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Increased anxiety and depression among collegiate athletes with comorbid ADHD and history of concussion

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ABSTRACT

Background: Attention Deficit Hyperactivity Disorder (ADHD) is prevalent among student-athletes when compared to the general population. Mental health disruptions (i.e., depression or anxiety) are common among student-athletes, and risk of experiencing depressive and anxious symptoms may be even greater among student-athletes that have incurred concussion.
Objective: To examine the influence of pre-existing ADHD and history of concussion on mental health in collegiate student-athletes.
Design: Retrospective cross-sectional study.
Setting: National Collegiate Athletic Association Division-I (NCAA) athletics.
Patients: Between 2010 and 2017, student-athletes at a Southeastern NCAA Division-I institution were surveyed as part of a Performance, Health, and Wellness Program. Analyses were conducted using a sample of 324 student athletes (212 female) with either a prior diagnosis of ADHD, a prior history of a sport-related concussion, both prior diagnosis of ADHD and a history of sport-related concussion, or neither (controls).
Main outcome measure(s): Symptomatology associated with ADHD was characterized using the Behavior Assessment System for Children Self-Report of Personality College Version. The State-Trait Anxiety Inventory and the Center of Epidemiological Studies-Depression Scale examined anxious and depressive symptomatology.
Results: Student-athletes with ADHD and a history of concussion had 16.4 times greater odds of exhibiting clinically significant symptoms of state anxiety and 7.9 times greater odds of exhibiting clinically significant symptoms of depression, relative to control student-athletes. Every participant with both a diagnosis of ADHD and a history of concussion exhibited clinically significant attentional problems.
Conclusions: Having both ADHD and a history of concussion may have a synergistic effect on mental health beyond that of ADHD and/or concussion alone. Additional longitudinal research is necessary to verify current findings. However, athletic trainers and other health care professionals are encouraged to be mindful of student-athletes with ADHD, as they may be more vulnerable to experiencing symptoms of depression and state anxiety with elevated inattentive behaviors following a concussion.

Increased media attention associated with high-profile athletes reporting mental health concerns has elevated psychological well-being to a salient issue in sports medicine [1]. Beyond the broader stressors imposed upon athletes that might contribute to the developmental of mental health issues [2], a growing body of evidence has suggested concussive injuries may be a risk factor for subsequent mental health problems such as depression and anxiety [3,4]. However, the evidence regarding mental health in collegiate student-athletes is limited, and a substantial gap exists in our current understanding of how neuro-developmental disorders such as attention deficit hyperactivity disorder (ADHD) might interact with a history of concussion to influence mental health. This knowledge gap is particularly important given that ADHD

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has been shown to increase risk of depression and anxiety [5] and may complicate recovery from concussive brain injury [6].

Although traditionally thought of as only an acute perturbation of normal functioning, a growing body of evidence has begun to highlight the long-term effects of a concussion. Individuals with a history of concussion may exhibit persistent impairments across important aspects of neurocognitive functioning [7,8], poorer emotional and behavioral regulation [9] and greater endorsement of affective symptomatology [4]. As such, the most recent Consensus Statement on Concussion in Sport highlights the importance of understanding aspects of concussion recovery across a broad array of neurobehavioral outcomes [10].

Epidemiological estimates indicate that clinical depression manifests in approximately 6% of individuals following a concussive injury [11]; however, changes in affective symptomatology which are of insufficient magnitude to cross diagnostic thresholds appear to be a more common phenomenon [10]. Specifically, studies have observed elevated levels of depression in both high school and collegiate student-athletes in both acute (<1 week) and post-acute (2–3 weeks) phases of recovery [12,13]. Additionally, recent systematic reviews have highlighted the relationship between concussive injuries and later-life depression in terms of symptom severity and clinical diagnoses [9]. In contrast to the consistent finding that a history of concussion predisposes athletes towards an elevated risk of depression symptomatology, less is known regarding how concussive injuries may impact other mental health outcomes, such as anxiety [4]. Inconsistencies within the literature may be attributable to failing to differentiate between state and trait anxiety, in addition to failing to account for potential injury related anxiety [14].

Although the prevalence of neurodevelopmental disorders within collegiate and professional athletes appears consistent with that of the general population — presenting in 7-to-8% of athletes [15], athletes with ADHD appear to exhibit greater risk of incurring concussive injuries while also exhibiting more severe symptoms following such injuries [16,17]. ADHD is itself a risk factor for declines in mental health. Recent longitudinal studies have observed that children with ADHD have a 1.35 times greater risk of developing depression as adults [18], whereas adults with ADHD are 2.7 and 3.7 more likely to have comorbid depression and anxiety, respectively [5]. Thus, gaining a better understanding of how the presence of ADHD might influence concussion outcomes is critical for guiding clinical decision making and developing population specific return-to-activity protocols.

The primary purpose of the present investigation and explore the extent to which ADHD might interact with a history of concussion to influence mental health. Specifically, we sought to characterize the extent to which symptom ratings of ADHD, state and trait level anxiety, as well as depression might differ as a function of ADHD, history of concussion, and the combination of both ADHD and history of concussion. Further, beyond analysis of scale level data, we also considered how symptomatology at or beyond clinical levels may differ between groups. In doing so, this investigation sought to provide key insight into the synergistic influence of ADHD and concussion on psychological health.

1. Methods

1.1. Participants

Analyses were conducted using a sample of 324 student-athletes (mean age: 19.6 ± 1.2 years [17.0–23.0], 212 female) who were a part of a Performance, Health, and Wellness Program at a southeastern NCAA Division-I athletic institution between 2010 and 2017. The program was designed to advance the clinical care and well-being of student athletes by screening key health behaviors that may influence sport and academic performance. Following Institutional Review Board approval to conduct research, student athletes were informed of the clinical research activities at preseason team meetings. Athletes who agreed to participate completed informed consent prior to enrollment and then completed measures of attention/hyperactivity behaviors, anxiety, and depression via online surveys. During each sport's pre-season meeting, athletes were provided log in credentials for the online survey portal (REDCap) to complete the online surveys. All methods were carried out in accordance with approved Institutional Review Board protocols and relevant guidelines/regulations regarding the use of human subjects.

From the pool of 1042 student athletes who participated in this program, a retrospective cross-sectional design was utilized to identify subsamples of individuals with ADHD and/or sport-related concussions. Self-reported ADHD diagnoses were verified via review of athlete medical records (i.e., confirmed diagnosis by MD or clinical psychologist) to ensure diagnosis occurred prior to annual team pre-performance examinations. Individuals with an unconfirmed diagnosis of ADHD were excluded from this investigation. All concussive injuries were incurred during university sport participation and prior to survey responses. Athletes reporting a history of non-sport-related brain injury were excluded from this investigation. Sport related concussions were diagnosed by team physicians within 72 h using guidelines established by the Consensus Statement on Concussion in Sport [10]. Thus, all sport related concussions included in this investigation were evaluated by the same medical staff using the same criteria.

Participants were then grouped based upon the prescence/absence of ADHD and/or a history of concussion. Specifically, participants were grouped into those having a prior diagnosis of ADHD, but no history of concussion (n = 46); those with a history of concussion, but no prior attentional problems or diagnosis of ADHD (n = 41); and those identified as having both a history of concussion and diagnosis of ADHD (n = 21). Participants in these three groups were then double matched with control participants — whom had no prior attentional problems or diagnosis of ADHD, or history of a concussive injury (sport related or otherwise) — based upon age, biological sex, and body mass index (BMI) for a sample of 216 control participants. In cases where an exact match was not available, matching was carried out to maintain similar distributions of control variables within each group. Additionally, participants with both ADHD and a history of sport related concussion were matched with participants with only a history of sports related concussion for time since injury. Participants were drawn from eleven NCAA Division-I sport teams, including baseball, basketball, cheerleading, equestrian, football, golf, soccer, swimming, tennis, track and field, and volleyball. Demographic data is provided in Table 1.

1.2. Measures

ADHD Symptomatology: Attention problems and hyperactivity subscales from the Assessment System for Children (Second Edition), Self-Report of Personality College Version (SRP-CV) [19] were used to evaluate athletes' self-reported levels of ADHD related symptomatology. The SRP-CV has 185 items categorized into 20 subscales. The first 68 items are true-false questions, and the remaining 117 questions require the participant to respond on a four-point Likert scale regarding frequency (i.e., 0 = Never, 1 = Sometimes, 2 = Often, and 3 = Almost always. T-scores between 60 and 69 are considered at-risk for characteristics that may lead to functional problems, and scores of 70 or greater being considered clinically significant. The SRP-CV of the BASC-2 has been used in various collegiate settings as a multidimensional measure of behavior and personality and demonstrates strong reliability (ICC = 0.71–0.96) in identifying symptoms of ADHD among athlete and non-athlete samples [20].

Anxiety Symptomatology: The State-Trait Anxiety Inventory (STAI) was used to characterize athletes' levels of anxiety. The STAI State Anxiety scale utilizes 20 questions to assess current emotional status relative to situational stress, and the Trait Anxiety scale utilizes 20 questions to assess general predisposition for anxiety. All items are rated on a four-point frequency scale (i.e., 1 = Not at all or Almost never, 2 = Somewhat or Sometimes, 3 = Moderately so or Often, and 4 = Very much so or Almost always). Participants were considered "At Risk" for

Table 1
Participant demographics.

	Control	ADHD	Concussion	ADHD + Concussion
N	216	46	41	21
% Female	63.4%	63%	75.6%	71.4%
Age (Years)	19.5 ± 1.3	19.8 ± 1.0	19.7 ± 1.2	19.7 ± 1.2
Years of Education	14.3 ± 1.2	14.7 ± 1.2	14.5 ± 1.1	14.9 ± 1.1
BMI kg/m^2	23.3 ± 3.2	24.6 ± 3.8	23.4 ± 3.0	24.4 ± 4.3
Current psychostimulant use	0 (0.0%)	31 (67.4%)	0 (0.0%)	13 (61.9%)
Time since Injury (months)	0 ± 0	0 ± 0	8.5 ± 7.9	9.9 ± 8.0
Attentional Problems (t-score)	58.4 ± 5.3	69.2 ± 7.4	58.6 ± 5.5	69.3 ± 8.2
Hyperactivity (t-score)	57.9 ± 5.5	67.3 ± 13.8	56.1 ± 3.6	64.9 ± 17.4
State Anxiety	30.4 ± 7.1	33.9 ± 9.5	33.8 ± 9.9	39.1 ± 8.3
Trait Anxiety	33.0 ± 7.8	35.1 ± 9.6	34.1 ± 9.0	34.4 ± 9.7
Depression	15.1 ± 4.8	16.0 ± 6.4	16.4 ± 5.6	29.4 ± 15.9
Sport Participation n (%)				
Baseball	16 (7.4%)	5 (10.9%)	2 (4.9%)	0 (0.0%)
Basketball	3 (1.4%)	0 (0.0%)	1 (2.4%)	0 (0.0%)
Cheerleading	11 (5.1%)	7 (15.2%)	5 (12.2%)	2 (9.5%)
Equestrian	19 (8.8%)	1 (2.2%)	5 (12.2%)	1 (4.8%)
Golf	4 (1.9%)	0 (0.0%)	0 (0.0%)	1 (4.8%)
Soccer	28 (13.0%)	4 (8.7%)	5 (12.2%)	7 (33.3%)
Softball	9 (4.2%)	3 (6.5%)	6 (14.6%)	1 (4.8%)
Swimming & Diving	33 (15.3%)	5 (10.9%)	6 (14.6%)	0 (0.0%)
Tennis	5 (2.3%)	1 (2.2%)	2 (4.9%)	0 (0.0%)
Track & Field/Cross Country	39 (18.1%)	5 (10.9%)	4 (9.8%)	1 (4.8%)
Volleyball	11 (5.1%)	1 (2.2%)	2 (4.9%)	2 (9.5%)
Football	38 (17.6%)	14 (30.4%)	3 (7.3%)	6 (28.6%)

state anxiety if they scored higher than a 45 for males and 47 for females. Participants were considered "At Risk" for trait anxiety if they scored higher than 46 for males and 50 for females [21]. The STAI has been used in a variety of higher education settings, across both athlete and non-athlete populations, and demonstrates strong reliability (ICC = 0.86–0.95) in identifying symptoms of anxiety [22].

Depression Symptomatology: The Center for Epidemiological Studies-Depression Scale (CES-D) [23] was used to characterize athletes' current levels of symptomatology associated with depression. The CES-D was designed to assess depressive symptom burden in the general population and is comprised of 20 questions reflecting the frequency of depression symptoms "during the past week". All items are rated on a four-point frequency scale (i.e., 0 = Rarely or none of the time: less than 1 day, 1 = Some or a little of the time: 1–2 days, 2 = Occasionally or a moderate amount of time: 3–4 days, 3 = All of the time: 5–7 days). The possible range of scores is 0–60 with scores of 16 or greater considered at-risk for clinical depression. The CES-D has been widely utilized in collegiate settings, across both athlete and non-athlete populations, and demonstrates strong reliability (ICC = 0.82–0.93) in identifying symptoms of depression [24].

1.3. Statistical analysis

All data analyses were performed in R Version 4.0 utilizing a familywise alpha level of $p = 0.05$. To examine the potential additive and interactive effects of prior diagnosis of ADHD and a history of sport-related concussion, 2 (ADHD: absent vs present) × 2 (Concussion: absent vs present) univariate ANOVAs were conducted separately using the ez and Rmimic packages for ADHD symptomatology, Anxiety symptomatology (both State and Trait), and Depression symptomatology. Analysis utilized the Greenhouse-Geisser sphericity correction and False Discovery Rate Control for multiple-comparison correction on post-hoc tests. To examine the extent to which prior diagnosis of ADHD and a history of sport-related concussion might predispose student-athletes to greater risk of clinically significant symptoms of ADHD, Anxiety, and Depression; Chi-Square analysis were conducted using the gmodels, epitools, and Rmimic packages. Test statistics and odds ratios were computed using Fisher's Exact test and conditional maximum likelihood estimation using the False Discovery Rate Control approach for post-hoc comparison corrections. Given a beta of 0.20 (i.e., 80% power), the present research design theoretically had sufficient sensitivity to detect differences between groups exceeding d = 0.27 (with a two-sided alpha) and differences in the likelihood between groups exceeding w = 0.32 as computed using G*Power 3.1.2. See Fig. 1 for graphical illustration of the resultant findings.

2. Results

2.1. ADHD attentional problem symptomatology

Scale Analysis: ANOVA analysis observed only a main effect of ADHD such that individuals with a prior diagnosis of ADHD exhibited greater attentional problems (69.2 ± 7.6) than individuals without ADHD (58.4 ± 5.3), $F_{(1, 320)} = 127.5$, $p < 0.001$, $d_s = 1.5$ [95% CI: 1.1 to 1.9]. Neither the main effect of Concussion nor the interaction of ADHD × Concussion were statistically significant, F's$_{(1, 320)} < 0.1$, p's > 0.9, f^2's < 0.01 [95% CI: 0.0 to 0.0].

Risk Analysis: Chi-Square analyses indicated that the likelihood of clinically significant attentional problems was observed to relate to group membership; 43.1% of controls (n = 93), 89.1% of ADHD (n = 41), 41.5% of concussion (n = 17), and 100% of ADHD + Concussion (n = 21), $X^2_{(3, 324)} = 53.5$, $p < 0.001$. Post-hoc comparisons were conducted by examining the expected frequency of clinically significant attentional problems for each group relative to controls. Prior diagnosis of ADHD was associated with 10.7 [95% CI: 4.0 to 36.3] times greater odds of clinically significant attentional problems, $p < 0.001$. Prior history of a sport-related concussion made no difference in the expected frequency of clinically significant attentional problems, Odds Ratio = 0.9 [95% CI: 0.4 to 1.9], $p > 0.99$. Finally, every participant with both a diagnosis of ADHD and a history of concussion in the current investigation exhibited clinically significant attentional problems, Odds Ratio = Inf [95% CI: 6.6 to Inf], $p < 0.001$.

2.2. ADHD hyperactive symptomatology

Scale analysis: ANOVA analysis observed only a main effect of ADHD such that individuals with a prior diagnosis of ADHD exhibited greater hyperactive symptomatology (66.6 ± 14.9) than individuals without ADHD (57.6 ± 5.3), F(1, 320) = 50.4, $p < 0.001$, $d_s = 0.7$ [95% CI: 0.4–1.0]. Neither the main effect of concussion nor the interaction of ADHD × Concussion were statistically significant. F's$_{(1,320)} \leq 1.5$, p's ≥ 0.2 f^2's ≤ 0.01 [95% CI 0.0 to 0.02.

Risk Analysis: Chi-Square analyses indicated that the likelihood of clinically significant hyperactive symptomatology was observed to relate to group membership; 50.5% of controls (n = 109), 82.6% of ADHD (n = 38), 0% of concussion (n = 0), and 61.9% of ADHD + concussion (n = 13), $X^2_{(3, 324)} = 61.7$, $p < 0.001$. Post-hoc comparisons were conducted by examining the expected frequency of clinically significant hyperactive symptomatology for each group relative to controls. Prior diagnosis of ADHD was associated with an increased likelihood in

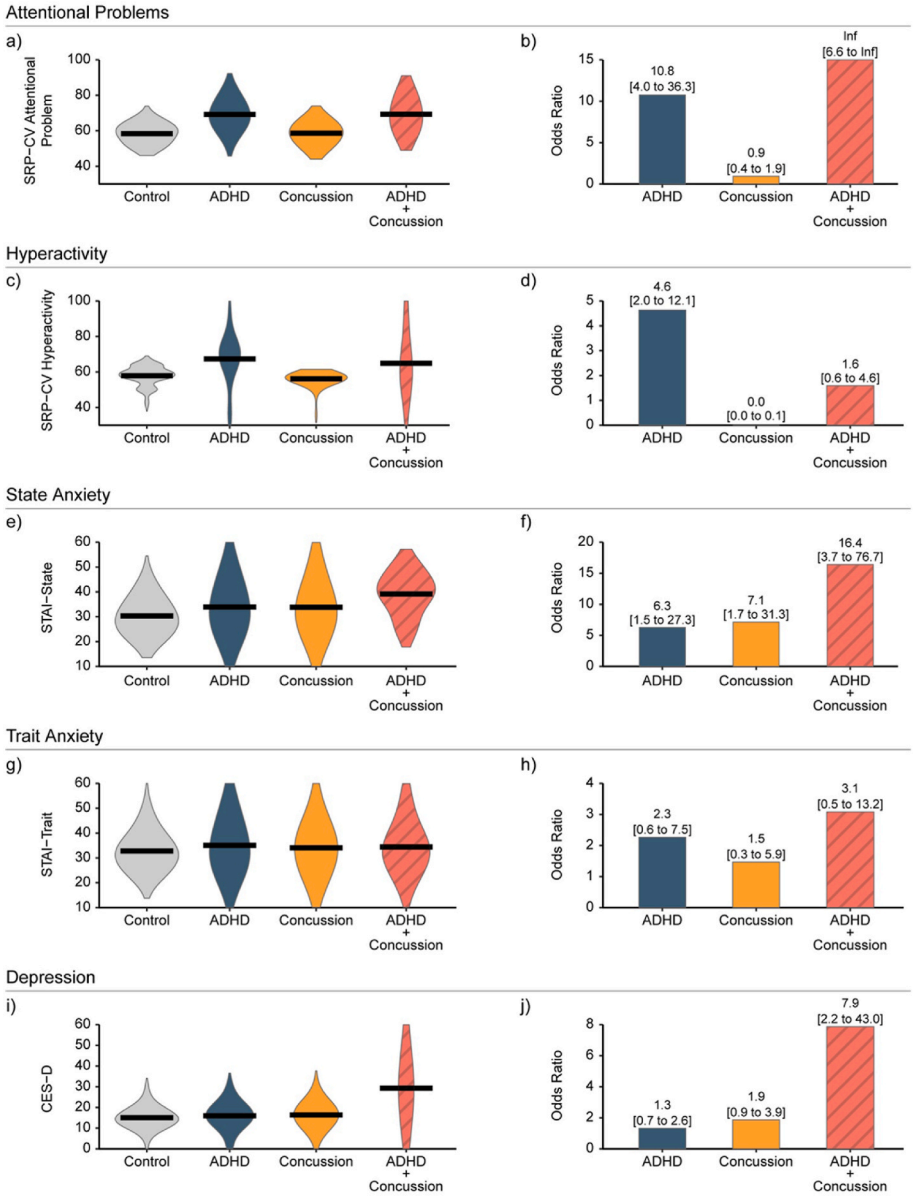

Fig. 1. Violin plots (left) illustrating the distributions of symptomatology associated with ADHD, Anxiety, and Depression for each group. The black bars indicate the group mean for each scale. Bar graphs (right) illustrating the likelihood (using odds ratios with 95% confidence intervals) of exhibiting clinically significant symptomatology associated with ADHD, Anxiety, and Depression for each group, relative to the control group.

the expected frequency of clinically significant hyperactive symptomatology, Odds Ratio = 4.6 [95% CI: 2.0 to 12.1], $p < 0.001$. As no participants with a history of a sport-related concussion exhibited clinically significant hyperactive symptomatology, there appears to be a reduction in its likelihood, Odds Ratio = 0.0 [95% CI: 0.0 to 0.1], $p < 0.001$. Prior diagnosis of ADHD appears to be offset by a history of sport-related concussion such that there was no difference in the expected frequency of clinically significant hyperactive symptomatology for individuals with both, Odds Ratio = 1.6 [95% CI: 0.6 to 4.6], $p = 0.37$.

2.3. State Anxiety Symptomatology

Scale Analysis: ANOVA analysis revealed a main effect of ADHD such that individuals with a prior diagnosis of ADHD exhibited greater State Anxiety (35.5 ± 9.4) than individuals without ADHD (30.9 ± 7.7), $F_{(1, 319)} = 7.5$, $p = 0.006$, $d_s = 0.5$ [95% CI: 0.2 to 0.8]; as well as a main effect of concussion such that individuals with a prior history of sport-related concussion exhibited greater State Anxiety (35.6 ± 9.7) than individuals without history of sport-related concussion (31.0 ± 7.6), F (1, 319) = 6.5, $p = 0.011$, $d_s = 0.49$ [95% CI: 0.20 to 0.78]. There was no interaction of ADHD × Concussion, F(1, 319) = 0.5, $p = 0.47$, f [2] < 0.01 [95% CI: 0.0 to 0.01].

Risk Analysis: Chi-Square analyses indicated that the likelihood of clinically significant State Anxiety was observed to relate to group membership; 2.3% of controls (n = 5), 13.0% of ADHD (n = 6), 14.6% of concussion (n = 6), and 28.6% of ADHD + Concussion (n = 6), $X^2_{(3, 324)} = 28.2$, $p < 0.001$. Post-hoc comparisons were conducted by examining the expected frequency of clinically significant State Anxiety for each group relative to controls. Both prior diagnosis of ADHD and a history of sport related concussion were separately associated with an increased likelihood of clinically significant State Anxiety, Odds Ratio's ≥ 6.3 [95% CI: 1.5 to 31.3], p's ≤ 0.005. The combination of diagnosis of ADHD and a history of sport-related concussion was associated with an even larger increase in the likelihood in the expected frequency of clinically significant State Anxiety, Odds Ratio = 16.4 [95% CI: 3.7 to 76.7], p < 0.001.

2.4. Trait Anxiety Symptomatology

Scale Analysis: ANOVA analysis observed no main effects or interactions involving ADHD or Concussion for Trait Anxiety, F's$_{(1, 320)} \leq$ 2.4, *p's* $\geq$ 0.12, f^2*'s* $\leq$ 0.01 [95% CI: 0.0 to 0.03]. *Risk Analysis:* Chi-Square analyses indicated that there was no difference in the expected frequency of clinically significant Trait Anxiety as a function of group membership; 5.1% of controls (n = 11), 10.9% of ADHD (n = 5), 7.3% of concussion (n = 3), and 14.3% of ADHD + Concussion (n = 3), $X^2_{(3, 324)} = 4.1$, $p = 0.18$.

2.5. Depression Symptomatology

Scale Analysis: ANOVA analysis observed an interaction of ADHD × Concussion, $F_{(1, 320)} = 36.0$, $p < 0.001$, f [2] = 0.11 [95% CI: 0.04 to 0.19]. Post-hoc decomposition of the ADHD × Concussion interaction was conducted by examining the effect of concussion history within those with and without prior diagnosis of ADHD. For individuals without a prior diagnosis of ADHD, there were no differences between those with (16.4 ± 5.6) and without (15.1 ± 4.8) a history of sport-related concussion in depression symptomatology, $t_{(255)} = 1.6$, $p = 0.12$, $d_s = 0.27$ [95% CI: 0.07 to 0.60]. For individuals with a prior diagnosis of ADHD, a history of sport-related concussion was associated with greater depression symptomatology (29.4 ± 15.9) relative to those without a history of sport-related concussion (16.0 ± 6.4), $t(23.1) = 3.7$, $p = 0.001$, $d_s = 0.98$ [95% CI: 0.39 to 1.56].

Risk Analysis: Chi-Square analyses indicated that the likelihood of clinically significant depression symptomatology was observed to relate to group membership; 43.1% of controls (n = 93), 50.0% of ADHD (n = 23), 58.5% of concussion (n = 24), and 85.7% of ADHD + concussion (n = 18), $X^2_{(3, 324)} = 15.9$, p < 0.001. Post-hoc comparisons were conducted by examining the expected frequency of clinically significant depression symptomatology for each group relative to controls. Neither prior diagnosis of ADHD nor history of a sport-related concussion made a difference in the expected frequency of clinically significant depression symptomatology, Odds Ratio's $\leq$ 1.9 [95% CI: 0.7 to 3.9], p's $\geq$ 0.09. The combination of diagnosis of ADHD and a history of sport-related concussion was associated with an increased likelihood in the expected frequency of clinically significant depression symptomatology, Odds Ratio = 7.9 [95% CI: 2.2 to 43.0] $p < 0.001$.

3. Discussion

The primary purpose of the present investigation was to characterize the independent and combined influences of ADHD and a history of concussion for mental health. Consistent with their diagnosis, collegiate student-athletes with ADHD exhibited elevated inattention and hyperactive symptomatology (*cohen's ds* $\geq$ 0.7) as well as greater likelihood of clinically significant symptomatology relative to their peers without ADHD or a history of concussion (odds ratios $\geq$4.6). Such findings replicate well-established symptomatologic patterns associated with ADHD and provide support for our methodology for assigning athletes to particular diagnostic groups. However, while a history of a sport-related concussion (~8 months post-injury) did not appear to influence overall symptomatologic ratings for either inattentive or hyperactive behaviors, examination of the likelihood of exhibiting clinically significant ADHD-related symptomatology provides additional insights. Specifically, although a history of concussion by itself appeared to have negligible impact upon attention, every participant with both a prior diagnosis of ADHD and a history of sport-related concussion exhibited clinically significant attentional problems. Whereas no participants with a history of a sport-related concussion exhibited clinically significant hyperactive symptomatology. Participants with both a prior diagnosis of ADHD and a history of sport-related concussion exhibited similar likelihood for clinically significant hyperactive symptomatology as peers in the control group. Thus, the combination of ADHD and concussive history appear to exacerbate inattentive symptomatology and offset each other for hyperactive symptomatology. Furthermore, we failed to observe any associations between psycho-affective measures and time since injury in this subgroup, further suggesting that individuals with a history of concussion and ADHD may exhibit altered recovery profiles. Although it is important to emphasize the preliminary nature of such findings given the retrospective cross-sectional design; such findings have important clinical implications for assessing ADHD related behaviors as hyperactive symptomatology may be suppressed during the more protracted period following recovery from a concussive injury.

The present investigations demonstrated that athletes with a prior diagnosis of ADHD exhibited greater levels of state anxiety (*Cohen's d* = 0.50) as well as a greater likelihood of reporting clinically significant levels of state anxiety compared to controls (OR = 6.30), while no effects were observed related to trait anxiety. Similarly, athletes reporting a history of concussion reported greater state anxiety (*Cohen's d* = 0.49) and greater likelihood of clinically significant levels of state anxiety (OR = 7.10), with no effects observed for trait anxiety. Of particular interest within the present investigation is the apparent additive contributions of a diagnosis of ADHD and history of concussion, which when combined, were associated with a greater likelihood of exhibiting clinically significant levels of state anxiety (OR = 16.4). Thus, there seems to be an additive effect between having a diagnosis of ADHD and history of concussion on state anxiety. The observed relationship between concussion and state anxiety replicates previous findings that demonstrated current university athletes with a history of concussion reported greater state anxiety/tension when assessed over a year since their last injury. Furthermore, these authors found state anxiety/tension was related to irregularities in resting neural frequency oscillations, indicative of persistent abnormal neural functioning [25].

A shortcoming of previous investigations into the psycho-affective impact of concussion is the failure to distinguish between state and trait anxiety, which makes results difficult to interpret. Trait anxiety is characterized as an individual's innate tendency to respond to a given situation whereas, state anxiety is thought to reflect transient emotional fluctuations based on situational arousal and perceptions [26]. While the independent effect on state anxiety only is not clear, we postulate that overlapping anatomical brain regions and circuits implicated in both ADHD and concussion may play a pivotal role. Endler and Kocovski [27] proposed that state anxiety consists of two components: "cognitive-worry" and "autonomic-emotion." Cognitive and emotional control and autonomic function are heavily associated with prefrontal brain regions [28,29]. Similarly, autonomic regulations is modulated by consistent feedback from Unsurprisingly, both ADHD and concussion are associated with anatomical and functional alterations in prefrontal brain regions [30–34]. Therefore, pathological alterations in overlapping brain regions and networks may provide a mechanistic link to the observed effects in state, but not trait anxiety.

Novel to the present investigation was the examination of how prior diagnosis of ADHD and prior history of concussion may independently and additively influence depression symptomatology. Absent a prior diagnosis of ADHD, there was only a small non-significant elevation in depression symptomatology for athletes with a history of concussion relative to control athletes (*Cohen's* d_s = 0.27). Interestingly, a prior diagnosis of ADHD appears to interact with a history of concussion to exacerbate depression symptomatology such that athletes with ADHD and a history of sport-related concussion exhibit greater depression symptomatology (*Cohen's* d_s = 0.98) relative to athletes with ADHD alone. Additionally, the combination of diagnosis of ADHD and a history of sport-related concussion was associated with the greatest likelihood of exhibiting clinically significant depression symptomatology (OR = 7.9). Thus, the combination of a prior diagnosis of ADHD and a prior history of concussion more than quadruples the risk of exhibiting clinically significant depression symptomatology than ADHD or a concussion history alone. Similar to state anxiety, depression-like symptoms are frequently reported among individuals with ADHD and in those with

a history of concussion [35,36]. Therefore, the observed interaction among ADHD and history of concussion may result from dysfunction within overlapping brain regions and neural networks.

3.1. Limitations & future research

Despite the strengths of the present investigation and the general replication of key findings, data analyzed for this study were obtained from routine pre-performance examinations at the start of each sport season and collected at varying times throughout the academic year. Thus, athlete's mental health was not evaluated at the same time point following concussion. Although there were no significant differences in time since injury between groups, this inconsistency may result in symptom report bias depending on athletes' concurrent involvement in sport if they attempted to minimize symptom report to maintain active status in their sport. Additionally, despite utilizing valid and reliable measures of symptomatology; future research may benefit from incorporating clinical assessments to ensure other comorbid conditions are properly accounted for and better address potential differences related to ADHD subtype. Finally, the design of the current investigation limits the ability to make causal inferences as pre-season/pre-injury baseline levels of mental health are not available. Incorporating of more frequent assessments and longitudinal designs may provide more nuanced insight into how neurodevelopmental disorders may alter factors that contribute to mental health risk.

Although the mental health risks associated with concussive injuries cannot be retroactively eliminated, gaining an understanding of how risk factors interact is essential to allow for the identification of potential complications early in the post-concussive injury recovery process to help athletic trainers and other healthcare professionals to intervene and potentially prevent chronic alterations in psychological health. Gaining additional insight into how the associations observed in the present study may differ across acute and later stages of recovery will be critical for advancing this area of work. Similarly, future investigations with larger sample sizes should aim to explore how findings of the current study may differ across age, biological sex, ADHD presentations (i.e., predominately-inattentive, or combined-presentation), and ADHD medication status (i.e., psychostimulant, non-stimulant medication). Given the substantial overlap between neural factors impacted by ADHD and concussive injury, future research should investigate shared and differing mechanistic theories underlying the manifestation of ADHD and mood related disorders as well as potential shared genetic variance associated with ADHD and affective dysregulation. Lastly, it is important to acknowledge that our own research and the research of others, has shown that athletes with ADHD and a priori mood disorders appear to place athletes at elevated risk of incurring a concussion and catastrophic injuries [16,37]. It is conceivable that aspects of affective dysregulation could similarly increase concussion risk.

4. Conclusion

The present findings suggest having both ADHD and a history of concussion may have a negative synergistic effect on mental health beyond that of ADHD and/or concussion alone. Furthermore, student-athletes in the current study with a history of concussion were evaluated an average of eight months after their injury, indicating that alterations in psycho-affective health may persist beyond typical recovery for those with ADHD. These findings highlight the importance of screening for anxiety and depressive symptoms among those with pre-existing ADHD. Without early identification and subsequent intervention, acute mood disturbances following concussion may lead to chronic alterations in psychological functioning and overall well-being. Developing a more thorough understanding on the association between ADHD, concussion, and psychological health with respect to other important moderators of recovery will help to identify the most vulnerable populations and lead to better treatment and prevention of chronic alterations in psychological functioning.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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