Early Indicators of Enduring Symptoms in High School Athletes With Multiple Previous Concussions

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Received, June 14, 2010.
Accepted, October 21, 2010.

BACKGROUND: Despite recent findings of cognitive, emotional, physical, and behavioral symptomatology in retired professional athletes with a history of multiple concussions, there is little systematic research examining these symptoms in high school athletes with a history of concussion.

OBJECTIVE: To identify cognitive, emotional, and physical symptoms at baseline in nonconcussed high school athletes based on concussion history.

METHODS: A multicenter sample of 616 high school athletes who completed baseline evaluations were assigned to groups based on history of concussion (none, 1, 2, or more previous concussions). The Post-Concussion Symptom Scale was administered as part of a computerized neuropsychological test battery during athletes' preseason baseline evaluations. Cross-sectional analyses were used to examine symptoms reported at the time of baseline neuropsychological testing.

RESULTS: High school athletes with a history of 2 or more concussions showed significantly higher ratings of concussion-related symptoms (cognitive, physical, sleep difficulties) than athletes with a history of one or no previous concussions.

CONCLUSION: It appears that youth athletes who sustain multiple concussions experience a variety of subtle effects, which may be possible precursors of the future onset of concussion-related difficulties.

KEY WORDS: Concussion symptoms, Long-term effects, Post-Concussion Symptom Scale, Postconcussion syndrome

Neurosurgery 68:1562–1567, 2011 DOI: 10.1227/NEU.0b013e31820e382e www.neurosurgery-online.com

Sports-related concussion has become so commonly discussed that it is difficult to watch a televised professional football or ice hockey game without hearing about athletes sustaining, recuperating from, or returning to play after a concussion. Approximately 1.6 to 3.0 million concussions occur every year in the United States,[1] which has caused the Centers for Disease Control and Prevention to identify concussion from sports at an "epidemic level" in the United States.[2]

A history of repeated concussions has been linked to significant emotional sequelae and related brain tissue pathology.[3-5] The long-term effects of multiple concussions in professional football players have been documented in cases of chronic traumatic encephalopathy (CTE) and neurodegeneration in adult athletes.[3,4,6] Similarly, former high profile athletes with a history of concussion have been found to experience significant depression and cognitive impairment.[7,8] As a result of these findings, there is concern that repeated concussions can result in brain pathology that leads not only to cognitive difficulties, but to serious emotional sequelae in later life.[7,8] In a study of 2552 retired professional football players with a history of concussion, those who had reported 3 or more previous concussions were 3 times more likely to be diagnosed with depression than those players who reported no history of concussion.[8]

ABBREVIATIONS: CTE, chronic traumatic encephalopathy; **MANOVA,** multivariate analysis of variance; **PCSS,** Post-Concussion Symptom Scale

The prevalence of sports-related concussion in youth athletes (high school age and younger) has the potential for an even greater public health problem than previous generations because youth now begin sports at earlier ages and play multiple sports year round.[9] Researchers[10] have estimated the rate of concussion in high school athletes to be as high as 17.15 per 100 000 athlete exposures, whereas others[11] have observed that 63% of a sample of 223 high school students reported at least 1 previous concussion. Similar to adults, high school and college athletes have been shown to increase their likelihood of sustaining a second concussion after the first.[12] Specifically, high school athletes who had been concussed were 3 times more likely to have another concussion in the same season.[13] High school athletes who had sustained 3 or more concussions were more likely to experience loss of consciousness with future concussions.[14] Healthy high school students with a history of 2 or more concussions exhibited poorer performance on cognitive testing than healthy students with a history of 1 or no concussion.[11]

Similar to postmortem findings in adults, pathologists documented the first case of CTE in an 18-year-old football player.[15] These troubling findings beg the question of whether high school athletes with a history of repeated concussions may also be exhibiting the reported cognitive, emotional, physical, and behavioral symptomatology as seen in retired professional athletes with CTE.[16] The purpose of this study was to identify possible precursors to postconcussion syndrome by documenting emotional and behavioral symptoms in high school athletes who had sustained multiple concussions before adulthood. The authors hypothesized that healthy high school athletes with a history of multiple concussions would demonstrate more concussion-related symptoms in physical, emotional, cognitive, and sleep domains compared with high school athletes with a history of 1 or no concussion.

PARTICIPANTS AND METHODS

Participants

Participants were 2557 high school athletes from high schools in Michigan, New Jersey, and Pennsylvania. The athletes selected for this study were practicing and/or competing in the academic/athletic seasons between 1997 and 2008. High school athletes were 12.0 to 16.9 years of age (mean, 15.08, standard deviation, 0.80). In those cases when athletes completed a second follow-up baseline evaluation after resolution of a concussion, only their first baseline data were used. Also, to control for suboptimal effort and invalid baseline scores, athletes scoring more than 30 on the ImPACT Impulse Control composite score were excluded from analyses (n = 342; approximately 13%).

Athletes were assigned to independent groups based on self-reported history of concussion: none (n = 1850), 1 previous (n = 260), or 2 or more previous (n = 105). As this yielded unequal groups, 251 athletes were randomly sampled from the no previous concussion group (matching for age and history of learning problems) to balance group sizes. As such, there were no significant between-group differences on age ($F_{2,426}$ = 1.20; P = .30) or likelihood of self-reporting learning problems (eg, attended special education, received speech therapy, having a diagnosis of attention-deficit/hyperactivity disorder or learning disorder (χ^2_2 = 5.39; P = .07). No athletes in the 1 previous and 2 or more previous concussion groups had sustained a concussion within the past 4 months. Although the mean time since concussion was more than 2 years for both concussion groups, athletes in the 2 or more concussions group had a significantly shorter time since concussion ($F_{1,171}$ = 12.05; P = .001). Sixty-two percent of the athletes were male, with no significant differences in sex distribution across concussion history groups (χ^2_2 = 0.62; P = .73). Athletes in the 2 or more concussion group were significantly more likely to have received treatment for headache (χ^2_2 = 12.6; P = .002) and migraines (χ^2_2 = 8.0; P = .02) (Table 1).

Outcome Measures

Because of the multiyear, multisite location of data collection, ImPACT versions 1.2 through 6.7 were used for the study. The ImPACT instrument is a computer-based program used to assess neuropsychological (also referred to as neurocognitive) function and concussion symptoms. Concussion-related symptoms are self-reported by athletes using the Post-Concussion Symptom Scale (PCSS[17]), and this scale remained unchanged in ImPACT versions 1.2 to 6.7. The PCSS requires athletes to report their "current" experience of concussion-related symptoms and to choose the number that best describes the way they have been feeling that day. Symptoms are presented 1 at a time on the computer screen (as listed in Table 2) on a 0 to 6 scale, with 0 denoting no symptoms, and 1 to 6 denoting mild to severe symptoms. Symptoms were further categorized into physical, emotional, cognitive, and sleep, in accordance with Pardini et al[18] (Table 2).

TABLE 1. Group Demographics[a]

	0 Concussions (n = 251)	1 Concussion (n = 260)	≥2 Concussions (n = 105)
Sex[b]			
Male	167 (66.5%)	179 (68.8%)	74 (70.5%)
Female	84 (33.5%)	81 (31.2%)	31 (29.5%)
Age[c]	15.8 (1.2)	15.8 (2.0)	16.1 (1.3)
Learning problems[d]			
Yes	47 (18.7%)	42 (16.2%)	28 (26.7%)
No	204 (81.3%)	218 (83.8%)	77 (73.3%)
Treatment for headache[e]			
Yes	22 (8.8%)	44 (16.9%)	23 (21.9%)
No	229 (91.2%)	216 (83.1%)	82 (78.1%)
Treatment for migraine[f]			
Yes	16 (6.4%)	32 (12.3%)	16 (15.2%)
No	235 (93.6%)	228 (87.7%)	89 (84.8%)
Last concussion, y[g]	—	3.7 (3.2)	2.2 (2.0)

[a]Sex, learning problems, headache, and migraine data presented as number (%) and age data presented as mean (standard deviation).
[b]χ^2_2 = 0.62; P = .73.
[c]$F_{2,426}$ = 1.20; P = .30.
[d]Learning problems denotes those athletes self-reporting having attended special education, received speech therapy, or having had a diagnosis of attention-deficit/hyperactivity disorder or learning disorder; no. (%); χ^2_2 = 5.39; P = .07.
[e]χ^2_2 = 12.6; P = .002.
[f]χ^2_2 = 8.0; P = .02.
[g]$F_{1,171}$ = 12.05; P = .001.

TABLE 2. Physical, Cognitive, Emotional, and Sleep Symptom Clusters[a]

Physical	Cognitive	Emotional	Sleep
Headache	Feeling mentally "foggy"	Irritability	Drowsiness
Nausea	Feeling slowed down	Sadness	Sleeping less than usual
Vomiting	Difficulty concentrating	More emotional	Sleeping more than usual
Balance problems	Difficulty remembering	Nervousness	Trouble falling asleep
Dizziness			
Visual problems			
Fatigue			
Sensitivity to light			
Sensitivity to noise			

[a]Symptom clusters from Pardini et al.[18]

Protocol

Athletes completed a baseline neuropsychological evaluation as part of their institutional requirements for participation in athletics. Permission for inclusion of data in research was obtained and approved by institutional review boards, and parental consent and student assent were obtained from all student athletes who volunteered to participate in this study. Athletes reported to their own institution's computer laboratory where the test procedures were explained to them. Athletes completed the PCSS as the first part of the ImPACT computerized neuropsychological test battery, all of which required approximately 40 minutes.

Data Analysis

Two multivariate analyses of variance (MANOVAs) were conducted, using the following dependent variables: (1) all 22 baseline concussion-related symptoms and (2) baseline concussion symptoms grouped into physical, emotional, cognitive, and sleep symptom clusters.

To determine the likelihood of self-reporting or endorsing symptoms within a specific symptom cluster, athletes were subsequently assigned to 2 independent groups based on having reported no symptoms (eg, a score of 0) or the presence of symptoms (a score of 1 to 6 on any symptom) within the symptom cluster. After the presence of symptom endorsement was dichotomized within each symptom cluster (yes/no), χ^2 analyses were performed to identify the likelihood of a specific type of symptom endorsement as a function of concussion history.

Effect sizes are reported as partial η_p^2 (for MANOVAs) and Cramer's V (V for χ^2 analyses). All analyses were conducted using SPSS, version 16 (SPSS Inc., Chicago, Illinois). A priori statistical significance was set at $P < .05$ for all analyses, and exact P values are documented.

RESULTS

Concussion-Related Symptoms in High School Athletes

MANOVA (Wilks Λ) revealed a significant multivariate effect of concussion history group on concussion-related symptoms at baseline ($F_{66,1765} = 6.57$; $P = .001$; $\eta_p^2 = 0.20$). Subsequent univariate analyses revealed that multivariate effects were explained by group differences in all 22 symptoms ($P = .001$). Post hoc analyses revealed high school athletes with a history of 2 or more concussions endorsed higher ratings on headache, balance problems, and dizziness than their peers with a history of 1 or no concussion; high school athletes with a history of 2 or more concussions endorsed higher ratings on nausea and fatigue than did their peers with a history of no concussion (Table 3).

Concussion-Related Symptoms Group by Symptom Cluster

MANOVA (Wilks Λ) revealed a significant multivariate effect of concussion history group on concussion-related symptoms grouped by category at baseline ($F_{12,1614} = 29.1$, $P = .001$; $\eta_p^2 = 0.16$). Subsequent univariate analyses revealed that multivariate effects were explained by group differences on all 4 symptom clusters ($P = .001$). Post hoc analyses revealed high school athletes with a history of 2 or more concussions endorsed higher ratings on physical symptoms compared with high school athletes with a history of 1 or no previous concussion (Table 4).

Symptom Endorsement by Concussion Group and Symptom Cluster

After symptom scores were recoded within each symptom cluster to reflect whether an athlete endorsed any symptoms in the cluster, χ^2 analyses revealed that athletes in the 2 or more previous concussions group were significantly more likely to endorse symptoms within the physical ($\chi^2_2 = 11.90$; $P = .003$; V = 0.14), cognitive ($\chi^2_2 = 7.48$; $P = .024$; V = 0.11), and sleep ($\chi^2_2 = 8.85$; $P = .012$; V = 0.12) symptom clusters than athletes in the 1 or no previous concussion groups; no significant differences were noted for the emotional symptom cluster ($\chi^2_2 = 3.91$; $P = .14$; V = 0.08) (Table 5).

DISCUSSION

The concussion sequelae of dementia and depression in adults have recently received widespread attention, have been discussed at Congressional hearings, and have spurred the National Football League to support scientific investigation of this public health concern.[19] With this concern in mind, this study sought to identify whether precursors of postconcussion syndrome, as well as other cognitive, emotional, physical, and sleep difficulties, might be present during the adolescent athletic years of development. In this study, high school athletes at baseline (with no recent concussion) were asked to endorse and rate any symptoms that they might be experiencing based on a checklist of cognitive, emotional, physical, and sleep symptoms. It was observed that student athletes with a history of concussion consistently endorsed more symptoms than their peers who had no concussion history. Subtle, yet statistically significant differences in the level of symptomatology were identified, resulting in those athletes

TABLE 3. Concussion Symptoms by Concussion History Group[a]

Symptom	None	1	≥2	*F*	η_p^2
Physical					
Headache	0.60 (1.2)	0.70 (1.3)	1.08 (1.5)	68.8[b]	0.25
Nausea	0.10 (0.5)	0.19 (0.7)	0.30 (0.9)	15.3[b]	0.07
Vomiting	0.00 (0.0)	0.03 (0.2)	0.05 (0.3)	4.8[c]	0.02
Balance problems	0.07 (0.5)	0.04 (0.3)	0.19 (0.6)	9.5[b]	0.05
Dizziness	0.12 (0.7)	0.21 (0.7)	0.42 (1.0)	24.8[b]	0.11
Visual problems	0.12 (0.6)	0.12 (0.6)	0.18 (0.8)	9.3[b]	0.04
Fatigue	0.68 (1.5)	0.94 (1.5)	1.12 (1.6)	77.7[b]	0.28
Sensitive to light	0.10 (0.8)	0.20 (0.7)	0.21 (0.7)	12.9[b]	0.06
Sensitive to noise	0.08 (0.4)	0.12 (0.6)	0.13 (0.5)	7.9[b]	0.04
Numbness/tingling	0.08 (0.4)	0.10 (0.6)	0.21 (0.8)	9.3[b]	0.04
Cognitive					
Feeling mentally foggy	0.12 (0.6)	0.16 (0.6)	0.27 (0.8)	13.9[b]	0.06
Feeling slowed down	0.30 (0.9)	0.30 (0.8)	0.38 (1.0)	24.7[b]	0.11
Difficulty concentrating	0.45 (1.2)	0.53 (1.2)	0.65 (1.3)	38.8[b]	0.16
Difficulty remembering	0.26 (0.9)	0.26 (0.9)	0.38(1.1)	18.4[b]	0.08
Emotional					
Irritability	0.34 (1.0)	0.39 (1.1)	0.59 (1.3)	29.1[b]	0.13
Sadness	0.44 (1.2)	0.29 (0.9)	0.37 (1.1)	24.7[b]	0.11
Feeling more emotional	0.31 (1.0)	0.30 (1.0)	0.36 (1.1)	20.1[b]	0.09
Nervousness	0.54 (1.2)	0.45 (1.1)	0.70 (1.4)	44.0[b]	0.18
Sleep					
Drowsiness	0.65 (1.3)	0.69 (1.2)	0.81 (1.3)	64.3[b]	0.24
Trouble falling asleep	0.59 (1.4)	0.69 (1.4)	0.57 (1.2)	43.6[b]	0.18
Sleeping more than usual	0.27 (1.0)	0.20 (0.8)	0.42 (1.1)	17.5[b]	0.08
Sleeping less than usual	0.43 (1.2)	0.54 (1.2)	0.70 (1.5)	36.4[b]	0.15

[a]Scores presented as mean (standard deviation).
[b]Significant at the .001 level.
[c]Significant at the .003 level.

with multiple concussions experiencing more difficulties. In the absence of a direct, causal relationship, it is not clear whether high school athletes with a history of multiple concussions are experiencing enduring postconcussion symptoms or are simply more sensitive to physical, cognitive, and emotional fluctuations. Given that athletes with a history of multiple concussions are more likely to report concussion-related symptoms at baseline and that these athletes were more likely to have sought treatment (eg, for headaches), the current results may reflect a combination of enduring symptoms and increased sensitivity to these symptoms.

TABLE 4. Concussion Symptom Clusters by Concussion History Group

Symptom Cluster	None	1	≥2	*F*	η_p^2
Physical	1.89 (3.3)	2.65 (3.8)	3.89 (4.9)	98.1[a]	0.32
Cognitive	1.10 (2.6)	1.25 (2.6)	1.68 (3.1)	46.3[a]	0.19
Emotional	1.61 (3.3)	1.43 (2.8)	2.02 (3.3)	55.5[a]	0.21
Sleep	1.91 (3.1)	2.12 (3.0)	2.50 (3.0)	98.2[a]	0.33

[a]Significant at the .001 level.

This study is not without its limitations. First, although data were gathered prospectively as part of ongoing concussion testing and management programs, athletes were retrospectively assigned to groups. As such, the experimental design is cross-sectional and lacks the controls traditionally seen in longitudinal studies. As a result, it was not possible to place a priori controls or measurements for all demographic variables that could influence

TABLE 5. Percentage of Athletes Endorsing Symptoms by Cluster and Concussion Group

	Previous Concussion Group		
Cluster	None	1	≥2
Physical[a]	46.0%	57.7%	63.8%
Cognitive[b]	24.4%	31.9%	38.1%
Emotional	32.0%	34.2%	42.9%
Sleep[c]	43.6%	52.3%	60.0%

[a]Significant at the .003 level.
[b]Significant at the .012 level.
[c]Significant at the .025 level.

symptom reporting. Second, concussion-related symptoms were based on self-report by student athletes and not on objective observations or interviews. Patient recall of symptoms in an open-ended interview was found to be more conservative than in a closed-ended questionnaire.[20] Although decreased symptom reporting in a face-to-face interview may be expected in a high school sample of athletes with a history of concussion, such tendencies have not been extended to, and may not apply to, nonconcussed high school athletes. Third, although symptom data from athletes were restricted to their first documented exposure to the PCSS in high school, it is possible that some athletes had been previously exposed to the scale, particularly those with a history of multiple concussions. Similarly, athletes with a history of multiple concussions may have been exposed to concussion symptoms and terminology, but not the PCSS or formal neuropsychological testing, making them more likely to be familiar with symptoms included on the PCSS. Fourth, test-retest data for symptom reporting in high school athletes reflect moderate stability over a 7-day range (intraclass correlation coefficient = 0.65[21]). In context of the current results, athletes with a history of multiple concussions may be experiencing a greater incidence of symptoms or possibly more variability.

Despite these limitations, this is the first study to document increased concussion-related symptoms in nonconcussed high school athletes based on multiple previous concussions. Our sample size was quite large compared with previous studies investigating the history of multiple concussions.[11,14,22] Although the generalizability of these results may be tempered by the limitations of the study, the current findings raise the possibility that the process of cognitive impairment and symptom destabilization related to postconcussion syndrome in adult athletes exposed to multiple concussions may start as early as the adolescent years. The vulnerability of youth brains has been a topic of controversy and speculation in the clinical management of pediatric sports concussion. Younger brains have been postulated to be more vulnerable and exhibit longer recovery periods after concussive injury,[23] and high school athletes have been shown to recover more slowly than collegiate[24] or professional[22,25] athletes. Furthermore, there has been some support for the enduring effects of concussion in youths,[11] although that finding has been challenged.[26]

The implications of these findings may extend not only to the management of youth athletes with a history of multiple concussions, but also beyond. Coaches, parents, athletic trainers, school physicians, and all individuals involved in the organization, implementation, and supervision of high school and youth athletics may need to consider policy and practice revisions to ensure the long-term safety of sport participants. Although it may be premature to place widespread restrictions on athletic participation for high school athletes with a history of multiple concussions based solely on the results of this study, particular care with youths is advised. Future, prospective (and perhaps longitudinal) research should focus on tracking emotional destabilization and cognitive impairment in high school and youth athletes with and without a history of concussion.

These research findings in a substantial sample of youth athletes should serve as a caution for parents, coaches, and sports medicine personnel supervising high school and other youth athletes with a history of concussion. Furthermore, these study results support the recent surge in advocacy on state and federal governmental levels to establish youth concussion management programs and to better regulate the rules of youth sports.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Acknowledgment

The authors thank Jeffrey Trichon, FCAS, MAAA, for assistance with data preparation.

COMMENT

Examining the long-term outcome of mild traumatic brain injury (mTBI) in younger, more vulnerable, student athletes is critical for establishing effective pre- and postinjury systems of care and appropriate postinjury management guidelines. The study by Schatz et al titled presents thought-provoking findings regarding possible enduring symptom patterns in multiply concussed high school student athletes. Prolonged injury recovery and the potential for long-term "cognitive impairment and symptom destabilization" exhibited in these adolescents with multiple injuries is indeed a concerning prospect.

A better understanding of the relationship between persisting post-concussion symptoms after multiple injuries and potential underlying neuropathological change is still needed. Recent research examined the association between subjective postinjury symptom report and imaging measures of neuronal dysfunction after a single mTBI.

Chu et al[1] and Wilde et al[2] showed a correlation between increased symptom reporting and abnormal axonal integrity (decreased fractional anisotropy and increased diffusivity) through diffusion tensor imaging.

Decreases in the neurometabolites glutamate and *N*-acetylaspartate, assessed through proton magnetic resonance spectroscopy, have also been correlated with concussive symptom severity in a study of adult athletes.[3] However, in the extant literature (and in particular research with animals), it is predominantly reported that the pathophysiology of a single mTBI results in temporary neural dysfunction, not permanent damage.[4,5] Establishing how and why pathological change after multiple injuries may be different and in particular why multiple injuries may lead to persisting symptoms is crucial.

In the Schatz et al article, symptom differences became apparent across retrospective group samples. From a study design perspective, a known limitation of group research is that group differences do not apply to all individual cases and may not apply to all clinical subgroups. A particular attribute of a subgroup may provide protection from a harmful effect that can more readily occur in the population. Conversely, a particular group trait may make a subgroup more vulnerable to a deleterious effect relative to the population. Clinical trials research provides useful examples of how the hidden risks or benefits of treatment may not be visible through group analyses, but important findings can be identified after studying subgroups.[6]

The broad range of individual outcomes after TBI will also be hidden within group level analysis. Indeed, in the case of pediatric mTBI, some student athletes may have preinjury risk factors (developmental disabilities, neurological or psychiatric premorbidities, genetic profiles), unique injury characteristics (severity of injury, nature of the force or forces sustained), or postinjury behaviors (immediate postinjury physical activity, sustained physical or cognitive exertion during recovery, repeat injuries), which individually, or in combination, may modify that particular individual's recovery. Iverson[4] proposed that anxiety and/or depression may relate to persistent symptoms after multiple mTBIs and that the nature of self-reported symptoms may make respondents vulnerable to expectancy bias or attributional errors. Nevertheless, the search to identify which individuals may have worse outcomes after multiple mTBIs has only begun, and the increase in reported symptoms in the Schatz et al sample of multiply concussed adolescents is compelling. Understanding who these individuals are and why their symptoms persist is important.

Elucidating individual differences in mTBI outcome will ultimately serve to predict who is at greatest risk and what can be done to help them.

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