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RESEARCH PAPER

Multiple prior concussions are associated with symptoms in high school athletes

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Abstract

Objectives: The purpose of this study was to evaluate the association of prior concussion on baseline computerized neurocognitive testing in a large cohort of high school athletes. **Methods:** This is a retrospective cohort study of student athletes from 49 Maine High Schools in 2010 who underwent baseline computerized neurocognitive evaluation with Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT®). As part of the ImPACT®, subjects reported a prior history of concussion as well as demographic information and a symptom questionnaire. We used linear regression to evaluate the association of prior concussion with baseline: (1) ImPACT® composite scores; and (2) symptom scores. **Results:** Six thousand seventy-five subjects were included in the study, of whom 57% were boys. The majority of student athletes (85.3%) reported no prior history of concussion while 4.6% reported having sustained two or more prior concussions. On simple linear regression, increasing number of concussions was related to worse performance in verbal memory ($P = 0.039$) and greater symptoms scores ($P < 0.001$). On multivariate modeling, only the association with baseline symptoms remained ($P < 0.001$). Other factors associated with baseline symptom reporting in the multivariate model included mental health history, headache/migraine history, gender, developmental and/or learning problems, and number of prior concussions. **Interpretation:** In this large-scale, retrospective survey study, history of multiple prior concussions was associated with higher symptom burden but not baseline computerized neurocognitive testing. The association between baseline symptom reporting and clinical and demographic factors was greater than the association with a history of multiple concussions.

Introduction

The Centers for Disease Control and Prevention described sports-related concussion as an epidemic.[1] In an epidemiological study of high school athletes, concussion rates have increased steadily in the past decade,[2] possibly due to greater awareness and documentation sensitivity, with recent estimates suggesting rates as high as 0.51 concussion per 1000 athlete exposures.[3] There is considerable concern regarding the long-term effects of this injury, especially in children who suffer repetitive injuries. Some evidence from experimental models and clinical studies suggest that the effects of multiple injuries might be cumulative and long lasting.[4–9] However, many of these studies include Division I collegiate and professional athletes, for whom the number and severity of injuries are likely greater than most high school athletes.

Whether or not there is a long-term effect of multiple concussions in high school athletes has not been established, with conflicting results from the literature. A large recent study of elite Canadian hockey players aged 13–17 years found no association between prior concussions and baseline neurocognitive functioning, although athletes with greater number of concussions did report more subjective symptoms.[10] Another similar study showed no effect of one or two previous concussions on computerized neurocognitive testing.[11] Other studies have suggested that athletes with a prior history of concussion have worse performance on neurocognitive testing than those without prior injury, as well as more self-reported symptoms.[12–14] However, most of these studies had relatively small numbers of athletes with multiple concussions, leading to insufficient power to evaluate the effect of multiple injuries, or the possible frequency-dependent effect of one versus two versus three or more prior injuries.

The purpose of this study was to determine whether history of prior concussions is associated with differences in baseline computerized neurocognitive testing. We hypothesized that there is a frequency-dependent effect of number of prior concussions on computerized neurocognitive test results for high school athletes. Establishing whether or not athletes with prior concussion history have differences in neurocognitive performance could be important for evaluating risks of multiple concussions, as well as guiding decisions about return to play.

Methods

Study design

This is a retrospective cohort study of student athletes from 49 Maine High Schools in 2010. The purpose of this study was to evaluate the relationship of prior concussions on baseline Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT®).

Participants

As part of a statewide concussion initiative, Maine high schools were invited to participate in ImPACT® evaluations, sponsored at the time by the Maine Concussion Management Initiative at Colby College. Students in participating schools completed baseline testing prior to taking part in their first sport for that school year (some students participated in several sports during the year). Because the purpose of this study was to evaluate the possible cumulative but not acute effects of prior concussions, baseline testing results were excluded for those subjects who reported a recent concussion (concussion within 26 weeks of the 2010 baseline test). Subjects with an invalid baseline test, history of epilepsy, or history of brain surgery were also excluded.

Measure

ImPACT® is a brief computer-administered neuropsychological test battery consisting of six neuropsychological test modules that measure cognitive functioning in attention, memory, reaction time, and processing speed. Composite scores from these modules are reported in five domains: verbal memory, visual memory, reaction time, processing speed, and impulse control. “Verbal Memory” and “Visual Memory” are reported as the average percent correct for several tasks including word recognition, symbol matching, letter memory, discrimination of abstract line drawing, and a symbol memory task. “Reaction Time” is reported in milliseconds based on a symbol-matching task and a go/no-go task. “Processing Speed” is the weighted average of responses to three interference tasks. The “Impulse Control” composite is used to determine if the test taker is giving their best effort. This is reported as the number of errors on both the go/no-go test and the choice reaction time task. In addition, ImPACT® includes a validity algorithm that utilizes cut-off scores in five components of testing that identify the test results as being potentially invalid. Baseline tests with this designation were not included in the study.

In addition to the neuropsychological test battery and tests of validity, the ImPACT® program includes demographic questions including age, gender, handedness (right or left), whether or not the student has had any developmental or learning difficulties (attended Special Education, repeated one or more grades, diagnosed with a learning disorder, or has attention deficit disorder or attention deficit hyperactivity disorder [ADHD]), a health history survey, and a postconcussion symptoms scale. The health survey asks about the number of times the student has been diagnosed with a concussion, as well as the dates of prior concussions. In addition, the health survey asks whether there is a history of treatment for headaches/migraine, a history of brain surgery, a history of epilepsy, or a history of treatment for psychiatric condition. The Post-Concussion Scale (PCS), which consists of 22 symptoms (e.g., headache, dizziness, “fogginess”), yields a total score that correlates with symptom burden.

ImPACT® testing is used for concussion management as follows: Athletes undergo preseason testing which is used as a baseline for comparison. If an athlete sustains concussion, he/she undergoes postinjury testing which is then compared to the baseline testing.

Primary and secondary outcomes

The primary outcomes for this study are ImPACT® cognitive composite scores. The secondary outcome is the PCS total score.

Statistical analyses

Data are mean ± standard deviation or median (interquartile range) as appropriate. Simple descriptive statistics are used for demographic data. To evaluate the effect of prior concussions on baseline ImPACT® testing, a linear regression was constructed with composite score as the outcome and number of concussions (0, 1, 2, 3, and 4 or more) as the predictor. Because the effect of prior concussion on composite score could be confounded by other variables, we next constructed a multivariate model. We decided a priori to include the following predictors in the multivariate model: age, gender, history of ADHD or any learning difficulties, history of headache or migraine treatment, and history of treatment for a psychiatric condition. All statistical analyses were conducted using Stata (version 13; Stata Corp, College Station, TX).

Results

In 2010, 7053 student athletes from Maine completed baseline, preseason testing with ImPACT®, of whom 6657 had a valid baseline test. Of these, 201 reported a concussion within 26 weeks of baseline leaving 6456 eligible for the study. In addition, 381 were missing information about prior concussions, and 70 reported a history of epilepsy or brain surgery leaving the final study sample of 6005 student athletes.

The mean age of the sample was 16.0 (SD = 2.7 years) and 3415 (57%) were boys. At the time of assessment, the most frequent sports were football, soccer, and basketball for boys and soccer, field hockey, and cheerleading for girls (Table 1). The majority of athletes (85.3%) reported no prior history of concussion; 34 (0.6%) reported a history of four or more prior concussions (Table 1). Composite scores by number of previous concussions are shown in Table 2. On simple linear regression, increasing number of concussions was related to decreased baseline composite scores in verbal memory ($P = 0.039$) and increased scores on impulse control ($P = 0.002$; Table 3) although the effect was small (Table 3). Increasing number of prior concussions was also associated with increased total scores on the PCS ($P < 0.001$). The R^2 value (Table 3) was very small for the overall association, but the means and SDs in Table 2 reveal medium effect sizes when comparing those with three or more concussions to those with no history of concussion on the total symptom score. On multivariate modeling, the number of prior concussions was associated with increased scores on impulse control ($P = 0.021$) and increased baseline total

Table 1. Characteristics of the study sample.

	N (%)
Age[1]	16 (2.7)
Gender	
Male	3415 (56.9)
Female	2590 (43.1)
Sport (boys)	
Football	1026 (30.0)
Soccer	800 (23.4)
Basketball	426 (12.5)
Ice hockey	339 (10.0)
Lacrosse	181 (5.3)
Track and field/cross country	155 (4.5)
Wrestling	122 (3.6)
Baseball	97 (2.8)
Other	269 (7.9)
Sport (girls)	
Soccer	746 (28.8)
Field hockey	434 (16.8)
Cheerleading	312 (12.0)
Basketball	275 (10.6)
Lacrosse	196 (7.6)
Track and field/cross country	143 (5.5)
Volleyball	97 (3.8)
Ice hockey	87 (3.4)
Swimming	84 (3.2)
Softball	75 (2.9)
Other	141 (5.4)
Number of prior concussions	
0	5121 (85.3)
1	609 (10.1)
2	174 (2.9)
3	67 (1.1)
4 or more	34 (0.6)
History of learning problem	722 (12.0)
No history of learning problem	5283 (88.0)
Treatment for headache/migraine	641 (10.7)
No treatment for headache/migraine	4742 (79.0)
Missing	622 (10.3)
Treatment for psychiatric condition	315 (5.2)
No treatment for psychiatric condition	4948 (82.4)
Missing	742 (12.4)

[1]Data are mean (SD).

Table 2. Composite scores by number of previous concussions.

	Number of prior concussions				
	0 (*n* = 5121)	1 (*n* = 609)	2 (*n* = 174)	3 (*n* = 67)	4 or more (*n* = 34)
Verbal memory	84.1 (9.6)	83.9 (9.8)	83.1 (9.7)	82.0 (10.9)	83.3 (10.1)
Visual memory	71.5 (13.2)	71.9 (13.2)	70.7 (13.5)	69.4 (15.1)	75.2 (13.2)
Reaction time	0.60 (0.08)	0.60 (0.08)	0.60 (0.09)	0.61 (0.08)	0.60 (0.08)
Processing speed	35.7 (7.6)	35.4 (7.6)	35.5 (8.6)	34.7 (7.5)	38.4 (7.5)
Impulse control	7.5 (5.0)	7.6 (5.0)	8.9 (6.0)	7.8 (5.2)	8.5 (7.3)
Total symptom score	5.1 (8.2)	6.0 (9.6)	7.9 (10.3)	9.2 (12.3)	10.6 (18.9)

scores on the Post-Concussion Symptom Scale ($P < 0.001$). However, only 2% of the variance in impulse control scores was accounted for by the multivariate model, indicating very poor predictive validity, and learning problems (including ADHD) were more strongly related to impulse control scores than concussion history. For symptoms, the multivariate model accounted for only 10% of the variance in symptom scores, and most other variables were stronger predictors of symptoms than concussion history (including gender, learning problems, headache/migraine history, and psychiatric history).

Discussion

In this study, prior history of concussion was associated with subjectively reported symptom burden. With 279 athletes reporting a history of two or more prior concussions, this is the largest study to date evaluating the association of prior history of concussions with baseline computerized neurocognitive testing and symptom burden in high school athletes. By including both male and female athletes from multiple sites and multiple sports, our study results may be more generalizable than prior similar studies.[10,11,15]

We hypothesized that increasing number of concussions would be consistently associated with composite measures on baseline neurocognitive testing. The association, however, was neither consistent nor strong across the five composite ImPACT® measures. It is important to note that there were a small number of children with a history of four or more concussions, that is, those most likely to be affected. Although the verbal memory and impulse control composite scores were associated in a frequency-dependent manner with number of prior concussions in simple linear regression, only the association between impulse control and number of concussions remained on multivariate modeling. Because the impulse control measure is mainly used as a measure of test validity and possible misunderstanding of test instructions (it is not routinely used as a measure of cognitive functioning), and the association only accounted for 2% of the variance, it is doubtful whether this finding has any clinical relevance.

Our findings are in contrast to some prior studies that have found an association of prior concussions with neurocognitive testing. Moser et al. reported that athletes with a history of two or more prior concussions had similar performance on neurocognitive measures to those who had a concussion within a week of testing, although the athletes with two or more prior concussions also had similar results to those with a history of no or one prior concussion.[13] In a study of collegiate athletes, Collins et al. found a significant effect of concussion history on neuropsychological measures, and an interaction between multiple concussions and learning disabilities.[16] Other studies have reported that athletes with a history of more than two concussions have persistent changes in neuropsychological test performance[17] and electrophysiology.[18,19] There are also experimental models that suggest long-term functional deficits after multiple concussions.[4,5] This study is consistent with prior smaller studies that reported no effect of multiple concussions on ImPACT® testing.[20–22] Most recently, Brooks et al. showed no association between prior concussions and baseline neurocognitive performance.[10]

Although the association of prior concussion and cognitive composite scores did not remain in multivariate modeling, the association between baseline symptoms and number of concussions was present after controlling for possible confounders. This finding supports a recent study by Brooks et al. that found that 13- to 17-year-old elite male hockey players with a prior history of multiple concussions had greater baseline symptom scores compared to those without a similar history.[10] Having excluded subjects with a concussion within 6 months of baseline testing, our study adds to the growing literature that suggests that a history of multiple concussions is associated with differences in subjective symptom burden.[16–18,22] Further studies are warranted to explore whether this increase in subjective symptoms scores in high school athletes with history of multiple concussions is associated with the long-term development of depression, anxiety, or other mental health problems.

In this study, there were consistent gender-associated differences in both ImPACT® cognitive composite scores and symptoms scores. Girls had higher scores on verbal

Table 3. Effect of concussion history on baseline ImPACT testing.

	Univariate model β		Multivariate model						
	R^2	Number of prior concussions β (95% CI)	R^2	Number of prior concussions β (95% CI)	Gender β (95% CI)	Age β (95% CI)	Headache/migraine β (95% CI)	Psychiatric history β (95% CI)	Learning problems β (95% CI)
Verbal memory	0.00	−0.43 (−0.83, −0.02)*	0.02	−0.22 (−0.65, 0.22)	1.69 (1.12, 2.22)*	0.01 (−0.09, 0.12)	−0.15 (−1.01, 0.72)	−0.46 (−1.60, 0.68)	−2.92 (−3.79, −2.05)*
Visual memory	0.00	0.03 (−0.53, 0.58)	0.01	0.22 (−0.39, 0.82)	−1.08 (−1.81, −0.35)*	−0.03 (−0.16, 0.09)	−0.75 (−1.93, 0.43)	−0.72 (−2.39, 0.94)	−3.22 (−4.41, −2.04)*
Processing speed	0.00	−0.02 (−0.29, 0.33)	0.04	0.10 (−0.25, 0.44)	1.11 (0.72, 1.51)*	0.21 (0.08, 0.34)*	−0.14 (−0.79, 0.52)	1.09 (0.18, 2.00)*	−3.48 (−4.12, −2.83)*
Reaction time	0.00	0.00 (−0.00, 0.00)	0.01	0.00 (−0.00, 0.00)	−0.00 (−0.00, 0.00)	−0.00 (−0.00, 0.00)	−0.00 (−0.00, 0.00)	−0.01 (−0.02, 0.00)	0.02 (0.02, 0.03)*
Impulse control	0.00	0.33 (0.12, 0.54)*	0.02	0.31 (0.05, 0.56)*	−0.52 (−0.79, −0.25)*	−0.13 (−0.20, −0.06)*	−0.11 (−0.57, 0.33)	0.05 (−0.57, 0.67)	1.29 (0.83, 1.76)*
Post-concussion scale	0.01	1.28 (0.92, 1.64)*	0.10	0.95 (0.42, 1.5)*	1.75 (1.30, 2.20)*	0.02 (−0.04, 0.09)	3.83 (2.86, 4.81)*	7.52 (5.90, 9.14)*	1.71 (0.93, 2.49)*

ImPACT, Immediate Post-Concussion Assessment and Cognitive Testing.
$^*P < 0.05$.

memory and processing speed, and boys had higher scores on visual memory. Girls reported more baseline symptoms than boys. In a large study of Division I National Collegiate Athletic Association athletes, Covassin et al. also found that women athletes had better verbal memory scores and greater symptom scores compared to men, but lower visual memory scores.[23] Our study extends these findings to a large sample of high school athletes. In addition, we found that a history of developmental and learning problems was consistently associated with all the ImPACT® measures. Subjects who reported a history of learning problems (including ADHD) had lower composite scores in verbal memory, visual memory, and processing speed, slower reaction time, greater impulse control scores, and greater symptom scores. These findings support prior recent work by Zuckerman et al. who showed that athletes with a history of ADHD or learning problems had significantly lower verbal memory, visual memory, and visual motor processing speed scores, slower reaction time, and greater symptom scores.[24] Student athletes who reported a history of medical treatment for headaches or migraines also reported greater baseline symptoms. It is important to note that the variable that was most strongly associated with baseline symptom reporting was history of mental health problems. This is consistent with past studies showing that student athletes with symptoms of depression also report diverse post-concussion-like symptoms during preseason testing.[25]

This study has several important limitations. First, the self-report of prior concussion is subject to recall bias as well as reporting bias. Although many prior studies have used self-report of prior concussion, prospective data would be ideal. Second, the results of this study might not translate to other states, where statewide concussion initiatives and awareness might alter the self-reported incidence and prevalence of concussion in high school athletes. Third, this study employed ImPACT®, a computerized screen of neurocognitive abilities. It is possible that more comprehensive testing of neurocognitive functioning, or more sensitive tests, would discern an effect of multiple prior concussions not found in this study. Fourth, while this is the largest study of high school athletes to our knowledge, the number of adolescents with four or more prior concussions was still small, and the effect of multiple injuries may therefore be subject to sample size error. Further studies are needed to evaluate longer term effects of multiple concussions in high school athletes.

Conclusion

It is essential to appreciate that concussion history is only one of many factors that relate to symptom reporting in adolescent student athletes. In this study, the multivariate model revealed that several factors were significantly related to baseline, preseason symptom reporting. In descending order of magnitude, baseline symptom reporting was related to: mental health history, headache/migraine history, gender, developmental and/or learning problems, and number of prior concussions. In total, those factors accounted for only 10% of the variance in total symptom scores. Therefore, additional research is needed to better understand and quantify the diverse range of factors that can influence symptom reporting in adolescent athletes.

Conflicts of Interest

None declared.

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