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Multiple prior concussions are associated with symptoms in high school athletes

Rebekah Mannix1,2, Grant L. Iverson2,3,4,5, Bruce Maxwell6, Joseph E. Atkins7, Ross Zafonte2,3,4,5 & Paul D. Berkner8

1Division of Emergency Medicine, Boston Children’s Hospital, Boston, Massachusetts
2Harvard Medical School, Boston, Massachusetts
3Department of Physical Medicine and Rehabilitation, Harvard Medical School, Boston, Massachusetts
4Red Sox Foundation and Massachusetts General Hospital Home Base Program, Boston, Massachusetts
5Spaulding Rehabilitation Hospital, Boston, Massachusetts
6Department of Computer Science, Colby College, Waterville, Maine
7Department of Psychology, Colby College, Waterville, Maine
8Health Services, Colby College, Waterville, Maine

Correspondence
Rebekah Mannix, Division of Emergency Medicine, Boston Children’s Hospital, 300 Longwood Avenue, Boston, MA 02115. Tel: 617-355-9858; Fax: 617-730-0335; E-mail: rebekah.mannix@childrens.harvard.edu

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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. 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. Another similar study showed no effect of one or two previous concussions on computerized neurocognitive testing. 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. 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 scores on the PCS ($P < 0.001$).

### Table 1. Characteristics of the study sample.

| Age | N (%) |
|-----|-------|
| 16 (2.7) | |

| Gender | N (%) |
|-------|-------|
| Male 3415 (56.9) | |
| Female 2590 (43.1) | |

| Sport (boys) | N (%) |
|-------------|-------|
| 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) | N (%) |
|---------------|-------|
| 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 | N (%) |
|-----------------------------|-------|
| 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 | N (%) |
|------------------------------|-------|
| 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 | N (%) |
|-----------------------------------|-------|
| No treatment for psychiatric condition 4948 (82.4) | |
| Missing 742 (12.4) | |

1Data are mean (SD).
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.\(^\text{10,11,15}\)

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\(^\text{®}\) 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, 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.\(^\text{10}\) 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.\(^\text{16-18,22}\) 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\(^\text{®}\) 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 β |
|-------------------|--------------------|----------------------|
|                   | R²                 | R²                  |
| Number of prior concussions β (95% CI) | 0.02 (−0.22, 0.22)* | 0.01 (−0.09, 0.12) |
| Gender β (95% CI) | 1.69 (1.12, 2.22)* | 0.21 (0.08, 0.34)* |
| Age β (95% CI)    | 0.01 (−0.09, 0.12) | 0.01 (−0.09, 0.12) |
| Headache/migraine β (95% CI) | 0.01 (−0.09, 0.12) | 0.01 (−0.09, 0.12) |
| Psychiatric history β (95% CI) | 0.01 (−0.09, 0.12) | 0.01 (−0.09, 0.12) |
| Learning problems β (95% CI) | 0.01 (−0.09, 0.12) | 0.01 (−0.09, 0.12) |

ImPACT, Immediate Post-Concussion Assessment and Cognitive Testing.

*P < 0.05.
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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