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# Multiple Past Concussions in High School Football Players:

## Are There Differences in Cognitive Functioning and Symptom Reporting?

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## Abstract

**Background—**There is increasing concern about the possible long-term effects of multiple concussions, particularly on the developing adolescent brain. Whether the effect of multiple concussions is detectable in high school football players has not been well studied, although the public health implications are great in this population.

**Purpose—**To determine if there are measureable differences in cognitive functioning or symptom reporting in high school football players with a history of multiple concussions.

**Study Design—**Cross-sectional study; Level of evidence, 3.

**Methods—**Participants included 5232 male adolescent football players (mean [±SD] age, 15.5 ± 1.2 years) who completed baseline testing between 2009 and 2014. On the basis of injury history, athletes were grouped into 0 (n = 4183), 1 (n = 733), 2 (n = 216), 3 (n = 67), or ≥4 (n = 33) prior concussions. Cognitive functioning was measured by the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) battery, and symptom ratings were obtained from the Post-Concussion Symptom Scale.

**Results—**There were no statistically significant differences between groups (based on the number of reported concussions) regarding cognitive functioning. Athletes with ≥3 prior concussions reported more symptoms than did athletes with 0 or 1 prior injury. In multivariate analyses, concussion history was independently related to symptom reporting but less so than developmental problems (eg, attention or learning problems) or other health problems (eg, past treatment for psychiatric problems, headaches, or migraines).



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**Conclusion—**In the largest study to date, high school football players with multiple past concussions performed the same on cognitive testing as those with no prior concussions. Concussion history was one of several factors that were independently related to symptom reporting.

**Keywords**

child; adolescent; traumatic brain injury; sports; postconcussion syndrome

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Football is one of the most popular high school sports, with more than 1,000,000 participants each year.[57] Over the past few years, there has been increasing scientific, lay press, and legislative attention to the possible risk of long-term effects associated with playing football and sustaining multiple concussions. On the basis of autopsy cases, some professional football players have neurodegenerative changes that might be related to neurotrauma sustained during their playing careers.[50] Recent studies of retired professional football players revealed both functional changes in brain metabolism,[25] as measured by functional magnetic resonance imaging, and microstructural differences in white matter,[26,66] as measured by diffusion tensor imaging (DTI), in some athletes. Moreover, studies have suggested that starting to play football at an earlier age (<12 years) was associated with greater cognitive difficulties in later life and altered neurobiology in former National Football League (NFL) players.[63,64] In a small study of 10 collegiate football players who underwent clinical testing and DTI before and after the season, white matter changes in the brain correlated with helmet impact measures (in the absence of a concussion), and these white matter changes persisted at 6-month follow-up.[2]

Whether neuroimaging changes are associated with changes in cognitive function in high school and collegiate football players has not been determined, but both high school and college football players are exposed to large numbers of head impacts per playing season,[5,16,74,75] with a high incidence of concussions.[18,77] Given the large number of participants, risk for repetitive head trauma, and risk for concussions, it is important to study both the immediate and long-term cognitive health of high school football players who have a history of multiple concussions.

To our knowledge, there are no published studies relating to risks associated with multiple concussions specifically and solely in high school football players. That is, the majority of prior studies that have included football players have combined high school and college athletes and athletes from numerous sports, with mixed results in terms of the effects of multiple concussions.[¶¶] Two recent studies relating to prior concussions in adolescent athletes, using different methodologies, had similar results. Brooks and colleagues[7] reported that a history of multiple concussions in elite-level adolescent hockey players (top 20% of each division) was associated with greater self-reported symptoms but not neurocognitive differences compared with those with 0 or 1 prior concussion. Similarly, in a large-scale study with more than 6000 high school athletes (not sport specific), Mannix and colleagues[42] also found no significant association between prior concussions and cognitive

[¶¶]References 4, 9, 11, 14, 21, 30, 32, 55, 61, 70.

test performance but found that concussion history was associated with more self-reported symptoms. However, the association was considerably weaker than other factors including mental health history, history of headaches, sex, or history of developmental or learning problems.

The purpose of this study was to determine if a history of concussions is associated with differences in cognitive functioning or symptom reporting in a very large sample of high school football players. There were 3 primary hypotheses based on previous studies and recent work.[7,42] First, it was hypothesized that there would be no differences in cognitive functioning in those with or without prior concussions, including those with multiple prior concussions. Second, it was hypothesized that football players with prior concussions would report more symptoms than football players without prior concussions, with a dose effect in which increasing numbers of prior concussions would be associated with greater symptom reporting. Third, it was hypothesized that the association between concussion history and symptom reporting would remain significant in multivariate analyses but be weaker than the association between symptom reporting and other factors, such as history of attention problems, learning problems, headaches or migraines, and psychiatric problems.

# METHODS

## Participants

Participants in this cross-sectional, descriptive cohort study included 6069 high school football players (14–18 years of age) from Maine. All completed baseline preseason testing with the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) battery between the years 2009 and 2014. As part of the ImPACT program, there is an embedded self-reported demographic and history questionnaire that provides limited information about developmental, academic, and medical history.[49] Exclusion criteria for this study were based on the questionnaire and were the following: (1) missing data on the number of prior injuries (n = 115); (2) a concussion within 6 months before baseline testing (n = 156) to restrict this study to longer term outcomes; (3) positive history of meningitis, epilepsy, or brain surgery (ie, those with missing responses were treated as negative to these questions) (n = 87); (4) testing completed in a language other than English (n = 34); and (5) baseline testing deemed to be possibly questionable (questionable validity is flagged by the ImPACT program as “baseline++” and is based on an algorithm involving improbably low scores[28]) (n = 445). Youth with a history of academic, learning, or attention problems as well as treatment for headaches, migraines, psychiatric conditions, or substance/alcohol use were included. After applying exclusion criteria, the final sample was 5232 football players. Of these, 1026 (19.6%) were included in a previous study.[42] Institutional review board approval for this deidentified database was obtained.

## Measures

The baseline preseason assessment for all players included the ImPACT battery. ImPACT is a brief computerized screen of cognitive abilities that has been used previously in several studies investigating neurocognitive functioning after concussive injuries.[7,8,30,31,42,43,69] ImPACT includes 6 tests/modules (ie, word discrimination, design memory, *x*s and *o*s, symbol match, color match, and 3 letters) that yield 5 composite/domain scores (ie, verbal memory, visual memory, visual-motor speed, reaction time, and impulse control). ImPACT was administered in a group setting in high school computer laboratories by the local athletic training staff. This study protocol was established before the work published on group versus individual results.[56]

In addition to the cognitive measures, ImPACT also contains a Post-Concussion Symptom Scale that consists of 22 commonly reported symptoms (eg, headache, dizziness, "fogginess") that are rated from 0 (none) to 6 (severe). The primary dependent measure is the total raw score derived from this 22-item scale (range, 0–132). In addition, 4 symptom domain scores can be computed for secondary analyses (eg, cognitive-sensory, sleep-arousal, vestibular-somatic, and affective) based on the factor structure of the scale.[39]

### Analyses

All analyses were completed using SPSS (version 21.0; IBM Corp). Before analyzing the cognitive and symptom data from ImPACT, a comparison of age (dependent variable [DV]) across the number of prior concussions (independent variable [IV]) was conducted using analyses of variance (ANOVAs). Group comparisons of the 4 primary cognitive composite scores (verbal memory, visual memory, reaction time, and visual-motor speed as the DVs) by the number of concussions (IV) were conducted using a multivariate analysis of covariance (MANCOVA, with age as a covariate because of analyses that showed significant age differences across groups). A group comparison of symptom ratings (DV) by the number of concussions (IV) was conducted using an ANOVA with age as a covariate (ANCOVA). Nonparametric versions were used (eg, Kruskal-Wallis and Mann-Whitney) when assumptions of the general linear model were violated. Correlations between cognition and symptoms used Spearman rho because of nonnormal distributions of symptom ratings. After ensuring that the assumptions of linear regression were met (including normal distribution of the residuals), a multivariate linear regression model was used to predict total symptom ratings (DV) using the following predictors (IVs): number of prior concussions, age, history of attention deficit hyperactivity disorder (ADHD), history of learning disability, treatment for headaches by a physician, treatment for migraines by a physician, treatment for a psychiatric condition, and treatment for a substance/alcohol problem. Predictors for the multivariate model were chosen a priori based on the literature[42] and per screening procedures described above.

Because of the large sample size and high statistical power, it was determined that an emphasis would be placed on interpreting results with at least medium effect sizes. Effect sizes for the general linear model analyses are reported with partial eta-squared ($\eta^2$ partial), as follows: $\eta^2$ partial = 0.01 as small, $\eta^2$ partial = 0.09 as medium, and $\eta^2$ partial = 0.25 as large.[58] Effect sizes for pairwise group comparisons use Cohen $d$ effect sizes, as follows: $d$ = 0.2 as small, $d$ = 0.5 as medium, and $d$ = 0.8 as large.[10]

## RESULTS

Sample characteristics are presented in Table 1. Most players reported no prior concussions (80.0%). Of those with a positive history, 14.0% reported 1 past injury, 4.1% reported 2, 1.3% reported 3, and 0.6% reported ≥4. None of these injuries occurred within 6 months of baseline testing. A small proportion of athletes reported a history of ADHD, learning disability, or treatment for headaches or a psychiatric condition (ie, 4.5%–9.6%). Comparing prevalence rates with those with 0 concussions, those with prior concussions were more likely to have developmental problems such as ADHD (odds ratio [OR], 1.4 [95% CI, 1.1–1.8]) or learning disabilities (OR, 1.6 [95% CI, 1.2–2.2]). Those with prior concussions were also more likely to report a history of treatment for headaches (OR, 3.1 [95% CI, 2.5–3.8]), migraines (OR, 2.4 [95% CI, 1.9–3.1]), mental health problems (OR, 1.8 [95% CI, 1.4–2.4]), and substance abuse problems (OR, 2.4 [95% CI, 1.3–4.5]).

The cognitive test performance of the football players, stratified by their concussion history, is presented in Table 2. There was a significant main effect of age across the 5 groups stratified by concussion history (F(4, 5227) = 12.92, $P < .001$, $\eta^2$ partial = 0.10 [medium effect size]), and age was found to be significantly correlated with 3 of 4 cognitive scores (verbal memory, reaction time, and visual-motor speed) and total symptoms. Therefore, age was entered as a covariate for subsequent group analyses. Considering performance on the 4 primary cognitive domain scores across the concussion history groups, there was no statistically significant multivariate effect (Box's *M*, $P = .163$; Wilks lambda = .998; F(16, 15,957.17) = 0.78, $P = .716$, $\eta^2$ partial = 0.001 [very small effect size], age as covariate).

For completeness, and to reduce the possibility of a type II statistical error, further exploratory univariate analyses and pairwise comparisons were conducted for the 4 primary cognitive domain scores. There were no significant main effects or pairwise differences across the 5 groups (0, 1, 2, 3, or ≥4 prior concussions) on any of the cognitive test scores when considered individually in univariate analyses (with age as covariate; $P = .54–.67$). Moreover, there was no significant group effect for the cognitive test scores when comparing those with 0 versus multiple (≥3) prior concussions (Box's *M*, $P = .202$; Wilks lambda = .999; F(4, 4277.00) = 1.02, $P = .396$, $\eta^2$ partial = 0.001 [very small effect size], age as covariate).

Symptom ratings for high school football players stratified by the number of prior concussions are also presented in Table 2. There was a significant univariate effect for total symptom scores across the groups (F(4, 5226) = 14.42, $P < .001$, age as covariate), but there was only a small effect size ($\eta^2$ partial = 0.011). Because of a significant Levene test finding for homogeneity of variance, a nonparametric group comparison using the Kruskal-Wallis test was also used and indicated a significant group effect for total symptom ratings ($\chi^2(4) = 40.52$, $P < .001$). Follow-up nonparametric analyses (not corrected for age differences) indicated that those with 0 prior concussions reported significantly fewer symptoms than those with 3 ($Z = -3.30$, $P = .001$, $d = 0.50$) or ≥4 ($Z = -3.15$, $P = .002$, $d = 1.01$) prior concussions. Those with 1 prior concussion reported fewer total symptoms than those with ≥4 prior concussions ($Z = -2.46$, $P = .014$, $d = 0.79$). The remaining group comparisons had small or small-to-medium effect sizes ($d$ <0.50). Similar results were found for the 4 symptom domains, with significant group effects (Wilks lambda = .984; F(16, 15,957.17) = 5.27, $P < .001$, age as covariate) suggesting that those with prior concussions had greater scores on the symptom domains. Commonly endorsed symptoms in those with multiple prior concussions were headaches, light sensitivity, noise sensitivity, visual problems, feeling mentally foggy, and difficulty concentrating. It is important to appreciate, however, that athletes with no prior concussions sometimes endorse those symptoms as well.[35]

Multivariate linear regression was used to examine the independent contribution of concussion history to symptom reporting after controlling for other developmental and health factors. The multivariate regression equation was significant ($F(8, 4605) = 45.71$, $P < .001$); however, the multivariate model only accounted for 7% of the variance in total symptom scores (Table 3). Age was not a significant independent predictor of symptom scores in this model. All the remaining variables significantly predicted symptoms, with concussion history being the smallest independent predictor compared with all other variables (ie, in descending order: treatment for a psychiatric condition, history of substance/alcohol use, treatment for headaches, history of a learning disability, history of attention problems/ADHD, treatment for migraines, and concussion history).

## DISCUSSION

In the largest study to date of multiple concussions in high school football players, we found no differences in cognitive test performance associated with concussion history. Compared with players with no reported concussion history, players with 1, 2, or multiple prior concussions did not perform differently on any ImPACT cognitive domain. It is not clear whether these negative findings for cognitive effects associated with multiple prior injuries in adolescent football players represent recovery and neuroplasticity, a shorter duration of overall exposure (eg, to concussions and repetitive blows to the head), less intense exposure (ie, fewer hits and lesser forces than in college and professional players), study bias, or a combination of factors, but these results are somewhat reassuring given the current concern over possible long-term cognitive effects of multiple injuries, especially in football players. Prospective studies are needed to determine whether the lack of adverse cognitive effects found here is sustained over the course of one's lifetime. Importantly, in 1 epidemiological study, there was no association between playing high school football and the diagnosis of neurological or neurodegenerative disorders in later life such as Parkinson's disease or Alzheimer's disease.[60]

These results are consistent with prior studies involving computerized cognitive testing of adolescents in mixed sports,[42,71,72] computerized testing with adolescent elite hockey players,[7,8] and a study involving traditional paper-and-pencil neuropsychological testing of youth who are not injured specifically in sports.[15] Collectively, these studies contain fairly large sample sizes and suggest that multiple prior concussions do not result in obvious lingering cognitive effects in adolescent athletes. However, studies containing both high school and college athletes have provided mixed results, with some suggesting cognitive effects from prior concussions[14,21,32,55,61] but others suggesting no lingering effects.[4,9,11,30,70] Therefore, the aggregated literature remains mixed and inconclusive.

Although we did not find an association between multiple concussions and cognitive functioning, we did find an association with self-reported symptoms and past injuries. In particular, greater symptom scores were reported in those with multiple prior concussions compared with those with no or fewer prior injuries not only for total symptom scores but also across the 4 subdomain scores (eg, cognitive-sensory, sleep-arousal, vestibular-somatic, and affective). Greater symptom endorsement in those with multiple past concussions has been a fairly consistent finding in our prior research on possible lingering effects for adolescents[7,42]; it has been considered a possible modifier of outcomes from a concussion[48] and has been identified as one of the predictive factors for slower recovery from a concussion.[76] Given that this is a cross-sectional quasiexperimental study, we cannot infer causation from these findings. One can speculate, however, that multiple prior concussions in adolescent football players might be associated with underlying changes in brain physiology that contribute to these subjectively reported symptoms, at least in some athletes. However, other factors clearly contribute to symptom reporting as well, and these factors may be considered some of the more important reasons for having elevated and lingering symptoms after an injury. As seen in Table 1, those with prior concussions were more likely to have developmental problems such as ADHD or learning disabilities. Students with ADHD or learning disabilities reported more symptoms on the Post-Concussion Symptom Scale than students who did not have these conditions.[6,20,78] Moreover, those with prior concussions were also more likely to report a history of treatment for headaches, migraines, mental health problems, and substance abuse problems, and students with a history of these conditions also reported more symptoms on the Post-Concussion Symptom Scale.[35] We did not have access to medical records, and the health survey did not include information about when the students sustained their prior concussions or when they received treatment for headaches or mental health problems. Therefore, we have no way of knowing whether the treatment for certain health conditions (eg, headaches) was directly related to prior concussions in some students or predated the injuries themselves. Developmental and health problems were more common in those with multiple concussions, and these problems, as illustrated in the multivariate analyses presented in Table 3, were independently related to greater symptom reporting.

The strongest independent predictor of symptom reporting in this sample of male adolescent football players was a history of treatment for a psychiatric condition. The importance of considering psychiatric history in the reporting of symptoms has been highlighted by the fourth consensus statement on concussion in sport[48] as a possible comorbidity or premorbidity that may affect outcomes after an injury and plays a greater role with increasing time since the injury.[51] Research with adult samples has shown that preinjury psychiatric problems are among the strongest and most consistently found predictors of outcomes from a concussion[17,27,52,59] and may be more predictive of persistent postconcussion syndrome than having a concussion itself.[53,59] On their own, psychiatric conditions such as depression, anxiety, and emotional stress can mimic post-concussion syndrome in nonconcussed persons because of the considerable overlap of symptoms.[19,22,29,33,34]

In addition to past treatment for a psychiatric condition, prior treatment for headaches, a diagnosis of learning disability, and a diagnosis of ADHD were also more strongly associated with symptom reporting than concussion history. Therefore, vulnerability factors, such as a propensity for mood or anxiety disorders or a diagnosis of a developmental disorder (such as a learning disability or ADHD), might increase the risk for slower recovery after a concussion[38,41] and be independently related to increased symptom reporting[20,78] in the presence or absence of prior concussions. With male adolescent football players who have a concussion and are showing prolonged recovery through elevated symptoms, it is important to consider all of the premorbidites and comorbidities that may moderate or even mediate symptom levels. This is important because rest or restriction from activities may further exacerbate rather than ameliorate symptoms that arise from pre-existing comorbidities.

There are limitations to this study. First, similar to past studies,[##] we did not define the injury severity characteristics of prior concussions, nor did we define when the prior concussions occurred.[a] As a result, we were not able to ascertain the nature or severity of the injuries, although we were able to limit our study to athletes who had been cleared for return to play at baseline testing and had not sustained an injury within the prior 6 months. Second, having only athletes who were cleared to return to play could lead to excluding those football players who have a slow recovery after an injury and are either not cleared for baseline testing or are no longer playing football. Third, the reporting of prior concussions is based on self-reports. Although the health question asks about diagnosed concussions (ie, "indicate number of times diagnosed with a concussion"), these were not confirmed as diagnosed injuries using medical records or parental input, which can result in slightly different information.[49] Fourth, this study used a cross-sectional methodology, similar to other studies examining small[21,32,37,40] or large[b] groups of athletes during baseline preseason testing. Further research with a longitudinal design is warranted, as is the inclusion of other investigative methods (eg, neuroimaging). A longitudinal design that also follows these youth into adulthood may be able to inform us on the trajectories of injuries and even longer term outcomes for cognitive and symptom sequelae. Fifth, these data are derived entirely from high school athletes in the state of Maine, so the results may not represent amateur football players from other areas. Sixth, the primary outcome measure is a rapid computerized test of cognitive abilities and does not represent a complex and comprehensive neuropsychological evaluation. Although prior studies with traditional neuropsychological testing have also suggested no long-term cognitive differences in those with prior concussions (for a meta-analysis, see Belanger et al[3]), it is possible that a different test battery used in this population would find different results. Finally, although we used a multivariate model to better understand symptom reporting in these high school football players, the full model only accounted for 7% of the variance in total symptom scores, and concussion history was the smallest independent predictor. Clinicians and researchers should appreciate that postconcussion-like symptoms are nonspecific[33,36]; they can be influenced by situational factors such as life stress,[23,47] insufficient sleep,[62] and recent strenuous exercise[1]; they occur in a large number of healthy student athletes with no pre-existing conditions[35]; and they are reported more frequently by those with a history of mental health problems,[35] ADHD,[20,78] learning disabilities,[20,78] and migraines.[42] Future research might help better understand the relationship between multiple prior concussions and symptom reporting in high school athletes and factors that mediate and moderate that relationship.

[##]References 4, 11, 13, 30, 32, 44–46, 55, 68, 73.

[a]References 4, 11, 21, 24, 30, 32, 44–46, 54, 55.

[b]References 4, 11, 12, 24, 30, 55, 65, 67, 73.

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## TABLE 1

Characteristics of the Sample of High School Football Players[a]

| | Total Sample | Sample Divided by Number of Prior Concussions | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | ≥4 |
| No. of participants (% of total sample) | 5232 (100.0) | 4183 (80.0) | 733 (14.0) | 216 (4.1) | 67 (1.3) | 33 (0.6) |
| Age, mean ± SD, y | 15.5 ± 1.2 | 15.5 ± 1.2 | 15.6 ± 1.2 | 15.8 ± 1.4 | 16.2 ± 1.3 | 16.1 ± 1.2 |
| Attended special education classes | | | | | | |
| Yes | 400 (7.6) | 306 (7.3) | 60 (8.2) | 23 (10.6) | 6 (9.0) | 5 (15.2) |
| No | 4832 (92.4) | 3877 (92.7) | 673 (91.8) | 193 (89.4) | 61 (91.0) | 28 (84.8) |
| Repeated ≥1 year of school | | | | | | |
| Yes | 468 (8.9) | 374 (8.9) | 65 (8.9) | 21 (9.7) | 6 (9.0) | 2 (6.1) |
| No | 4764 (91.1) | 3809 (91.1) | 668 (91.1) | 195 (90.3) | 61 (91.0) | 31 (93.9) |
| History of ADHD | | | | | | |
| Yes | 504 (9.6) | 375 (9.0) | 81 (11.1) | 35 (16.2)[b] | 6 (9.0) | 7 (21.2)[b] |
| No | 4728 (90.4) | 3808 (91.0) | 652 (88.9) | 181 (83.8) | 61 (91.0) | 26 (78.8) |
| History of learning disability | | | | | | |
| Yes | 238 (4.5) | 170 (4.1) | 42 (5.7)[b] | 18 (8.3)[b] | 6 (9.0)[b] | 2 (6.1) |
| No | 4994 (95.5) | 4013 (95.9) | 691 (94.3) | 198 (91.7) | 61 (91.0) | 31 (93.9) |
| History of treatment for headache | | | | | | |
| Yes | 477 (9.1) | 278 (6.6) | 114 (15.6)[b] | 54 (25.0)[b] | 20 (29.9)[b] | 11 (33.3)[b] |
| No | 4253 (81.3) | 3451 (82.5) | 584 (79.7) | 151 (69.9) | 46 (68.7) | 21 (63.6) |
| Missing | 502 (9.6) | 454 (10.9) | 35 (4.8) | 11 (5.1) | 1 (1.5) | 1 (3.0) |
| History of treatment for migraine | | | | | | |
| Yes | 354 (6.8) | 222 (5.3) | 76 (10.4)[b] | 36 (16.7)[b] | 12 (17.9)[b] | 8 (24.2)[b] |
| No | 4356 (83.3) | 3497 (83.6) | 616 (84.0) | 165 (76.4) | 54 (80.6) | 24 (72.7) |
| Missing | 522 (10.0) | 464 (11.1) | 41 (5.6) | 15 (6.9) | 1 (1.5) | 1 (3.0) |
| History of treatment for psychiatric condition | | | | | | |
| Yes | 267 (5.1) | 182 (4.4) | 44 (6.0) | 23 (10.6)[b] | 12 (17.9)[b] | 6 (18.2)[b] |
| No | 4421 (84.5) | 3515 (84.0) | 648 (88.4) | 178 (82.4) | 54 (80.6) | 26 (78.8) |
| Missing | 544 (10.4) | 486 (11.6) | 41 (5.6) | 15 (6.9) | 1 (1.5) | 1 (3.0) |

| | Total Sample | Sample Divided by Number of Prior Concussions | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | ≥4 |
| History of treatment for substance/alcohol use | | | | | | |
| Yes | 46 (0.9) | 28 (0.7) | 8 (1.1) | 6 (2.8)[b] | 2 (3.0)[b] | 2 (6.1)[b] |
| No | 4609 (88.1) | 3640 (87.0) | 685 (93.5) | 190 (88.0) | 64 (95.5) | 30 (90.9) |
| Missing | 577 (11.0) | 515 (12.3) | 40 (5.5) | 20 (9.3) | 1 (1.5) | 1 (3.0) |

[a]Data are reported as n (%) unless otherwise indicated. ADHD, attention deficit hyperactivity disorder.

[b]Statistically significant difference when comparing the proportion with the group with 0 concussions ($P$ <.05).

## TABLE 2

Cognitive Test Performance and Symptom Ratings by Number of Previous Concussions[a]

| | No. of Prior Concussions | | | | |
|---|---|---|---|---|---|
| | **0** | **1** | **2** | **3** | **≥4** |
| Age, y | 15.5 ± 1.2 | 15.6 ± 1.2 | 15.8 ± 1.4 | 16.2 ± 1.3 | 16.1 ± 1.2 |
| Cognitive test scores | | | | | |
| Verbal memory[b] | 81.96 ± 9.78 | 81.99 ± 10.04 | 81.30 ± 10.15 | 80.43 ± 10.00 | 81.82 ± 8.99 |
| Visual memory[b] | 71.11 ± 13.13 | 71.52 ± 13.17 | 70.54 ± 13.90 | 69.61 ± 14.01 | 68.97 ± 13.36 |
| Visual-motor speed[b] | 32.49 ± 6.61 | 32.89 ± 6.90 | 33.22 ± 7.00 | 32.63 ± 7.84 | 34.46 ± 8.71 |
| Reaction time | 0.64 ± 0.09 | 0.64 ± 0.10 | 0.64 ± 0.09 | 0.64 ± 0.11 | 0.64 ± 0.10 |
| Symptom ratings | | | | | |
| Total symptom score | 4.66 ± 7.87 | 5.46 ± 8.77 | 6.80 ± 8.93 | 8.66 ± 12.40 | 12.73 ± 18.41 |
| Cognitive-sensory domain | 1.25 ± 2.71 | 1.45 ± 3.00 | 1.85 ± 3.16 | 2.96 ± 4.72 | 4.03 ± 5.96 |
| Sleep-arousal domain | 1.56 ± 2.72 | 1.96 ± 3.16 | 2.37 ± 3.36 | 2.49 ± 3.60 | 3.36 ± 4.91 |
| Vestibular-somatic domain | 0.73 ± 1.92 | 0.80 ± 2.08 | 0.88 ± 1.88 | 1.45 ± 2.80 | 2.12 ± 4.20 |
| Affective domain | 0.86 ± 2.05 | 0.92 ± 2.32 | 1.30 ± 2.64 | 1.37 ± 3.41 | 2.52 ± 5.01 |
| Individual symptoms, % endorsing as present | | | | | |
| Headache[VS] | 17.8 | 21.1 | 20.8 | 28.4 | 33.3 |
| Nausea[VS] | 4.4 | 2.3 | 2.3 | 3.0 | 9.1 |
| Vomiting[VS] | 4.6 | 4.0 | 6.0 | 3.0 | 9.1 |
| Balance problems[VS] | 5.8 | 5.5 | 7.9 | 11.9 | 15.2 |
| Dizziness[VS] | 8.3 | 8.5 | 10.6 | 14.9 | 21.2 |
| Sensitivity to light[CS] | 21.9 | 25.1 | 29.6 | 25.4 | 30.3 |
| Sensitivity to noise[CS] | 19.2 | 22.2 | 26.9 | 28.4 | 30.3 |
| Numbness or tingling | 8.3 | 8.6 | 9.7 | 9.0 | 9.1 |
| Visual problems[CS] | 18.6 | 22.8 | 25.9 | 23.9 | 27.3 |
| Fatigue[SA] | 10.9 | 10.9 | 15.3 | 13.4 | 21.2 |
| Trouble falling asleep[SA] | 12.5 | 13.1 | 15.3 | 11.9 | 33.3 |
| Sleeping more than usual | 4.2 | 6.0 | 6.9 | 11.9 | 12.1 |
| Sleeping less than usual[SA] | 11.3 | 12.0 | 18.5 | 13.4 | 24.2 |

| | No. of Prior Concussions | | | | |
|---|---|---|---|---|---|
| | **0** | **1** | **2** | **3** | **≥4** |
| Drowsiness[SA] | 14.6 | 13.8 | 21.8 | 14.9 | 15.2 |
| Feeling slowed down[CS] | 9.9 | 9.4 | 9.7 | 11.9 | 21.2 |
| Irritability[A] | 7.5 | 8.2 | 9.7 | 16.4 | 21.2 |
| Sadness[A] | 4.8 | 5.7 | 6.9 | 6.0 | 15.2 |
| Nervousness[A] | 7.6 | 7.2 | 9.3 | 11.9 | 18.2 |
| Feeling more emotional[A] | 8.6 | 6.0 | 12.5 | 20.9 | 18.2 |
| Feeling mentally "foggy"[CS] | 17.0 | 19.1 | 27.3 | 26.9 | 39.4 |
| Difficulty concentrating[CS] | 10.9 | 11.1 | 13.9 | 29.9 | 30.3 |
| Difficulty remembering[CS] | 6.0 | 7.6 | 8.3 | 14.9 | 18.2 |

[a]Data for age are reported as mean ± SD; data for cognitive test scores and symptom ratings are reported as mean raw scores ± SD. Symptom domains are identified based on Kontos et al[39]: A, affective; CS, cognitive-sensory; SA, sleep-arousal; and VS, vestibular-somatic. Two symptoms, "numbness or tingling" and "sleeping more than usual," do not load onto any specific domain.

[b]Higher raw scores reflect better performance.

## TABLE 3

Multivariate Regression Model for Effect of Concussion History, Age, and Health History on Symptom Ratings[a]

| Variable | B (95% CI) | SE B | β | *P* Value |
|---|---|---|---|---|
| Psychiatric history | 5.37 (4.27 to 6.48) | 0.56 | 0.14 | <.001 |
| Substance/alcohol use | 3.47 (1.02 to 5.93) | 1.25 | 0.04 | .006 |
| Headache | 3.08 (2.09 to 4.07) | 0.51 | 0.11 | <.001 |
| Learning disability | 2.20 (1.07 to 3.32) | 0.57 | 0.06 | <.001 |
| ADHD | 1.84 (1.02 to 2.66) | 0.42 | 0.07 | <.001 |
| Migraine | 1.47 (0.33 to 2.60) | 0.58 | 0.04 | .012 |
| No. of concussions | 0.70 (0.35 to 1.05) | 0.18 | 0.06 | <.001 |
| Age | 0.14 (−0.05 to 0.33) | 0.10 | 0.02 | .158 |

[a]Dependent variable for this multiple regression is the total raw score from the Post-Concussion Symptom Scale. ADHD, attention deficit hyperactivity disorder; B, unstandardized beta coefficient; SE B, standard error of the unstandardized beta coefficient; β, standardized beta coefficient.