EXAMINING THE ROLE OF DEPRESSION ON THE RELATIONSHIP BETWEEN OBJECTIVE AND SUBJECTIVE COGNITIVE FUNCTIONING AFTER SPORT-RELATED CONCUSSION

A Thesis in
Psychology
by
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Abstract

Objective: Studies examining the relationship between objective and subjective cognitive functioning after sport-related concussion (SRC) are surprisingly scarce, and results are mixed. Although further research is needed, depression could influence this relationship. Accordingly, this study examined how depression impacts objective and subjective cognitive functioning in collegiate-level athletes who sustained an SRC. It was hypothesized that depression would both moderate and mediate this relationship.

Participants and Methods: Participants included 110 collegiate athletes who recently sustained an SRC. Objective cognitive functioning was measured using a comprehensive neuropsychological battery. The Post Concussion Symptoms Scale (PCSS-Cog) measured subjective cognitive functioning, and the Beck Depression Inventory-Fast Screen (BDI-FS) assessed depression. Neurocognitive scores, BDI-FS scores, and their interactions were entered into distinct hierarchical linear regression analyses with PCSS-Cog scores as the dependent variable to assess moderation. Mediation was analyzed using the PROCESS macro with 5,000 bootstrap samples and a 95% confidence interval with neurocognitive scores as the independent variable, depression as the mediator, and PCSS-Cog scores as the dependent variable.

Results: There was a significant interaction between the memory composite and depression when predicting cognitive symptom reporting, F(1,106)=4.04, p=.047. Simple effects tests revealed that for athletes who had a lower memory composite score, each additional 1-point increase in BDI-FS score increased athletes’ PCSS-Cog score by 0.60 points, t(107)=3.63, p<.001, η²=.11, 95%CI [-.27,-0.93]. For athletes who had a higher memory composite score, this relationship was not significant. The interactions between all other neurocognitive scores and depression were not significant. Depression partially mediated the relationship between the memory composite and cognitive post-concussion symptom reporting, indirect effect =-0.26, 95% CI [-0.58,0.001]. After controlling for depression, the relationship between the memory composite score and cognitive post-concussion symptom reporting decreased in significance (i.e., p=.008 before controlling for depression to p=.047 after controlling for depression). For all other neurocognitive scores, depression did not fully or partially mediate this relationship.

Conclusion: For tests of memory, depression moderated and partially mediated the relationship between objective and subjective cognitive functioning after SRC. Self-reported cognitive symptoms provide important information in SRC management, but it could also be critical to assess for depression, especially when athletes report high levels of cognitive dysfunction. Athletes reporting high depressive symptoms and cognitive dysfunction may need more comprehensive cognitive evaluations to inform return-to-play decisions, and depression could be a treatment target for athletes with a history of SRC who report high levels of cognitive dysfunction.
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<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>BDI-FS</td>
<td>Beck Depression Inventory-Fast Screen</td>
</tr>
<tr>
<td>BVMT-R</td>
<td>Brief-Visuospatial Memory Test-Revised</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence Interval</td>
</tr>
<tr>
<td>Cog.</td>
<td>Cognitive</td>
</tr>
<tr>
<td>CTMT</td>
<td>Comprehensive Trail-Making Test</td>
</tr>
<tr>
<td>Fx.</td>
<td>Functioning</td>
</tr>
<tr>
<td>HVLT</td>
<td>Hopkins Verbal Learning Test-Revised</td>
</tr>
<tr>
<td>ImPACT</td>
<td>Immediate Post-Concussion Assessment and Cognitive Testing</td>
</tr>
<tr>
<td>M</td>
<td>Mean</td>
</tr>
<tr>
<td>mTBI</td>
<td>Mild Traumatic Brain Injury</td>
</tr>
<tr>
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<td>Total Number of a Sample</td>
</tr>
<tr>
<td>NCAA</td>
<td>National Collegiate Athletics Association</td>
</tr>
<tr>
<td>PCSS</td>
<td>Post Concussion Symptoms Scale</td>
</tr>
<tr>
<td>PCSS-Cog</td>
<td>Post Concussion Symptoms Scale Cognitive Symptom Domain</td>
</tr>
<tr>
<td>PSU</td>
<td>The Pennsylvania State University</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
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<td>SDMT</td>
<td>Symbol-Digit Modalities Test</td>
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<tr>
<td>SPSS</td>
<td>Statistical Package for Social Science</td>
</tr>
<tr>
<td>SRC</td>
<td>Sport-Related Concussion</td>
</tr>
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<td>TBI</td>
<td>Traumatic Brain Injury</td>
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Acknowledgments

I would like to express my sincerest gratitude to my thesis advisor, Dr. Pete Arnett, for the guidance, input, edits, and advice he provided from this project’s nascence to its completion. His mentorship, including reminders to enjoy the journey, was instrumental in this process.

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Chapter 1. Introduction

With an estimated 1.6 to 3.8 million sport-related concussions (SRCs) occurring each year, proper understanding and management of SRCs are major public health priorities in the United States (Chandran et al., 2022; Langlois et al., 2006). An SRC is defined as a traumatic brain injury (TBI) that is sustained in a sports setting and can occur either by a direct or an indirect hit (i.e., a hit to another part of the body that generates force to the head; Patricios et al., 2023). Immediately after impact, acute neurological symptoms can include loss of consciousness, anterograde or retrograde amnesia, alteration of consciousness, or immediate post-concussion symptoms (Patricios et al., 2023; Silverberg et al., 2023). Post-concussion symptoms encompass a variety of neurobehavioral sequelae such as physical (e.g., nausea or dizziness), sleep-related (e.g., fatigue), affective (e.g., feeling sad or irritable), and cognitive (e.g., difficulty concentrating, feeling foggy or slow) symptoms, but these usually resolve within approximately four weeks of injury, and symptom profiles are notably heterogenous (McCrorry et al., 2017; Patricios et al., 2023; Reddy et al., 2008; Wait et al., 2022). Existing studies have found that the number of annually reported SRCs is steadily increasing, and a growing body of literature on the deleterious long-term effects of sustaining multiple SRCs has led to an emphasis on evidence-based SRC management to improve athlete safety and long-term health (Daneshvar et al., 2011; Manley et al., 2017; Patricios et al., 2023).

A critical component of athlete safety is determining when it is appropriate for an athlete to return to athletic settings after sustaining an SRC. Consensus statements from the National Athletic Trainers’ Association and the Concussion in Sport Group encourage
the use of multimodal assessments given at baseline (i.e., before a sports season) and after an SRC is sustained to determine when an athlete can safely return to practice and competition (Broglio et al., 2014; McCrory et al., 2017). These multimodal assessments include neuropsychological tests to evaluate cognitive functioning and self-report measures to assess post-concussion symptoms, as well as evaluations of sleep-related, ocular, and vestibular symptoms (Broglio et al., 2014; Patricios et al., 2023). It is recommended that athletes are gradually returned to athletic settings, with full participation resuming once an athlete’s cognitive functioning resembles their pre-injury functionality and their post-concussion symptoms are resolved (Broglio et al., 2014; Patricios et al., 2023).

Although athletes competing at elite levels (such as those playing at the professional level or those participating in Division I athletics under the National Collegiate Athletic Association [NCAA]) have ample access to neuropsychological testing and teams of medical staff who are well-trained in SRC evaluation, management, and rehabilitation, these services are much less available to non-elite athletes (Putukian et al., 2009). Self-reported, “subjective” cognitive post-concussion symptoms are particularly salient in clinical settings where athletic trainers and other medical personnel may have limited access to baseline neuropsychological data or extensive neuropsychological batteries to evaluate cognitive functioning in a more “objective” manner (Arnett et al., 2016; Lempke et al., 2020; Lynall et al., 2013; Notebaert et al., 2005). Indeed, studies on SRC assessment and management suggest that athletic trainers in non-elite settings rely heavily on self-reported symptoms to inform return to play
decisions and that approximately 50% of athletic trainers utilize neuropsychological testing and/or multimodal assessment (Lempke et al., 2020; Lynall et al., 2013).

While self-reported post-concussion symptoms play a central role in return to play decisions after SRC, the relationship between self-reported cognitive post-concussion symptoms (i.e., “subjective cognitive functioning”) and objective neuropsychological assessment performance (i.e., “objective cognitive functioning”) is surprisingly scarce, and results are mixed. Few studies have specifically examined the relationship between objective and subjective cognitive functioning in athletes with a history of SRC. Guty and Arnett (2018) and Bryant and colleagues (2023) found that cognitive post-concussion symptom endorsement was not significantly related to neuropsychological test performance in elite athletes with a history of SRC. However, Broglio and colleagues (2009) found a significant correlation between objective and subjective cognitive functioning in collegiate athletes who had been concussed and evaluated within 48 hours of injury. Similarly, Collie and colleagues (2006) and Fazio and colleagues (2007) compared athletes with a history of SRC who were experiencing post-concussion symptoms to asymptomatic athletes with a history of SRC. Both studies reported that symptomatic athletes performed poorer on objective measures of cognitive functioning than asymptomatic athletes, specifically on measures of visual memory, verbal memory, processing speed, and reaction time. The lack of extensive research on the relationship between objective and subjective cognitive functioning in athletes who have sustained an SRC could result in inaccurate return to play decisions (e.g., returning to play too early or being held from play for too long), especially in contexts where self-reported symptoms are heavily relied upon and multimodal assessment is limited.
One factor that may explain the imperfect relationship between objective and subjective cognitive functioning is depression. A growing body of literature has found that depression is related to increased cognitive post-concussion symptom reporting and poorer neuropsychological test performance in athletes after sustaining an SRC (Kontos et al., 2012; Riegler et al., 2020; Yrondi et al., 2017). A systematic review by Yrondi and colleagues (2017) found that depression can manifest in the acute stages after a concussion, that depressive symptoms appear to be associated with post-concussion symptoms, and that a history of mood disorder can be a risk factor for developing depression after sustaining an SRC. Riegler and colleagues (2020) reported that depressed athletes with SRC performed worse on neuropsychological measures of memory than nondepressed athletes with SRC. Kontos and colleagues (2012) found that increased depression in athletes with SRC was associated with neurocognitive deficits in tests of reaction time and visual memory; however, these results were not clinically significant. Moreover, there is evidence from studies on mild traumatic brain injury (mTBI) that higher levels of depression and anxiety may explain inconsistencies between objective and subjective cognitive functioning after mTBI (Hromas et al., 2020). Hromas and colleagues (2020) found that greater anxiety and depression were associated with larger discrepancies between self-reported cognitive functioning and performance on neuropsychological tests in individuals with a history of mTBI. Although further research is needed, it is possible that an athlete’s level of depression could influence the relationship between objective and subjective cognitive functioning after SRC.

Understanding the links between depression and cognitive functioning after SRC can help to further inform return to play decisions as well as the allocation of additional
mental health support for recovering athletes. Accordingly, the goal of the proposed study was to address the following question: is depression related to differences between objective performance on a comprehensive neuropsychological battery and subjective, self-reported post-concussion symptoms in collegiate-level athletes who have recently sustained an SRC? To answer this question, we investigated whether depression moderated and/or mediated differences between objective and subjective cognitive functioning, given that these questions have not been examined in the context of SRC. We hypothesized that depression would moderate the relationship between objective and subjective cognitive functioning such that increased depression would be associated with increased cognitive post-concussion symptom reporting in athletes who performed poorly on neuropsychological tests but that this relationship would not exist among athletes who performed well on these tests. We also hypothesized that depression would mediate the relationship between subjective and objective cognitive functioning through the following path: lower performance on neuropsychological tests is predicted to result in higher reporting of depressive symptoms, which in turn will lead to higher reporting of cognitive dysfunction. Of note, it is possible that other factors may impact this relationship, such as time since injury, number of past concussions, and gender. We elected to focus on depression because a well-established body of literature suggests that depression interferes with both perceptions of and actual cognitive functioning and because depression is an important dimension of athlete well-being (Kontos et al., 2012; Kriesche et al., 2022; Riegler et al., 2020; Yrondi et al., 2017)).
Chapter 2. Materials and Methods

Participants and Procedures

Participants in this observational cross-sectional study included collegiate athletes who recently sustained an SRC and were enrolled in an NCAA Division I University concussion management program. Athletes participating in football, basketball, baseball, softball, soccer, wrestling, lacrosse, ice hockey, crew, volleyball, and rugby were referred to this program by team physicians or athletic trainers. After obtaining informed consent, all athletes underwent baseline testing prior to participating in their respective sport and were re-assessed after sustaining an SRC. Testing at both time points included self-report measures of depression and post-concussion symptoms and a comprehensive neuropsychological battery. All measures were administered by trained undergraduate or graduate students under the supervision of a licensed clinical neuropsychologist. To be diagnosed with an SRC, athletes’ acute neurological symptoms were examined. Criteria for an SRC include anterograde and/or retrograde amnesia for less than 24 hours; loss of consciousness for 30 minutes or less; alteration of consciousness after injury; and/or post-concussion symptoms immediately after injury (Silverberg et al., 2023). Data collection occurred between 2002 and 2019. All study recruitment and procedures were conducted in accordance with the Pennsylvania State University Institutional Review Board and the latest version of the Declaration of Helsinki.

To be eligible for the current study, athletes had to (1) sustain a concussion due to sport-related activities; (2) be evaluated within 30 days of sustaining an SRC; (3) have complete data on the Beck Depression Inventory-Fast Screen (BDI-FS) and the Post
Concussion Symptoms Scale (PCSS; see Measures for further details); and (4) pass a performance validity test embedded in the neuropsychological battery (see Measures for further details). The final sample for the current study included 110 athletes (male = 92, female = 18) with a mean age of 20.16 years (SD = 1.41).

Measures

Neuropsychological Assessment

Objective cognitive functioning was measured by the following neuropsychological tests: the Brief-Visuospatial Memory Test-Revised (BVMT-R; Benedict, 1997); the Comprehensive Trail-Making Test (CTMT; Reynolds, 2002); the Digit Span Test, which was modified for the concussion management program (Wechsler, 1997); the Hopkins Verbal Learning Test-Revised (HVLT-R; Brandt & Benedict, 2001); the ImPACT (Lovell et al., 2000); the Pennsylvania State University Cancellation Test (PSU Cancelation; Echemendia et al., 2001); the Stroop Color-Word Interference Test (Trenerry et al., 1989); the Symbol-Digit Modalities Test (SDMT; Smith, 1991); and the Vigil/W Continuous Performance Test (Cegalis & Cegalis, 1994). The ImPACT Impulse Control subtest was used to assess performance validity, as a raw score greater than 30 is considered a cutoff for suboptimal effort (ImPACT Applications, 2021). Based on this criterion, only athletes with an ImPACT Impulse Control raw score of 30 or less were included in the current study.

From these tests, 16 variables were used to calculate cognitive composite scores in two neurocognitive domains: attention/processing speed and memory. Prorating was
used to account for missing data on neuropsychological measures. First, raw scores were converted to z-scores using sex-based norms (see Merritt et al., 2017), and z-scores were then averaged to create cognitive composite scores. The attention/processing speed composite was made of 10 variables: ImPACT Visual Motor Speed, Vigil Omissions, Vigil Average Delay, SDMT Total, Stroop 1, Stroop 2, PSU Cancelation, Digit Span Forwards, Digit Span Backwards, and CTMT. The memory composite was made of 6 variables: ImPACT Verbal Memory, ImPACT Visual Memory, BVMT Immediate, BVMT Delay, HVLT Immediate, and HVLT Delay. Intra-individual variability (IIV) scores were also calculated for each cognitive domain by averaging the z-scores of (1) the difference between the highest and lowest z-score in each cognitive domain and (2) the average of the standard deviations of the z-scores in each cognitive domain.

**Beck Depression Inventory-Fast Screen**

The 7-item Beck Depression Inventory-Fast Screen (BDI-FS) is a self-report measure on depressive symptoms (Beck et al., 2000). For each item, athletes are asked to rate the extent to which each depressive symptom has bothered them over the past two weeks on a scale of 0-3, where “0” indicates that the symptom is absent, and “3” signifies that the symptom is severe. Scores are then summed, with higher scores signifying more severe depressive symptoms. This measure has been validated for use in athletes with SRC, especially in its ability to distinguish post-concussion symptoms from depressive symptoms (Riegler et al., 2020).

**Post Concussion Symptoms Scale**
The 22-item Post Concussion Symptoms Scale (PCSS) is a self-report measure (Lovell et al., 2000; 2006). Using a 7-point Likert scale, where “0” indicates “none” and “6” indicates “severe”, athletes endorse the extent to which each post-concussion symptom (e.g., headache, fatigue, difficulty concentrating) is currently bothering them. The current study calculated a cognitive post-concussion symptom domain from the PCSS using a previous factor analysis using the following four PCSS items: “feeling slowed down”; “feeling mentally ‘foggy’”; “difficulty concentrating”; and “difficulty remembering” (range 0-24; see Merritt & Arnett., 2014).

Data Analysis

Data analysis was conducted using the Statistical Package for Social Science (SPSS), Version 27. Descriptive statistics were used to characterize sociodemographic and injury-related variables for the overall sample. To examine if depression is related to differences in objective and subjective cognitive functioning, depression was analyzed as a moderator and a mediator. Hierarchical linear regressions were first conducted to examine whether depression moderates the relationship between objective and subjective cognitive functioning. Specifically, neurocognitive scores, depression, and their interactions were entered into distinct hierarchical linear regression analyses, and cognitive post-concussion symptom reporting was the dependent variable. Simple effects tests were then used to further understand interactions and main effects. The effect of depression on cognitive post-concussion symptoms was examined at high and low levels (± 1 SD) of cognitive functioning as evaluated by neuropsychological assessment. The Process Macro package was used to determine if depression mediates the relationship
between neuropsychological test performance and self-reported cognitive functioning (Hayes, 2013). Depression was the mediator, neurocognitive scores were the independent variable, and cognitive post-concussion symptom reporting was the dependent variable. The mediation analyses was conducted with 5,000 bootstrap samples and a 95% confidence interval.
Chapter 3. Results

Sample Characteristics

Sociodemographic and injury-related characteristics of the sample are displayed in Table 1. Of the 110 athletes assessed in this study, 18 identified as female (16.4%) and 92 identified as male (83.6%). Regarding racial/ethnic identity, 72 athletes identified as non-Hispanic White (65.5%), 28 as Black (25.5%), 7 as Multiracial (6.4%), 2 as Asian (1.8%), and 1 as Another Race (0.9%). On average, athletes were assessed 6.46 days after sustaining an SRC (SD = 6.34) and were 20.16 years old at the time of assessment (SD = 1.41). Immediately after sustaining an SRC, 21 athletes endorsed loss of consciousness (19.1%), 35 athletes endorsed anterograde amnesia (31.8%), and 17 athletes endorsed retrograde amnesia (15.5%). The most common mechanism of injury was contact with oneself or another player (73.6%), and athletes had sustained an average of 1.03 previous SRCs (SD = 1.16).

Moderation Analyses

Attention and Processing Speed

As depicted in Table 2, a model including the attention/processing composite score, depression, and their interaction was conducted. There was a significant main effect of the attention/processing speed composite score ($t(108) = -2.29, p = .024, 95\% \text{ CI} [-1.61, -0.12]$) as well as a significant main effect of depression ($t(107) = 3.16, p = .002, 95\% \text{ CI} [0.16, 0.68]$) on cognitive post-concussion symptom reporting. However, the
interaction between the attention/processing speed composite score and depression was not significant ($t(106) = -1.19, p = .236, 95\% \text{ CI } [-0.44, 0.11]$).

A model including attention/processing speed IIV and depression was conducted next (see Table 2). There was not a significant main effect of attention/processing speed IIV ($t(108) = 1.70, p = .092, 95\% \text{ CI } [-0.09, 1.22]$), but there was a significant main effect of depression ($t(107) = 3.29, p = .001, 95\% \text{ CI } [0.17, 0.70]$). The interaction between attention/processing speed IIV and depression was not significant ($t(106) = -1.30, p = .197, 95\% \text{ CI } [-0.35, 0.07]$).

**Memory**

Next, a model including the memory composite score, depression, and their interaction was conducted. There were significant main effects for the memory composite score ($t(108) = -2.70, p = .008, 95\% \text{ CI } [-1.72, -0.26]$) and depression ($t(107) = 2.99, p = .003, 95\% \text{ CI } [0.14, 0.67]$), and the interaction between the memory composite score and depression was also significant ($t(106) = -2.01, p = .047, 95\% \text{ CI } [-0.59, -0.004]$; see Table 2). Specifically, the interaction between the memory composite score and depression accounted for 11\% of the variance in cognitive post-concussion symptom reporting. Results from simple effects tests demonstrated that for athletes who had a lower memory composite score (i.e., scoring one standard deviation below the mean), each additional 1-point increase in their BDI-FS score (i.e., an increase in depressive symptoms) increased their PCSS-Cog score (i.e., increase in cognitive post-concussion symptom reporting) by 0.60 points, $t(107) = 3.63, p < .001, \eta^2 = .11, 95\% \text{ CI } [.27, 0.93]$. For athletes who had a higher memory composite score (i.e., scoring one standard deviation above the mean), this relationship was not significant, $t(107) = 0.50, p = .618,$
\( \eta^2 < .01, 95\% \text{ CI} [-.30, 0.50] \). Figure 1 depicts the interaction between the memory composite score and depression on cognitive post-concussion symptom reporting.

Lastly, a model including memory IIV, depression, and their interaction was evaluated. There was not a significant main effect of memory IIV (\( t(108) = 1.52, p = .132, 95\% \text{ CI} [-0.15, 1.13] \)), but there was a significant main effect of depression (\( t(107) = 3.37, p = .001, 95\% \text{ CI} [0.18, 0.71] \)). The interaction between memory IIV and depression was not significant (\( t(106) = 1.36, p = .176, 95\% \text{ CI} [-0.09, 0.48] \)).

**Mediation Analyses**

**Attention and Processing Speed**

Results of a mediation analysis using 5,000 bootstrap samples demonstrated that depression did not significantly mediate the relationship between the attention/processing speed composite score and cognitive post-concussion symptom reporting, indirect effect = -0.22, 95\% CI [-0.57, 0.03]. For attention/processing speed IIV, a mediation analysis using 5,000 bootstrap samples also demonstrated that depression did not significantly mediate the relationship between attention/processing speed IIV and cognitive post-concussion symptom reporting, indirect effect = 0.16, 95\% CI [-0.12, 0.48].

**Memory**

A mediation analysis using 5,000 bootstrap samples indicated that depression partially mediated the relationship between the memory composite and cognitive post-concussion symptom reporting, indirect effect = -0.26, 95\% CI [-0.58, 0.001]. After
controlling for depression, the relationship between the memory composite score and cognitive post-concussion symptom reporting decreased in significance (i.e., $p = .008$ before controlling for depression to $p = .047$ after controlling for depression). If this were a full mediation as opposed to a partial mediation, the relationship between objective and subjective cognitive functioning would have become nonsignificant (i.e., $p > .05$) after controlling for depression. Figure 2 displays the results of the partial mediation for the memory composite score, depression, and cognitive post-concussion symptom reporting. Lastly, a mediation analysis using 5,000 bootstrap samples found that depression did not significantly mediate the relationship between memory IIV and cognitive post-concussion symptom reporting, indirect effect = 0.12, 95% CI [-0.07, 0.37].
Table 1. Participant characteristics.

<table>
<thead>
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<th>Sociodemographic Variables</th>
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<td>1.41</td>
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<tr>
<td>Sex</td>
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<td>83.6%</td>
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<td>Female</td>
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<td>White</td>
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<td>Black</td>
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<table>
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<td>Days Since SRC</td>
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<td>6.34</td>
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<tr>
<td>Number of Previous SRCs</td>
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<td>1.16</td>
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<tr>
<td>Mechanism of Injury</td>
<td>variables</td>
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<td>%</td>
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<tr>
<td>Contact with Self or Another Player</td>
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<td>73.6%</td>
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<tr>
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<td>Hit in Head by Object</td>
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<td>93</td>
<td>84.5%</td>
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<td>variables</td>
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<td>%</td>
</tr>
<tr>
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</tr>
<tr>
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<td>75</td>
<td>68.2%</td>
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*Abbreviations: SRC = sport-related concussion.*
Table 2. Hierarchical linear regression analyses: Neuropsychological test performance and depression on self—reported cognitive post-concussion symptoms.

<table>
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<th>Variables entered</th>
<th>$B$</th>
<th>$SEB$</th>
<th>$\beta$</th>
<th>$R^2$</th>
<th>$\Delta R^2$</th>
<th>$\Delta F$</th>
<th>$p$</th>
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<tr>
<td><strong>Attention/Processing Speed Composite</strong></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Step 1</td>
<td>Speed Composite</td>
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<td>0.38</td>
<td>-0.22</td>
<td>0.05</td>
<td>0.05</td>
<td>5.25</td>
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<tr>
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<td>0.13</td>
<td>0.29</td>
<td>0.13</td>
<td>0.08</td>
<td>10.01</td>
</tr>
<tr>
<td>Step 3</td>
<td>Speed Composite * BDI-FS</td>
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<td>0.14</td>
<td>-0.14</td>
<td>0.14</td>
<td>0.01</td>
<td>1.42</td>
</tr>
<tr>
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<td>0.16</td>
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<td>0.03</td>
<td>2.89</td>
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<td>0.01</td>
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<tr>
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*Abbreviations:* BDI-FS = Beck Depression Inventory-Fast Screen, IIV = intraindividual variability.
Figure 1. Moderation of the relationship between the memory cognitive composite score and cognitive post-concussion symptom reporting by depression.

Notes: BDI-FS = Beck Depression Inventory-Fast Screen, PCSS-Cog = cognitive subscale of the Post Concussion Symptom Scale. The high memory composite/BDI-FS represent a score one standard deviation above the mean, and the low memory composite/BDI-FS represent a score one standard deviation below the mean.
Figure 2. Partial mediation of the relationship between the memory cognitive composite score and cognitive post-concussion symptom reporting by depression.

Notes: Objective Cog. Fx. = objective cognitive functioning as evaluated by neuropsychological assessment; Subjective Cog. Fx. = subjective cognitive symptom functioning as evaluated by cognitive post-concussion symptom reporting.
Chapter 4. Discussion

Given the evidence that depression influences both post-concussion symptom reporting and neuropsychological test performance after SRC, the current study examined how depression is associated with the relationship between objective cognitive functioning (i.e., neuropsychological test performance) and subjective cognitive functioning (i.e., cognitive post-concussion symptom reporting). We found that following SRC, self-reported cognitive problems can reflect objective impairments in both attention/processing speed and memory. When examining depression in this context, we found that depression moderates and partially mediates the relationship between objective and subjective memory functioning.

Results from hierarchical linear regressions yielded significant main effects for the attention/processing speed and memory cognitive composite scores. Stated differently, athletes who performed poorly on tests of attention/processing speed and memory were significantly more likely to report elevated cognitive post-concussion symptoms than athletes who performed well on these tests, regardless of depression symptoms. Previous studies on the congruence of objective and subjective cognitive functioning are mixed in athletes with a history of SRC (Bryant et al., 2023; Broglio et al., 2009; Guty & Arnett, 2018). Guty & Arnett (2018) did not find a significant relationship between cognitive post-concussion symptom reporting and neurocognitive test performance in collegiate athletes, and Bryant and colleagues (2023) reported a similar nonsignificant relationship in former collegiate football players. However, Broglio and colleagues (2009) found a significant correlation between the PCSS cognitive symptoms and reaction time and verbal memory in collegiate athletes, which
resembles our findings. It is possible that the discrepancies in the literature could be explained by the time between SRC and evaluation, as Guty & Arnett’s (2018) sample was assessed an average of 5.67 days after SRC, Bryant and colleagues (2023) recruited former collegiate football players who had sustained SRCs over 15 years ago, and Broglio and colleagues (2009) assessed participants within 48 hours of sustaining an SRC. Our findings are also similar those of Collie et al. (2006) and Fazio et al. (2007), who found that athletes with a history of SRC and current post-concussion symptoms performed poorer on tests of memory, processing speed, and reaction time than asymptomatic athletes with a history of SRC. However, these studies examined post-concussion symptoms as a whole, not cognitive symptoms specifically.

Although we observed significant main effects of neurocognitive composite scores on cognitive post-concussion symptom reporting, there were no significant main effects for attention/processing speed or memory IIV. IIV, or the amount that an individual’s performance varies across neuropsychological tests, has been found to be sensitive to cognitive dysfunction after SRC (Merritt et al., 2019; Rabinowitz & Arnett, 2013). Importantly, studies like those by Merritt and colleagues (2019) and Rabinowitz and Arnett (2013) evaluated the relationship between IIV and performance on a neuropsychological battery, while we assessed the relationship between IIV and cognitive post-concussion symptom reporting as measured by the PCSS-Cog. When the PCSS is administered, participants are asked to rate the extent to which they are currently experiencing post-concussion symptoms, as opposed to any perceptions on the variability of their symptoms. Indeed, the presence of the main effects for cognitive composite scores but the absence of main effects for IIV when predicting subjective cognitive
functioning could suggest that what athletes are rating on the PCSS is not their variability but their perceived overall level of ability, which is congruent with the instructions of the PCSS.

Regarding moderation, we found that greater depressive symptoms are expected to increase cognitive post-concussion symptom reporting in athletes who recently sustained an SRC and performed poorly (i.e., one standard deviation below the mean) on tests of memory. However, this effect was not observed in athletes who recently sustained an SRC and performed well (i.e., one standard deviation above the mean) on tests of memory. Although no known SRC studies have examined whether depression moderates the relationship between subjective and objective cognitive functioning, these results are consistent with existing literature on the role of depression in neurocognitive test performance and symptom reporting after SRC. Compared to their nondepressed counterparts, depressed athletes with a history of SRC tend to perform worse on tests of memory (Kontos et al., 2012; Riegler et al., 2020). Moreover, there is evidence that depression and post-concussion symptoms are related to one another (Yrondi et al., 2017). Furthermore, depression has been related to deficits in many neurocognitive domains, including memory and attention (Kriesche et al., 2023), and a study by Hromas and colleagues (2020) found that individuals with a history of mTBI who reported greater symptoms of depression and anxiety were more likely to have larger discrepancies between their objective and subjective cognitive functioning. Our results are similar to those of Hromas and colleagues, as, taken together with the main effects found for neurocognitive composite scores, our findings suggest that athletes with a history of SRC report their cognitive symptoms in a way that relatively matches their objective
performance. However, when an athlete is also experiencing depressive symptoms and performs poorly on tests of memory, their symptom reporting increases compared to their peers with lower levels of depression but similar performances on neurocognitive tests.

We also found that depression partially mediated the relationship between objective and subjective cognitive functioning for tests of memory. This suggests that poorer performance on tests of memory can lead to increased depressive symptoms, and increased depressive symptoms contribute to heightened cognitive post-concussion symptom reporting. A large and growing body of research suggests that cognitive dysfunction is an important depressive symptom and could be a critical treatment target (Knight & Baune, 2018; Kriesche et al., 2023). A systematic review by Kriesche and colleagues (2023) found a significant positive correlation between depression severity and objective cognitive dysfunction, although further studies are needed to understand the nature of causal relationships between depressive symptoms and cognitive functioning. It is important to note that depression partially mediated this relationship, which suggests that other factors play an important role in influencing the connection between objective and subjective cognitive functioning. It will be critical to identify these factors and how strongly they influence this relationship to further understand potential treatment targets when athletes exhibit poor performance on neurocognitive tests and report elevated depression and post-concussion symptoms after SRC.
Limitations and Future Directions

We found that depression plays an important role in the relationship between objective and subjective cognitive functioning after SRC, which echoes calls to integrate depressive symptoms and other mental health factors into SRC assessment and management (Patricios et al., 2023; Solomon et al., 2016). However, several study limitations warrant mention. First, our sample was restricted to NCAA Division I athletes in a concussion management program at an R01 university. Because these “elite” athletes had ample access to athletic trainers, neuropsychologists, team physicians, and other medical personnel who were highly trained in SRC evaluation and management, it is possible that our findings do not generalize to athletes with less access to SRC-related care, such as athletes playing at community college, high school, and middle school levels (Putukian et al., 2009). Generalizability is also a limitation regarding sample sociodemographic characteristics, as the majority of the sample identified as male and as non-Hispanic White. Lastly, this study was based on cross-sectional data, so any discussions of causality are limited.

To address these limitations, it will be important to replicate these results in samples of athletes from “non-elite” athletic settings and in samples of athletes that include greater gender and racial/ethnic diversity. Because we found that depression partially mediates the relationship between subjective and objective cognitive functioning, it would also be useful to examine how other factors that impact neurocognitive test performance, cognitive post-concussion symptom reporting, and recovery after SRC, such as gender, ADHD, sleep quality, acute neurological symptoms at the time of injury, time since injury, and total number of past SRCs (Asplund et al.,
Clinical Implications and Conclusion

Our findings on how depression is associated with the relationship between subjective and objective cognitive functioning have important implications for assessment and treatment after SRC, particularly for athletes who report high levels of depression and cognitive dysfunction and perform poorly on tests of memory. First, the main effects we found for the memory and attention/processing speed cognitive composite scores on post-concussion symptom reporting provide some evidence of congruence between objective and subjective cognitive functioning. This suggests that, in the absence of access to a comprehensive neuropsychological battery, self-reported cognitive functioning can provide useful information about an athlete’s cognitive functioning after SRC. Although further research is needed to determine if our findings generalize to athletes in “non-elite” settings, these findings are particularly relevant to athletes playing in these settings, as they tend to have less access to multimodal assessment and neuropsychological services (Putukian et al., 2009). We also found that athletes who are experiencing depressive symptoms and perform poorly on tests of memory report more subjective cognitive dysfunction than athletes who do not report high depressive symptoms but perform identically on tests of memory. These results, combined with our findings that greater cognitive dysfunction can lead to elevated depressive symptoms, which in turn can lead to higher cognitive post-concussion symptom reporting, suggest that: (1) athletes who report high levels of cognitive
dysfunction should be evaluated for depression and may need more comprehensive
cognitive evaluations to inform return-to-play decisions; and (2) depressive symptoms
could be a critical treatment targets for athletes with SRC who continue to report high
levels of cognitive dysfunction.

Understanding the role of depression on the relationship between objective and
subjective cognitive functioning underscores the importance of assessing depressive
symptoms in athletes who have sustained SRCs as well as the potential of depression as a
treatment target for athletes reporting elevated cognitive dysfunction. Further study is
necessary to validate our findings in athletes playing at the community college, high
school, and middle school levels, but our results suggest that there is congruence between
objective and subjective cognitive functioning in athletes with SRC and that the presence
of depression can affect symptom reporting, especially for athletes who perform poorly in
tests of memory. Our findings contribute to the growing body of evidence that depression
plays an important factor in outcome after SRC and emphasize the importance of
identifying risk factors for poor outcome after SRC to inform care that promotes athlete
safety and well-being at all levels of sport.
References


Physician and Sportsmedicine, 44(1), 14-19. doi: 10.1080/00913847.2016.1121091


