slightly higher proportion of female athletes endorsing depression.

Findings also revealed that 96% of the athletes who endorsed depression at baseline endorsed scores in the mild to moderate depression range. Since baseline assessments are typically conducted at the beginning of the academic year (August), it can be posited that depression symptoms are likely to increase as academic responsibilities and athletic schedule commitments compound throughout the semester if they are not addressed or treated in the interim. Thus, identifying depression and providing mental health referrals and resources early may prevent symptoms from worsening. Considering that the depressed athletes in this study performed worse than non-depressed athletes in the Visual Motor Speed and Reaction Time Composites at baseline, early depression intervention may prevent exacerbation of these neurocognitive outcomes.

Chapter 7 Practical Implications

Previous studies have looked *only* at post-concussion depression when investigating the impact of depression on neuropsychological performance symptoms (Riegler et al., 2020). On the other hand, the present study measured depression at both baseline *and* post-concussion to deepen our understanding of the influence that mood has on neuropsychological performance before and after injury. This study found that those who endorsed significant depressive symptoms at baseline endorsed higher PHQ-9 scores post-concussion. The current study also revealed that a higher proportion of athletes endorsed depression at post-concussion versus at baseline. This emphasizes the importance of screening for depression at baseline and recommending early intervention. It also highlights the importance of making immediate referrals to mental health resources following a concussion since pre-existing depressive symptoms are likely to increase in severity due to the pathophysiological effects of the concussion itself and may be further exacerbated by the psychological components of concussion (e.g., temporarily suspended participation, reduced physical activity, and reduced social interaction with teammates). Thus, this study highlights the importance of screening for depression symptoms at both baseline and post-concussion to better understand likely neuropsychological performance outcomes before and after injury.

Since depressed athletes were found to have poorer Visual Motor Speed Composite scores and slower Reaction Time Composite scores at baseline, these athletes might be at greater risk of sustaining injuries. If an athlete is slower to respond and/or less coordinated, they might be more vulnerable during sport participation. This further highlights the importance of treating depression in college athletes. In other words, treating the depression would hopefully improve visual motor speed and reaction time to decrease injury risk.

Since athletes tend to be less likely to self-report depression symptoms than the general college population, outreach programming from campus and community mental health providers should be invited by athletic staff to destigmatize mental health concerns among the college athlete population. Student athletes should be ensured that they will not be negatively impacted but rather, supported should they experience depression or other mental health issues. Further, resources should be provided to college athletes who endorse PHQ-9 total scores of 5 or greater at baseline to prevent exacerbation of symptoms. Screening for depression using a brief measure such as the PHQ-9 is cost-efficient and is not time-consuming. Adding a depression screener to baseline protocols should not be burdensome to the institution/athletic staff since the PHQ-9 takes only approximately five minutes to administer and is available, free of charge in the public domain.

This study found that following a concussion, athletes who endorsed total PHQ-9 scores of 5 or greater performed worse on the Visual Motor Speed and Verbal Memory Composites than their non-depressed counterparts. This raises the possibility that concussed athletes who are experiencing significant depression may be more likely to experience academic difficulties, and therefore they might be in greater need of tailored academic accommodations until the concussion is resolved. Appropriate accommodations may include, extra time on tests and extensions on assignment due dates to account for these temporary cognitive deficiencies.

Chapter 8 Significance of This Study

The results of this research emphasized the importance of baseline and post-concussion depression screening within concussion management programs to better our understanding of how depression influences cognition and recovery following a concussion. Moreover, aside from aiding in the diagnosis of concussion, use of depression screeners at baseline and post-concussion promotes improved well-being and mental health of student-athletes whose depressive symptoms may not otherwise have been detected. Additionally, this study supported the use of neurocognitive testing at baseline and post-concussion to identify declines in performance and to more fully understand how symptoms contribute to neurocognitive deficits after a concussion. Further, the current study highlights the combined effects of depression and concussion together on neurocognitive performance. Overall, the research findings are hoped to inspire improvements to baseline and post-concussion evaluation protocols.

Chapter 9 Limitations

This study is not without limitations. The post-concussion sample size is relatively small, which may limit the generalizability to the wider athlete population. In addition, all athletes in this study were NCAA Division II athletes, and results may not generalize to all divisions. As is true with the existing literature, results of this study will be correlational in nature. Thus, it will not be possible to determine causality between depression and post-concussion cognitive performance. Additionally, this study relies on self-report of depressive symptoms at baseline and post-concussion. Some student-athletes may underreport their symptoms to minimize the severity of their depression. Alternatively, athletes may purposely overreport symptoms at baseline so that if assessed post-concussion, the disparity will not appear as striking or unusual and the athlete may be permitted to return to sport sooner. Consequently, using self-report measures may result in an inaccurate number of athletes in each of the groups. Further, over the course of data collection from 2015-2019, different versions of ImPACT were used. ImPACT does not provide standardized age and gender normative tables for comparison that can be applied to both previous and current versions. It would have been beneficial to have been able to conduct analyses of cognitive impairment based on normative percentiles. While the clinical summaries indicate scores in red if they show significant decline from baseline, these are within-subject comparisons. Normative percentiles would have given a clearer picture of between-subject impairment. Finally, recovery time was reported as the date of injury until follow-up evaluation. This report may be a somewhat inaccurate representation of recovery time since the athlete may have recovered sooner than they returned for a follow-up evaluation depending on concussion evaluation scheduling.

Chapter 10 Future Research

In future studies, more consistent methods of measuring of recovery time across studies would be beneficial. This may include measuring from the day of the injury to the first day the athlete was asymptomatic and their ImPACT performance has returned to baseline. Recovery time, however, can be complex. Some athletes' symptoms resolve but once they are exertion tested by their athletic trainer, symptoms return, and they are unable to return to sport until exertion testing does not exacerbate symptoms. Further, future studies should consider recovery time for individual symptoms to compare recovery time of depressive symptoms and non-depressive symptoms. Based on results from this study, it appeared that depressive symptoms did not correlate to longer recovery time, indicating that recovery time is similar across all symptoms. This was contrary to hypothesis 3 and research that has suggested prolonged recovery time in athletes who endorse depression post-concussion (Iverson et al., 2017, Stein et al., 2017).

Additionally, future research may include long-term follow up assessments to further bolster the evidence that concussion and depression in combination can lead to greater neurocognitive deficits than these conditions alone. Continued research in this area would be beneficial and larger sample sizes may produce clearer results that will better generalize to the college athlete population.

Chapter 11 Conclusions

When comparing baseline neuropsychological performance, depressed athletes showed slower Reaction Time Composite scores than their non-depressed counterparts. At post-concussion, neuropsychological performance in the Verbal Memory Composite was poorer in depressed athletes than in non-depressed athletes. Recent literature suggests that screening for depression and other psychological difficulties is critical and should be included in baseline protocols (Rice et al., 2018). Since depressed athletes showed lower scores on several domains in comparison with non-depressed athletes, screening for depression and providing resources for treatment is indicated by this study.

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