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Concussion Risk and Recovery in Athletes With Psychostimulant-Treated Attention-Deficit/Hyperactivity Disorder: Findings From the NCAA-DOD CARE Consortium

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The aim of the present study was to examine the effects of attention–deficit/hyperactivity disorder (ADHD) –related psychostimulant use in the context of concussion risk and symptom recovery. Data were obtained from the National Collegiate Athletic Association Department of Defense Grand Alliance Concussion Assessment, Research, and Education (NCAA-DOD CARE) Consortium from 2014 to 2017. Relative to individuals without diagnosed ADHD (i.e., control), both ADHD diagnosis and the combination of ADHD diagnosis and psychostimulant use were associated with a greater risk of incurring a concussive injury. Following a concussive injury, ADHD diagnosis was associated with longer symptom recovery time relative to the control group. However, individuals with ADHD who use psychostimulants did not take longer to resolve symptoms than controls, suggesting that psychostimulants may have a positive influence on recovery. Regardless of time point, ADHD diagnosis was associated with an elevated number of concussion-related symptoms; however, this effect appears mitigated by having used ADHD-related psychostimulants.

Keywords: SCAT symptoms, ADHD medication, sport-related injury, asymptomatic, return to play

Concussion is a crucial public health care concern in the United States as an estimated one in three people incur concussion during their lifetime (Daugherty et al., 2020), with the approximate incidence of concussion occurring in 700 of 100,000 persons per year (Lefevre-Dognin et al., 2021). The heterogeneous nature of these injuries makes them particularly difficult to manage, and as such, identifying risk factors that contribute to abnormal recovery is of paramount importance. Accordingly, over the last decade increasing efforts have been dedicated to identifying risk factors, at-risk populations, and potential modifiers that may influence injury recovery (Dougan et al., 2014; Harmon et al., 2019; Patricios et al., 2023). Athletes and military service academy cadets have been recognized as such at-risk populations as these individuals have a greater likelihood of sustaining a concussion and underreporting symptoms, which may prolong recovery and contribute to more serious injury (Bookbinder et al., 2020; Lininger et al., 2017; Sosin et al., 1996); however, it is important to acknowledge that these populations potentially reflect substantially different mechanisms of injury. Recent literature has acknowledged preinjury moderating factors including age (Dougan et al., 2014), biological sex (Merritt et al., 2019), prior concussion (Cook et al., 2022; Guskiewicz et al., 2003), and mental health (Yue et al., 2019) may further contribute to concussion risk and complicate recovery. Additionally, neurodevelopmental disorders, such as attention-deficit/hyperactivity disorder (ADHD), have been consistently identified within the literature as relevant factors for understanding both concussion risk and managing recovery (Guerriero et al., 2018; Iverson et al., 2017; Nelson et al., 2016). However, it is unclear the extent to which psychostimulant use may moderate such relationships.

ADHD is a neurodevelopmental disorder characterized by a persistent pattern of inattention, hyperactivity, and impulsivity which may increase the risk of injury (American Psychiatric Association, 2013). A growing body of research suggests that individuals with ADHD are more likely to sustain motor vehicle and bicycling accidents, falls, fractures, and head trauma compared to the general population (Chang et al., 2014; Ilie et al., 2015; Kieling et al., 2011; Philip et al., 2015). Furthermore, youth with ADHD exhibit a higher lifetime incidence of concussion and ADHD has shown to be an antecedent risk factor for concussion during adolescence (Biederman et al., 2015; Iaccarino et al., 2018; Iverson et al., 2014, 2020). While commonly recognized as a pediatric disorder, 65%–85% of children diagnosed with ADHD will meet diagnostic criteria into adulthood (Biederman et al., 2006; Mcgee et al., 1991; Penttilä et al., 2011). Further, the prevalence of ADHD is estimated to be as high as 10% in the collegiate athlete population (Alosco et al., 2014; Poysophon & Rao, 2018). Thus, while much of the ADHD literature has focused on outcomes in children, an increased risk of concussion may extend into adulthood for those with ADHD. Indeed, several studies have demonstrated that ADHD is overrepresented in concussed collegiate athletes, and these athletes may have a greater risk of sustaining concussion, regardless of prior injury (Alosco et al., 2014; Nelson et al., 2016).

An additional cause for concern is that ADHD may influence clinical outcomes following concussion. Individuals with ADHD have been shown to report greater concussion-related symptom severity and longer time to return to activity relative to their

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non-ADHD counterparts (Ali et al., 2021; Biederman et al., 2015; Houck et al., 2019; Iaccarino et al., 2018; Martin et al., 2022; Orban et al., 2021; Pullen et al., 2022); however, a recent systematic review observed no clear association between ADHD and clinical outcomes (Cook et al., 2020). One explanation for such findings is that ADHD may serve as a mediator between a greater lifetime history of concussion and poor clinical outcomes. Hence, ADHD has been shown to be a risk factor for sustaining multiple concussions, and a history of multiple concussions has been associated with an increase in concussion symptomatology (Cook et al., 2022; Guskiewicz et al., 2003; Nelson et al., 2016). Furthermore, clinicians may have difficulty distinguishing postconcussion deficits from a patient's baseline ADHD symptoms (Cook et al., 2020; Mautner et al., 2015). Yet much of the extant literature has overlooked the importance and wide use of psychostimulants in those with ADHD.

Over 50% of individuals with ADHD are prescribed a psychostimulant, usually in the form of, but not limited to, methylphenidate or an amphetamine salt (Wilens et al., 2004). Psychostimulants are an effective treatment for ADHD to improve executive functions (i.e., working memory, inhibition, and attentional focus; Faraone & Glatt, 2009; O'Driscoll et al., 2005; Tamminga et al., 2016). The improvements in attention, impulsivity, and risk-taking behaviors may explain why a reduced risk (hazard ratios = 0.49–0.93) of traumatic brain injuries (TBI) has been observed in youth with ADHD who use psychostimulants relative to those who do not, as they may be less likely to put themselves in potentially injurious situations (Ali et al., 2021; Liao et al., 2018; Liou et al., 2018; Mikolajczyk et al., 2015). Even so, contradicting evidence is present in the literature as adolescents with ADHD who were currently using psychostimulants exhibit greater odds of reporting a lifetime history of concussion (odds ratio [OR] = 1.67) than those who do not take ADHD-related medication (Iverson et al., 2020). The effects of psychostimulants are also reflected in baseline concussion assessments, whereby individuals with ADHD who use psychostimulants exhibit fewer baseline symptoms and greater neurocognitive performance compared to nonmedicated individuals with ADHD (Gardner et al., 2017; Littleton et al., 2015).

Yet, the effect of psychostimulant use on postconcussion symptoms or recovery time in those with ADHD is still inconclusive. Limited research has indicated ADHD medication status may not contribute to any change in time to return to school or return to sport for adolescents following concussion (Cook et al., 2021). However, it is important to note that such effects may be masked by policies and guidelines which require minimum return to play (RTP) periods for adolescent populations. Further, despite hypotheses suggesting that psychostimulants may alleviate concussion-induced symptoms, accelerate recovery, or reduce concussion risk (Coris et al., 2022; Iaccarino et al., 2020), the effects in those with ADHD, especially during adulthood, have not been thoroughly explored. Accordingly, the present investigation aimed to fill the current knowledge gap by evaluating if psychostimulant use in a large sample (n = 47,860) of collegiate athletes and military service academy cadets with ADHD may be associated with concussion risk and postconcussion symptomatology.

Methods

Participants

Data were obtained from the National Collegiate Athletic Association Department of Defense Grand Alliance (NCAA-DOD) Concussion Assessment, Research, and Education (CARE) Consortium from 2014 to 2017. The CARE Consortium database provided information for a total of 47,860 unique participants. Following the removal of individuals with a history of moderate-to-severe TBI, brain surgery, seizure disorders, non-ADHD-related psychostimulant use, or repeating a year of K–12 school, a sample of 45,375 participants remained. Individuals with ADHD were identified based upon self-reported ADHD diagnosis on the baseline clinical assessment. ADHD-related psychostimulant use was determined using the list of medications participants reported using. A string-matching approach identified psychostimulants commonly used for ADHD treatment using terms reflecting generic and brand name drugs and their common misspellings within the CARE Consortium database (Table 1). Participants were defined as "Controls" if they did not indicate ADHD diagnosis. Control participants with an Individualized Education

Table 1 Psychostimulant Identification

Psychostimulant	Common misspellings				
Adderall	Add	Addarell	Addderall	Adderal	Adderax
	Adderll	Adderol	Adderral	Adderrall	Addheral
	Aderrall	Adderhal	Addrell		
Concerta	Concena	Concertia	Concertu	Conserda	Conserta
Focalin	Focalan	Focilin			
Methylphenidate	Methalphenodate	Methalphymadate	Methlephenadate	Methlydate	Methlyphenidate
	Methylphenadate	Methylphenedate	Methylpenidate	Methylpheridate	Methylpzenidate
	Methyphenidate				
Ritalin	Riddilin	Riddled	Ridelin	Ritilan	Rittalin
Vyvanse	Vivance	Vyance	Vyanese	Vyanse	Vynase
	Vyranse	Vyvance	Vyvanes	Vyvanese	Vyvannse
	Vyvonse	Vyvvance			
Other	ADHD	ADHD medicine	ADHD meds	Amphetamine	

Note. The string-matching approach searched for psychostimulants commonly used for ADHD treatment using terms reflecting both generic and brand-name drugs and their common misspellings in the list of medications participants reported. The search process and results were manually validated and refined by C. Coffman and M. Pontifex to ensure that all psychostimulants commonly used for ADHD treatment present in the data set were identified. ADHD = attention-deficit/hyperactivity disorder.

Program (IEP) or a 504 plan were excluded from analyses to reduce the potential for individuals with cognitive/attentional symptomatologies consistent with/similar to ADHD to be included within the control group. Control participants were also excluded from analysis if they reported using any psychostimulants. Accordingly, preliminary analyses examining prospective concussion risk were completed on a sample of 44,308 participants (athletes: 43,426; cadets: 882); with 1,385 participants (3.1%) reporting having a diagnosis of ADHD with no ADHD-related psychostimulants' use, 947 participants (2.1%) reporting having a diagnosis of ADHD and having used ADHD-related psychostimulants, and 41,979 participants (94.7%) were classified as controls.

Primary analysis examining the impact of ADHD diagnosis and psychostimulant use on concussion recovery focused on only the remaining 4,387 participants (9.9%) who prospectively incurred a concussive injury during the study period. Concussion during study enrollment was identified and verified by medical personnel using evidence-based DOD criteria (Broglio et al., 2017). Following removal of participants missing >66% of data for the variables of interest and any participants who required >150 days to be determined asymptomatic (interquartile range > 5), analyses were conducted using data from 138 participants reporting a diagnosis of ADHD with no ADHD-related psychostimulants' use and 109 participants reporting a diagnosis of ADHD who used ADHD-related psychostimulants. Participants with ADHD who sustained a concussion during the study period were then matched in a 1:2 ratio to controls based upon sex and age; further, when possible, NCAA contact category (e.g., contact, limited contact, noncontact, and non-NCAA), NCAA division, sport, and/or if the injury occurred during the competitive season were also included as matching criteria. This process reduced the number of control athletes in the sample from 3,551 to 494. Demographic data are provided in Table 2. Written informed consent was obtained from each participant following site-specific and the Human Research Protection Office guidelines and regulations regarding the use of human subjects.

Procedure

The NCAA-DOD CARE Consortium was a multicenter, prospective study which enrolls collegiate athletes from NCAA Division I–III civilian schools and service academy cadets for preseason baseline and postconcussion testing. All participants completed a standardized battery including a comprehensive demographic and premorbid health history, postconcussion symptom surveys, and neuropsychological measures. For this investigation, postconcussion assessments used data from the following time points: 24–48 hr postinjury, time when the participant was determined to be asymptomatic, and time when the participant was classified into unrestricted RTP. Detailed NCAA-DOD CARE Consortium methodology has been described elsewhere (Broglio et al., 2017). Only data associated with the first concussion incurred by each participant were used for the purposes of this investigation.

Primary clinical recovery outcomes were defined as days to asymptomatic and full RTP. Concussion symptomatology was assessed using the Sport Concussion Assessment Tool (SCAT), third edition symptom inventory (McCrory et al., 2013). The SCAT symptom inventory is a subjective assessment of symptom severity on a 7-point Likert scale ranging from 0 (*none*) to 6 (*severe*) across 22 items. The total number of symptoms endorsed was calculated by summing all symptoms with a severity greater than 0 (maximum score of 22). The severity of symptoms endorsed was calculated by summing the severity for each of the 22 symptoms (maximum score of 132).

Statistical Analysis

All data analyses were performed in R (version 4.1; R Core Team, 2019) utilizing a familywise alpha level of $p = .05$. Preliminary analyses were conducted to examine the extent to which ADHD diagnosis and psychostimulant use might alter the risk of incurring a concussive injury. Test statistics and *OR*s were computed using Pearson's chi-squared test, conditional maximum likelihood estimation, and the false discovery rate control approach for post hoc comparison corrections using the gmodels (Warnes et al., 2018), epitools (Aragon, 2020), and Rmimic (Pontifex, 2020) packages in R. Given a sample size of 44,308 participants and beta of 0.20 (i.e., 80% power), the present research design theoretically had sufficient sensitivity to detect effect sizes exceeding $w = 0.015$ (effects are considered small if $w = 0.1$) as computed using G*Power (version 3.1.2; Faul et al., 2007).

Primary analysis examining the impact of ADHD diagnosis and psychostimulant use on concussion recovery utilized a

Table 2 Participant Demographics and Characteristics (*M* ± *SD*)

Measure	ADHD	ADHD + psychostimulant	Control
N	138 (40 female)	109 (49 female)	494 (179 female)
Age (years)	20.2 ± 1.3	20.4 ± 1.4	20.3 ± 1.3
Prior concussions	0.9 ± 1.0	0.9 ± 1.0	0.9 ± 0.9
NCAA category			
Contact	87 (63%)	79 (72.5%)	332 (67.2%)
Limited contact	13 (9.4%)	21 (19.3%)	68 (13.8%)
Noncontact	10 (7.2%)	7 (6.4%)	34 (6.9%)
Non-NCAA	28 (20.3%)	2 (1.8%)	60 (12.1%)
Division I	87%	87.2%	87.4%
Days to asymptomatic	11.9 ± 15.3	8.1 ± 7.0	9.6 ± 9.3
Days to return to play	17.8 ± 15.7	15.3 ± 10.3	18.8 ± 18.6
SCAT symptoms endorsed 24–48 hr postinjury	12.3 ± 5.8	12.1 ± 5.8	11.5 ± 5.6
SCAT symptom severity 24–48 hr postinjury	31.2 ± 23.3	29.4 ± 22.6	28.3 ± 21.4

Note. ADHD = attention-deficit/hyperactivity disorder; NCAA = National Collegiate Athletic Association; SCAT = Sport Concussion Assessment Tool.

two-part approach. First, analyses were conducted independently for the time to symptom resolution and time to unrestricted RTP using a three (Group: ADHD, ADHD + Psychostimulant, Control) univariate multilevel model including the random intercept for Site and Sex. Analyses were conducted using the lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), emmeans (Lenth et al., 2017), and Rmimic (Pontifex, 2020) packages. Second, analyses were conducted examining differences in the total number of symptoms endorsed and the severity of symptoms endorsed on the SCAT over time using a three (Group: ADHD, ADHD + Psychostimulant, Control) × 4 (Time: baseline, 24–48 hr postinjury, asymptomatic, RTP) univariate multilevel model including the random intercept for Site and Sex. For each inferential finding, the false discovery rate control approach was used for post hoc comparison correction, and Cohen's f^2 and d with 95% confidence intervals (CIs) were computed as standardized measures of effect size, using appropriate variance corrections for between-subject (d_s) and within-subject (d_{rm}) comparisons (Lakens, 2013). Given a sample size of 741 participants (138 ADHD, 109 ADHD + psychostimulant, 494 control) and beta of 0.20 (i.e., 80% power), the present research design theoretically had sufficient sensitivity to detect conventional t test differences exceeding $d = 0.36$ (with a two-sided alpha; effects are considered small if $d = 0.2$) as computed using G*Power (version 3.1.2; Faul et al., 2007).

Results

Risk of Concussion

Chi-square analyses revealed that Group was related to the likelihood of obtaining a concussive injury, χ^2 (2, 44,308) = 21.6, $p < .001$. ADHD diagnosis was associated with an increased likelihood of incurring a concussive injury during the study period, relative to the Control group, $OR = 1.21$, 95% CI [1.02, 1.43], $p = .027$ (see Figure 1A), Relative Risk = 1.20, 95% CI [1.02, 1.41], $p = .027$. Similarly, the combination of ADHD diagnosis and psychostimulant use was associated with an increased likelihood of incurring a concussive injury, relative to the Control group,

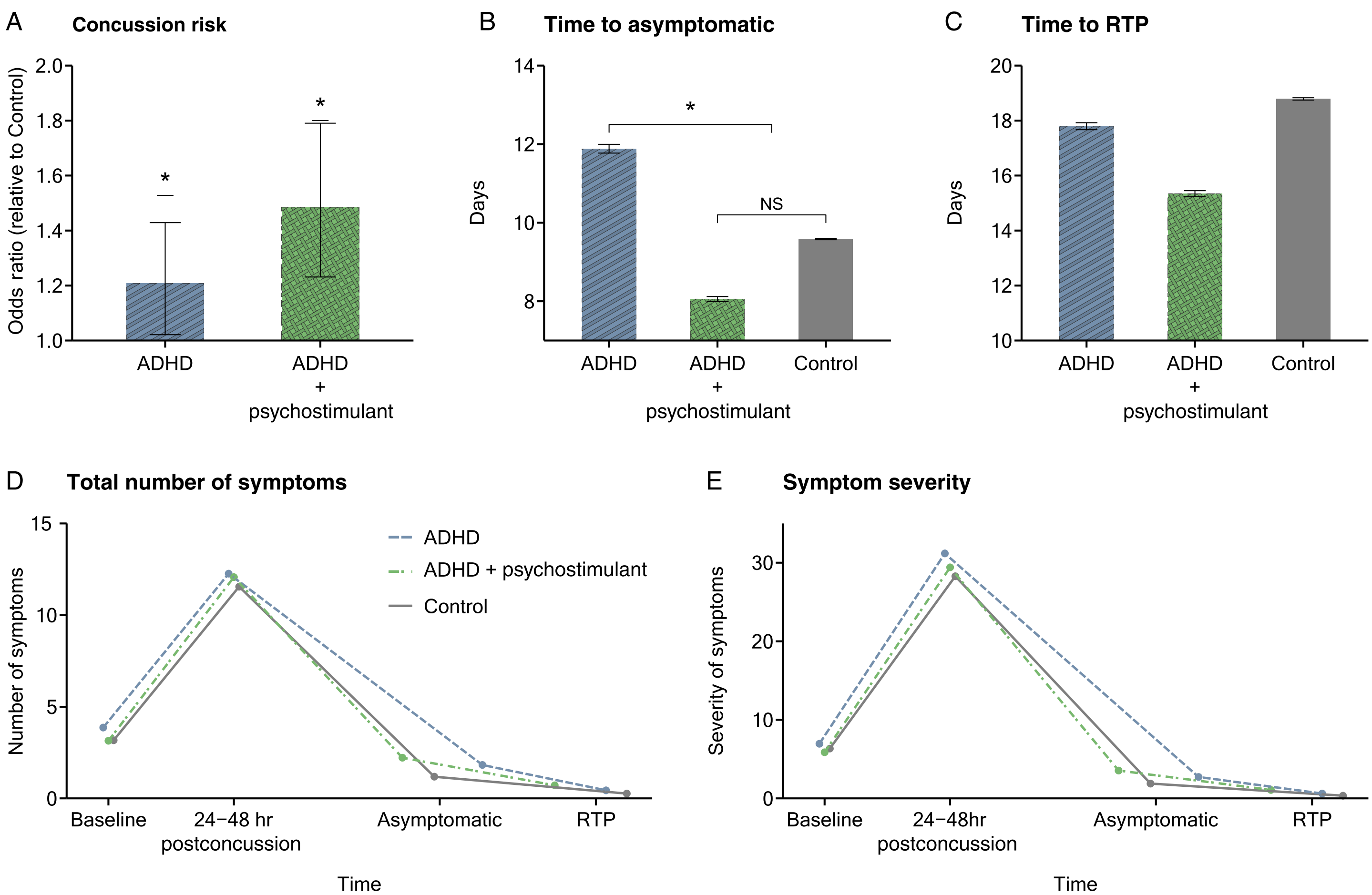

Figure 1 — Illustration showing differences (±1 *SE*) between individuals with a self-reported diagnosis of ADHD and the combination of ADHD and psychostimulant use relative to control participants. Panel A highlights the progressively greater risk of incurring a concussive injury for individuals with ADHD and the combination of ADHD diagnosis and psychostimulant use relative to control participants. Panel B highlights that while ADHD diagnosis is associated with a prolonged time to asymptomatic period, individuals with the combination of ADHD diagnosis and psychostimulant use have a shorter asymptomatic period that was not different from that of control participants. Panel C highlights that all three groups exhibited similar time until being returned to unrestricted activity. Panels D and E highlight the symptomatologic trajectory for each group over time. Note that for Panels D and E, a small offset was placed along the x-axis for Baseline and 24–48-hr-postconcussion measures to facilitate visual clarity. The asymptomatic and RTP time points were offset along the x-axis based on the mean number of days for each period for each group given differences illustrated in Panels B and C. RTP = return to play; ADHD = attention-deficit/hyperactivity disorder.

$OR = 1.48$, 95% CI [1.23, 1.79], $p < .001$ (see Figure 1A), Relative Risk = 1.47, 95% CI [1.23, 1.76], $p < .001$. Post hoc exploratory analysis revealed that the combination of ADHD diagnosis and psychostimulant use made no difference, relative to the ADHD diagnosis group, in the expected frequency of incurring a concussive injury, $OR = 1.23$, 95% CI [0.96, 1.57], $p = .1$, Relative Risk = 1.13, 95% CI [0.98, 1.29], $p = .1$.

Concussion Recovery

Days to Symptom Resolution

Analysis of the number of days to symptom resolution revealed a main effect of Group, $F(2, 732.9) = 4.3$, $p = .014$, $f^2 = 1.63$, 95% CI [1.36, 1.96]. Post hoc comparisons observed that having a diagnosis of ADHD was associated with a prolonged period until symptom resolution (11.9 ± 15.3 days) relative to Control participants (9.6 ± 9.3 days), $t(732) = 2.8$, $p = .005$, $d_s = 0.27$, 95% CI [0.08, 0.46]. However, individuals with a diagnosis of ADHD having used ADHD-related psychostimulants do not appear to show any difference in the days until symptom resolution (8.1 ± 7.0 days) relative to Control participants; $t(732) = 0.3$, $p = .8$, $d_s = 0.03$, 95% CI [–0.18, 0.24].

Days Until Being Cleared for Unrestricted RTP

Analysis of the number of days until being cleared for unrestricted RTP revealed no differences as a function of Group, $F(2, 659.9) = 0.7$, $p = .49$, $f^2 = 0.84$, 95% CI [0.67, 1.05].

Concussion Symptomatology

Total Number of Symptoms Endorsed

Analysis of the total number of symptoms endorsed revealed a main effect of Group, $F(2, 2{,}375.9) = 5.9$, $p = .003$, $f^2 = 0.02$, 95% CI [0.01, 0.03]. Post hoc decomposition of this effect revealed that having a diagnosis of ADHD was associated with an elevated number of symptoms endorsed (4.7 ± 6.2 symptoms) relative to Control participants (4.0 ± 5.9 symptoms), $t(2{,}386) = 3.2$, $p = .002$, $d_s = 0.30$, 95% CI [0.12, 0.49]. Similarly, the combination of ADHD diagnosis and psychostimulant use was associated with an elevated number of symptoms endorsed (4.4 ± 5.9 symptoms) relative to Control participants, $t(2{,}360) = 2.0$, $p = .048$, $d_s = 0.21$, 95% CI [0.01, 0.42]. However, that difference did not remain significant following false discovery rate control (Benjamini–Hochberg critical alpha = .044).

Analysis of the total number of symptoms endorsed also revealed a main effect of Time, $F(3, 2382.4) = 773.3$, $p < .001$, $f^2 = 2.97$, 95% CI [2.53, 3.53], but no Group × Time interaction, $F(6, 2{,}378.6) = 0.6$, $p = .69$, $f^2 < 0.01$, 95% CI [0.0, 0.02]. Post hoc decomposition of the main effect of Time revealed an elevated number of symptoms endorsed at baseline (3.3 ± 4.2 symptoms) relative to asymptomatic (1.5 ± 3.0 symptoms) and unrestricted RTP (0.4 ± 1.1 symptoms), $t(2{,}378) \geq 6.0$, $p < .001$, $d_{rm} \geq 0.38$, 95% CI [0.26, 0.82]. Similarly, an elevated number of symptoms were endorsed 24–48 hr postinjury (11.8 ± 5.6 symptoms) relative to baseline, asymptomatic, and unrestricted RTP, $t(2{,}377) \geq 30.9$, $p < .001$, $d_{rm} \geq 2.07$, 95% CI [1.93, 2.66]. Finally, an elevated number of symptoms were endorsed at asymptomatic relative to unrestricted RTP, $t(2{,}386) = 5.0$, $p < .001$, $d_{rm} = 0.22$, 95% CI [0.13, 0.30].

Symptom Severity

Analysis of symptom severity revealed a main effect of Time, $F(3, 2{,}385.4) = 476.3$, $p < .001$, $f^2 = 2.98$, 95% CI [2.54, 3.54], but no Group × Time interaction, $F(6, 2{,}380.7) = 0.5$, $p = .8$, $f^2 = 0.01$, 95% CI [0.0, 0.02]. Post hoc decomposition of the main effect of Time revealed greater symptom severity reported at baseline (6.4 ± 10.4) relative to asymptomatic (2.3 ± 6.2) and unrestricted RTP (0.5 ± 1.8), $t(2{,}381) \geq 4.1$, $p < .001$, $d_{rm} \geq 0.26$, 95% CI [0.14, 0.53]. Similarly, greater symptom severity was reported 24–48 hr postinjury (29.0 ± 21.9) relative to baseline, asymptomatic, and unrestricted RTP, $t(2{,}390) \geq 25.4$, $p < .001$, $d_{rm} \geq 1.61$, 95% CI [1.50, 2.02]. Finally, greater symptom severity was reported at the asymptomatic timepoint relative to unrestricted RTP, $t(2{,}389) = 2.5$, $p = .014$, $d_{rm} = 0.11$, 95% CI [0.02, 0.19].

Discussion

The purpose of the present study was to investigate how ADHD and ADHD-related psychostimulant use may be associated with prospective concussion risk as well as postconcussion symptom recovery in NCAA athletes and service academy cadets with ADHD. Consonant with other studies (Alosco et al., 2014; Poysophon & Rao, 2018; Putukian et al., 2011), approximately 5.3% of the current sample reported being previously diagnosed with ADHD, and 40.6% of those also reported using ADHD-related psychostimulants. ADHD was observed to be a small risk factor for sustaining future concussion within this population, regardless of psychostimulant use. No differences were observed between groups for the number of days until being cleared for unrestricted RTP. However, those who had ADHD and did not take psychostimulants required longer symptom recovery times compared to those who did take psychostimulants and those without ADHD. We also observed that individuals with ADHD reported more symptoms on the SCAT across all time points, including baseline, but this effect did not remain significant following false discovery rate control for those who had ADHD and take psychostimulants.

Although limited studies have examined the extent to which ADHD may be a risk factor for sustaining concussive injury in NCAA athletes, the current findings are in line with previous evidence indicating collegiate athletes with ADHD are more likely to have a history of multiple concussions compared to those without ADHD (Nelson et al., 2016). Additionally, given the prospective element of the present investigation, our findings suggest that ADHD is associated with greater antecedent risk for concussion (Biederman et al., 2015; Iaccarino et al., 2018). Interestingly, the observed magnitude of concussion risk for those with ADHD ($OR = 1.21$–1.48) was smaller than that which has been observed within investigations assessing concussion risk for youth with ADHD ($OR = 1.69$–1.71; Iverson et al., 2014, 2020). Speculatively, it may be that the likelihood of sustaining concussion associated with ADHD results from the underlying symptomatology; thus, as hyperactivity and impulsiveness behaviors associated with ADHD tend to diminish in severity as individuals age into adulthood, the risk of concussion diminishes as well (Wilens et al., 2009). However, as the present investigation was restricted to an adult population and did not specifically investigate ADHD-related symptomatology, clearly further research in this area is necessary to determine whether such speculation has merit, whether the observed differences in risk are simply manifestations of other differences between adults and children with ADHD and the samples used within the present literature, or whether the smaller risk is a result of the contrast against collegiate athletes/service academy cadets who themselves may have elevated risk. Nevertheless, such evidence highlights that those with a history of ADHD may be slightly more susceptible to incurring head trauma, especially within high-risk settings such as athletics or service academy/military training.

Of particular interest to the present investigation was the extent to which ADHD-related concussion risk might be altered with psychostimulant use. Contrary to prior findings in youth populations that observed reduced risk of concussion for those children with ADHD who are on psychostimulants (Liao et al., 2018; Liou et al., 2018), the present investigation observed that individuals with ADHD who reported taking psychostimulants had marginally higher odds of sustaining concussion than those who did not report taking psychostimulants ($OR = 1.48$ vs. $OR = 1.23$, 95% CI [0.96, 1.57]); however, this comparison was not statistically significant. One possible explanation for such divergent findings may be the breadth of TBI severity within the former studies and differences in sample characteristics. More specifically, our sample and other congruent findings focus on athletic populations (Iverson et al., 2020), whereas incongruent findings have utilized the general youth populations (Liao et al., 2018; Liou et al., 2018). Thus, despite helping with cognitive deficits in academic and vocational settings, psychostimulants may not be sufficient to prevent injury during more demanding psychomotor environments inherent to collegiate athletic competition and service academy/military training. Importantly, ongoing use of psychostimulants into adulthood could signify more severe ADHD symptomatology, which may also contribute toward the enhanced risk of concussion. Speculatively, a complex interrelationship may exist between psychostimulant use, athletic participation, and concussion risk—independent of ADHD status. While psychostimulant use may indeed reduce concussion risk associated with ADHD, it may also independently increase concussion risk by enabling athletes to continue to push through fatigue- and heat-related stress, increasing potential participation durations thereby increasing one's risk of concussion (Alosco et al., 2014; Berezanskaya et al., 2022). Future research in this area may benefit by considering alterations in concussion risk as it relates to other forms of stimulants and stimulant dose to provide greater clarity surrounding these issues. Nevertheless, these findings highlight that those with ADHD may be more susceptible to injury even when medicated with a psychostimulant.

Importantly, the present investigation provides novel findings into the association between ADHD-related psychostimulants and concussion recovery. Consonant with prior research suggesting that concussion symptoms are related to preexisting ADHD diagnosis/symptomatology (Bullard et al., 2022; Elbin et al., 2013; Houck et al., 2019; Kaye et al., 2019; Nelson et al., 2016), individuals with ADHD took on average 2–3 days longer to be determined asymptomatic compared to Controls. Yet individuals with ADHD who reported taking psychostimulants were determined to be asymptomatic at the same time as Controls despite having reported a marginally elevated number of symptoms at baseline and postconcussion time points compared to Controls. Given that greater concussion symptom severity at baseline and postconcussion time points was only observed for those with ADHD not using psychostimulants, it may be that psychostimulant use provides a therapeutic benefit to mitigate concussion-related symptom severity or that some aspects of concussion symptomatology are masked by the effects of the psychostimulant. Indeed, a prior CARE investigation, which created multivariable hazards models for recovery trajectory, found that when ADHD medication use was factored in as a covariate, it was associated with a small but significant decrease in total RTP duration (Broglio et al., 2022).

While neither ADHD group exhibited extended time to unrestricted RTP, it is important to highlight that concussion-related symptomatology was marginally elevated for individuals with ADHD across all time points—including baseline and RTP. Such findings replicate prior research which has observed elevated concussion-related symptomatology associated with ADHD even at baseline preseason assessments in children (Collings et al., 2017; Moran et al., 2021), adolescents (Biederman et al., 2015; Elbin et al., 2013; Iaccarino et al., 2018) and young adults (Biederman et al., 2015; Elbin et al., 2013; Houck et al., 2019; Iaccarino et al., 2018), as well as replicate the observation that the presence of ADHD appears unrelated to differences in RTP decisions (Cook et al., 2020). Speculatively, the current findings may be a result of the overlapping symptomatology, particularly items related to executive dysfunction (i.e., difficulty concentrating and difficulty remembering things) which are altered in both ADHD and post-concussion samples (Mautner et al., 2015). Although the design of the present investigation cannot rule out such potential, caution in such speculation is warranted given the findings by Bullard et al. (2022) who observed that while ADHD and concussion symptomatology in adolescents are related, they remain functionally distinct—such that concussion-related symptomatology—and their shared variance is not mediated by underlying executive dysfunction. Critically, an important factor highlighted by Bullard et al. that is not able to be considered within the present investigation is that prior ADHD symptomatology rather than diagnosis may be more relevant for postinjury symptomatology. Such findings are an important consideration and reinforce the need for additional research into the complex interplay between the ADHD continuum, concussive injuries, and recovery thereafter.

Despite the strengths of the present investigation, the nature of the NCAA-DOD CARE Consortium data set relies upon self-reported ADHD diagnoses and psychostimulant use. Therefore, it is unknown whether those who reported ADHD met diagnostic criteria, if any individuals declined to report prior diagnoses or the extent to which individuals with ADHD with or without psychostimulants may have differential symptom presentations. However, ADHD rates were consistent with previous studies within this population (Kessler et al., 2006). ADHD diagnosis status and psychostimulant use were only reported during the baseline assessment; therefore, we were unable to verify whether Control group individuals may have been diagnosed with ADHD following baseline assessment or whether psychostimulant use was discontinued postinjury. Additionally, we could not account for when ADHD was diagnosed, psychostimulant dosages, or the duration of current psychostimulant use in analyses as it was unavailable within the data. Prior investigations have demonstrated that TBI risk may differ according to methylphenidate dosage in children (Liao et al., 2018); thus, it is recommended that future directions focus on whether risk or recovery may fluctuate due to psychostimulant dosage. Furthermore, we relied upon subjective symptom inventories for assessing concussion recovery. While the SCAT is a widely used and reliable measure of symptom severity, it—like all subjective assessments—is prone to response bias, and athletes may be incentivized to underreport symptoms in order to accelerate return to normal activities (Conway et al., 2020). Further, although the SCAT has remained relatively consistent across versions, it is important to note that it is now on its sixth iteration reflecting changes in injury identification and diagnostic criteria (Echemendia et al., 2023). Current guidelines recommend practitioners utilize a multidimensional and objective approach when managing concussion (Patricios et al., 2023), and future investigations should incorporate this approach to gain a greater understanding of the relationship between ADHD-related psychostimulants and concussion recovery. Similarly, although allowing the local medical teams to make asymptomatic and RTP decisions within each site adds to the external validity of the study, this approach also introduces variance into these two time points. Future work may elect to develop strict asymptomatic and RTP criteria and/or provide the study personnel to make these decisions.

Irrespective, the present investigation provides valuable information regarding the influence of ADHD and psychostimulant use on both concussion risk and symptom presentation following concussion. Fortunately, ascertaining ADHD diagnoses and symptomatology, as well as medication status, is feasible and can provide clinicians, coaches, and commanders with critical insights. Hopefully, the current study underscores this point, and ADHD symptom assessments will become routine for baseline and post-injury evaluations. It is the hope that this study will also encourage further research in this area to better understand the extent to which psychostimulant use following a concussive injury may provide therapeutic benefits for recovery or simply mask symptom severity. Future prevention research is also necessary to direct efforts toward identifying the underlying mechanisms for why those with ADHD may be at greater risk for concussion.

Highlights

- Prospective assessment of concussion recovery of 741 college-age adults.
- Attention-deficit/hyperactivity disorder was associated with 1.2 times greater risk of a concussion.
- Attention-deficit/hyperactivity disorder + psychostimulant use was associated with 1.5 times greater risk of a concussion.
- Attention-deficit/hyperactivity disorder was associated with a prolonged period from injury to being determined to be asymptomatic.
- Postconcussive symptoms appear mitigated by psychostimulant use.

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