Prolonged Effects of Concussion in High School Athletes

Rosemarie Scolaro Moser, Ph.D.
RSM Psychology Center, LLC, Lawrenceville, New Jersey

Philip Schatz, Ph.D.
Department of Psychology, Saint Joseph's University, Philadelphia, Pennsylvania

Barry D. Jordan, M.D.
Brain Injury Program, Burke Rehabilitation Hospital, White Plains, New York

Reprint requests:
Rosemarie Scolaro Moser, Ph.D., ABPN, ABPP-RP, Director, RSM Psychology Center, LLC, 3131 Princeton Pike, Building 5, Lawrenceville, NJ 08648.
Email: r.moser@rcn.com.

Received, October 4, 2004.
Accepted, February 18, 2005.

OBJECTIVE: To identify enduring prolonged neuropsychological effects of cerebral concussion in high school youth athletes.

METHODS: High school athletes (n = 223) underwent baseline neuropsychological evaluation between 1999 and 2000, assigned to independent groups on the basis of concussion history: athletes with no concussion history or present medical and/or neuropsychological complaints (n = 82), symptom-free athletes who experienced one (n = 56) or two or more (n = 45) concussions (not in the prior 6 mo), and those who experienced a concussion 1 week before testing (n = 40). Main outcome measures included a structured clinical interview, demographic form, symptom checklist, the Repeatable Battery for the Assessment of Neuropsychological Status, and the Trail Making Tests A and B. Analyses of variance were used to determine between-group differences.

RESULTS: Athletes with recent concussions performed significantly worse on measures of attention and concentration than youth athletes with no concussion history. Symptom-free athletes with a history of two or more concussions performed similar on testing to youth athletes who had just experienced a recent concussion. Similarly, cumulative academic grade point averages were significantly lower not only for youth athletes with two or more previous concussion groups, but for youth athletes who experienced recent concussions, suggesting that athletes with lower grade point averages may be more prone to concussion.

CONCLUSION: There seem to be subtle yet significant prolonged neuropsychological effects in youth athletes with a history of two or more previous concussions.

KEY WORDS: Baseline screening, Concussion, Mild head injury, Neuropsychological testing, Youth sports

Neurosurgery 57:300-306, 2005 DOI: 10.1227/01.NEU.0000166663.98616.E4 www.neurosurgery-online.com

The epidemiology and implications of mild traumatic brain injury (e.g., concussion) are well documented (15, 28), and comprehensive programs for the assessment and management of sports-related concussion have become commonplace in college (6, 10, 16) and high school athletics (7, 28). In 1983, data on concussion rates among high school football players alone numbered 250,000 concussions per year, with 20% of all high school football players sustaining a yearly concussion (12). Powell and Barber-Foss (28) have since provided the most comprehensive breakdown of concussion incidence among high school athletes, with 3-year (1995–1997) concussion rates for a variety of sports, and have approximated the number of concussions in high school varsity athletics at 63,000 during this 3-year time span, or 5.5% of all sports-related injuries reported among 235 high schools.

Baseline and postconcussion assessment of athletes for the purpose of diagnosing cerebral concussions and managing return-to-play decisions was established by the hallmark Virginia football studies, in which symptoms after cerebral concussion were found to be alleviated after approximately 10 days (2, 4). Postconcussion symptoms in college athletes were later demonstrated to last up to 1 month after the injury (10). Recent research has demonstrated that a history of multiple previous concussions resulted in prolonged effects as observed in lowered performances on baseline testing (19) as well as demonstrating the synergistic effects of concussion history and learning disability (8). Three or more previous concussions have been demonstrated to have cumulative effects in high school athletes with respect to more severe on-field presentation of concussion markers (e.g., loss of consciousness, anterograde amnesia, confusion) (7). Concussed high school athletes have been demonstrated to experience prolonged memory dysfunction compared with college athletes as well as more protracted recovery curves (11). The importance of concussion management and the use of neuropsychological assessment in evaluating athletes are well documented (17), and the National Football League recently published findings from a 5-year study investigating numerous factors contributing to how professional athletes sustain and recover from cerebral concussion (20–27).

The current prospective study sought to identify enduring effects of concussion by investigating whether recently concussed youth athletes, youth athletes with no history of concussion, youth athletes with a history of one previous concussion, and youth athletes with a history of two or more previous concussions differed significantly in symptomatology and neuropsychological functioning.

SUBJECTS AND METHODS

Subjects

Subjects were 238 high school athletes attending a highly selective and academically competitive secondary boarding school in suburban New Jersey. These student athletes (age range, 13–19 yr) participated in a number of sports (predominantly ice hockey, football, field hockey, lacrosse, and soccer), and most participated in multiple sports throughout the year.

Program Protocol and Outcome Measures

Subjects were assigned to independent groups on the basis of the number of previous concussions or recency of concussion without regard to severity or grade. Eighty-two of the participants had never experienced a concussion of any grade, did not complain of overt symptoms or difficulties related to concussion at the time of their assessment, and were assigned to the "No Concussion" group. Fifty-six of the participants had previously experienced a concussion (but not within the past 6 mo), did not complain of overt symptoms or difficulties related to concussion at the time of their assessment, and were assigned to the "One Previous Concussion" group. Forty-five of the participants had previously experienced two or more concussions (but not within the past 6 mo), did not complain of overt symptoms or difficulties related to concussion at the time of their assessment, and were assigned to the "Two or More Previous Concussions" group. The remaining 40 participants had experienced a concussion within 1 week before testing and were assigned to the "Recent Concussion" group. Of these 40 participants, 9 subjects had experienced a single previous concussion and 23 had experienced two or more previous concussions, with only 8 participants in this group experiencing their first concussion.

Each of the participants in the No Concussion, One Previous Concussion, and Two or More Previous Concussion groups completed a voluntary neuropsychological screen as part of a baseline assessment and completed these assessment measures on only one occasion. Participants in the Recent Concussion Group had not completed a baseline neuropsychological screen and were referred for postconcussion assessment by the school physician or nurse within 1 week of experiencing a concussion. Fifteen potential participants in the Recent Concussion group had already completed baseline assessments and were excluded from the study because of potentially confounding practice effects caused by previous preconcussion exposure to the assessment measures.

Participants, along with their parents, completed an orientation questionnaire and a concussion history form, which facilitated the documentation and description of history of concussion. All participants completed the Trail Making Test (TMT) Parts A and B (31), which assesses visual-fine motor attention, mental coordination, cognitive flexibility, and basic executive functioning. Total time and number of errors were scored and converted to levels according to norms provided by the authors of the test.

Participants were then administered the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) (30), an instrument that assesses a variety of cognitive areas, including Immediate Memory (List Learning and Story Memory), Visuoconstructional Ability (Figure Copy and Line Orientation), Language (Picture Naming and Semantic Fluency), Attention (Digit Span and Coding), and Delayed Memory (List Recall, List Recognition, Story Recall, and Figure Recall).

Participants also completed a postconcussion scale (16) adapted for youth athletes. The modified Youth Post Concussion Scale includes a list of 24 symptoms, such as headache, dizziness, nausea, sleep difficulties, concentration problems, and irritability, which may be associated with concussion. Participants identified any symptoms and rated symptom intensity on a 0 to 3 scale (3 = severe) at the time of their participation in the present study. The total possible score range on the Youth Post Concussion Scale is 0 to 72; the greater the score, the greater the symptomatology.

Baseline Evaluation Procedures

Voluntary participation was solicited through mailings and educational information dissemination to parents and school medical personnel. Participating parents and students completed informed consent forms, which described the purpose, objective, and details of the testing and research participation. For those youth participants 18 years of age or younger, parental consent and signature were required as well as participant assent; in cases of joint parental custody, both parent signatures were required. Institutional review board approval was obtained for this study through the Saint Joseph's University Institutional Review Board.

Demographic information forms were completed before the evaluation and documented any history of learning disorder (LD) or attention deficit disorder (ADD), cumulative academic grade point average (GPA), estimated verbal and math achievement percentiles (on the basis of student and parent self-report of the student athletes' most recent performance on standardized achievement testing), and history of head injury or concussion. At the time of assessment, a thorough interview was also conducted to solicit further confirmatory information regarding history of concussion. More specifically, the definition of concussion put forth by the American Academy of Neurology (3) was described to participants, and they were asked if their experiences were similar to that definition. They were then interviewed regarding any changes in cognition or physical functioning after a hit to the head, with specific questions related to headache, dizziness, nausea, "blacking out" or loss of consciousness, having their "bell rung" or "seeing stars," visual changes, slower thinking or reactions, or feeling "different" than before experiencing the hit to the head. Participants were assessed by one of four testers, who were trained and employed at the clinical practice conducting the evaluations. Because these testers also conducted the clinical interview, they were not blinded to the participants' concussion history.

Data Analysis

Demographic data were compared across concussion groups using analyses of variance and χ^2 analyses. One-way analyses of variance were conducted to analyze between-group differences on neuropsychological and academic performance variables, and specific between-group differences were identified using Scheffé post hoc analyses.

RESULTS

Demographic Data

Sixty-three percent of the 223 participants in the sample reported a history of at least one recent concussion or one or more previous concussions, and 60% reported a history of at least one previous concussion (*Table 1*). GPAs and estimated achievement percentiles were in the average to above-average range, which is commensurate with the private preparatory nature of the boarding school. Of note, athletes who reported a history of two or more concussions averaged a significantly greater number of years participating in contact sports as well as a significantly lower cumulative GPA (*Table 2*). Lower cumulative GPAs reported by recently concussed youth athletes cannot be attributed to acute effects of cerebral concussion.

TABLE 1. Prevalence of concussion in youth athlete sample (n = 223)

Concussion group[a]	No. of previous concussions			
	0	1	≥2	No. (%)
0 Concussions	82			82 (36.8%)
1 previous concussion		56		56 (25.1%)
≥2 previous concussions			45	45 (20.2%)
Recent concussion	8	9	23	40 (17.9%)

[a] Total participants with previous or recent concussion = 141 (63%); total participants with history of previous concussion = 133 (60%).

Prevalence of ADD in the study population was 7% (n = 16), and prevalence of LD in the study population was 8% (n = 18), with no significant distribution differences across concussion groups (P = 0.52). The lower prevalence of LD as compared with that reported in the general population may be explained by the academic selectivity of the school the participants attended. Of note, there was no appreciable group difference in prevalence of reported ADD or LD, obviating the attribution of ADD or LD to any differences in cognitive functioning across groups.

History of Previous Concussion

Between-groups analyses demonstrate a significant difference in postconcussion symptoms reported among the four groups; recently concussed youth athletes endorsed a greater number or greater intensity of postconcussion symptoms than did nonconcussed youth athletes with a history of concussion. Concussion history did not significantly affect total RBANS scores [$F(3,218) = 2.30$; $P = 0.08$], although there was greater variation in these scores among recently concussed athletes (*Table 3*).

To identify the possible prolonged cognitive effects of previous concussion, analyses of variance were performed on RBANS subtests and TMT A and B levels. Results reveal the RBANS Attention Subtest [$F(3,210) = 3.71$; $P = 0.012$] and TMT B [$F(3,215) = 4.21$; $P = 0.006$] to be significantly affected by concussion history (*Table 4*). Post hoc Scheffé analysis revealed that recently concussed youth athletes performed significantly worse on the RBANS Attention Subtest than youth athletes with no concussion history or a history of one previous concussion. As well, post hoc analysis revealed that recently concussed youth athletes performed significantly worse on the TMT B than youth athletes with no concussion history. Most notably, all post hoc analyses revealed that the cognitive performance of youth athletes who experienced recent concussions was not statistically distinguishable from that of athletes with two or more previous concussions.

Because 42.5% of subjects in the Recent Concussion group had also experienced at least one previous concussion, we analyzed those recently concussed youth athletes to determine if history of concussion had a significant effect on their cognitive performance. On nearly all the test measures, the performance of recently concussed youth athletes with a history of no or one previous concussion was not significantly different from that of recently concussed youth athletes with a history of two or more concussions (*Table 5*). Performance on the Delayed Memory subtest did reveal a significant between-group difference, with youth athletes with a history of no or one previous concussion performing worse than recently concussed youth athletes with a history of two or more concussions [$F(1,38) = 4.72$; $P = 0.036$].

DISCUSSION

These data demonstrate that recently concussed youth athletes have significantly impaired performance on tests of at-

TABLE 2. Demographic data for youth athlete participants

Variable	Range	Concussion history group[a]				Test of significance
		None	1 previous	≥2 previous	Recent	
Age (yr)	13 – 19	15.4 (1.2)	15.8 (1.3)	15.9 (1.3)	15.8 (1.3)	$F(3,219) = 1.9$ $P = 0.13$
Grade (education)	9 – 13	10.1 (1.0)	10.4 (1.1)	10.5 (1.1)	10.5 (1.1)	$F(2,319) = 2.28$ $P = 0.08$
Estimated verbal achievement percentile	40 – 99	86.7 (11.9)	85.6 (12.8)	81.5 (15.4)	81.9 (15.4)	$F(3,164) = 2.07$ $P = 0.10$
Estimated math achievement percentile	40 – 99	90.0 (11.1)	87.7 (13.0)	84.5 (13.5)	87.5 (10.6)	$F(3,166) = 1.65$ $P = 0.18$
Grade point average	2.0 – 4.0	3.54 (0.5)	3.35 (0.5)	3.21 (0.5)	3.26 (0.5)	$F(3,215) = 5.73$ $P = 0.0009$[b]
Sports years	1 – 16	5.6 (3.5)	7.1 (3.6)	7.7 (3.3)	6.7 (3.5)	$F(3,219) = 3.97$ $P = 0.009$[c]

[a] Means ± standard deviation.
[b] ≥2 previous and Recent concussion groups < No concussion group.
[c] ≥2 previous concussion group > No concussion group.

TABLE 3. Concussion symptomatology and Repeatable Battery for the Assessment of Neuropsychological Status total (composite) score[a]

Variable	Range	Concussion history group[b]				Test of significance
		None	1 previous	≥2 previous	Recent	
Youth post-concussion symptom scale	0 – 35	3.7 (4.1)	4.3 (5.9)	3.9 (4.6)	9.6 (8.1)	$F(3,216) = 10.40$ $P = 0.0001$[c]
Total RBANS score		239.9 (4.1)	244.8 (5.9)	236.8 (4.6)	236.7 (8.1)	$F(3,218) = 2.30$ $P = 0.08$

[a] RBANS, Repeatable Battery for the Assessment of Neuropsychological Status.
[b] Means ± standard deviation.
[c] Recent concussion group > No concussion, 1 previous, and ≥2 previous concussion groups.

tention, concentration, processing speed, and mental flexibility compared with youth athletes with no history of concussion or history of one previous concussion. More importantly, these data reveal that youth athletes who have sustained two or more previous concussions but who do not report or demonstrate any physical, medical, or cognitive difficulties related to a history of concussion are not distinguishable from youth athletes who have experienced a concussion within the past week. Specifically, factors such as sustained attention and cognitive flexibility may be affected by mild concussion long after the insult. It seems that once there is a history of two or more concussions, a youth athlete's performance on subtle tasks of attention and processing speed does not differ significantly from that of a youth who has been recently concussed. In addition, youth athletes with two or more previous concussions had statistically longer exposure to contact sports (e.g., 2 yr), supporting the notion that increased exposure to participation places the athlete at risk for more chronic traumatic brain injury (29).

Scores on standardized educational achievement tests did not reveal between-group differences, but academic GPA was observed to be significantly lower for youth athletes with multiple previous concussions, which would suggest that these cumulative effects may extend to general academic performance. However, we found that recently concussed youth athletes also had decreased GPAs, which cannot be explained solely by the effects of recent concussions. It may be that youth athletes with lower GPAs are more susceptible to sustaining cerebral concussions, or to the effects of these concussions. However, our observations do not answer the question as to why this might occur, and such findings may be best examined in a future prospective study.

The finding that recently concussed youth athletes performed similar to youth athletes with a history of two or more previous concussions may provide further support for the vulnerability of the youth brain (13). Concussions sustained during critical developmental stages in brain development, stages marked by a period of increased brain plasticity, may

TABLE 4. Analysis of effects of concussion history on cognitive performance[a]

Variable	Range	Concussion history group[b]				F	Significance F
		None	1 previous	≥ 2 previous	Recent		
Attention (RBANS)	46 – 105	71.0 (10.7)	71.8 (10.5)	68.0 (10.0)	65.7 (8.3)	3.71	0.012[c]
Immediate Memory (RBANS)	37 – 64	50.6 (4.8)	52.0 (4.2)	50.1 (5.7)	52.3 (4.8)	2.32	0.08
Delayed Memory (RBANS)	37 – 62	53.3 (4.7)	53.9 (3.8)	53.5 (4.7)	53.6 (4.0)	0.28	0.82
Language (RBANS)	18 – 43	30.9 (4.4)	31.2 (5.1)	29.4 (5.2)	39.8 (4.1)	1.63	0.18
Visuoconstructional ability (RBANS)	20 – 40	34.9 (4.4)	36.3 (3.3)	35.7 (3.6)	35.6 (3.8)	1.60	0.19
Trail Making Test Part A (by level)	0 – 2	0.40 (0.6)	0.38 (0.6)	0.38 (0.6)	0.41 (0.6)	0.09	0.99
Trail Making Test Part B (by level)	0 – 3	0.10 (0.3)	0.18 (0.5)	0.22 (0.6)	0.44 (0.7)	4.21	0.006[d]

[a] RBANS, Repeatable Battery for the Assessment of Neuropsychological Status.
[b] Means ± standard deviation.
[c] Recent concussion group < No concussion and 1 previous concussion groups.
[d] Recent concussion group > No concussion group (higher scores relate to greater impairment).

TABLE 5. Effects of concussion history on cognitive performance and on academic achievement for participants in the recent concussion group[a]

Variable	Range	Concussion history		F	Significance F
		No or 1 previous (n = 17)	≥2 previous (n = 23)		
Attention (RBANS)	51 – 91	64.7 (9.1)	66.4 (7.9)	0.42	0.52
Immediate Memory (RBANS)	43 – 63	51.2 (4.9)	53.0 (4.7)	1.47	0.23
Delayed Memory (RBANS)	44 – 59	52.1 (4.2)	54.7 (3.8)	4.72	0.04
Language (RBANS)	20 – 38	30.1 (4.7)	29.8 (3.7)	0.14	0.71
Visuoconstructional ability (RBANS)	25 – 40	34.9 (4.0)	36.0 (3.6)	0.76	0.39
Total Score (RBANS)	208 – 276	232.5 (17.5)	239.9 (13.8)	2.18	0.15
Trail Making Test Part A (by level)	0 – 2	0.44 (0.63)	0.26 (0.54)	0.88	0.35
Trail Making Test Part B (by level)	0 – 3	0.31 (0.60)	0.33 (0.58)	0.01	0.92

[a] RBANS, Repeatable Battery for the Assessment of Neuropsychological Status.

ultimately impair this plasticity. Moreover, these results would support the finding that multiple previous concussions in college athletes reduce long-term cognitive reserve (13). Children have been found to be at higher risk for more diffuse cerebral swelling after minor head injury (18), which could lead to a delayed recovery period (1). In those cases in which children have been injured again during this recovery period, some have pointed to differences in cerebral autoregulatory responses to trauma as contributing to catastrophic effects (5, 32). As well, research on adults has revealed possible long-term sequelae of repeated mild head injury, such as an association with the development of Alzheimer's disease. A relationship between apolipoprotein 4 and repeated concussion has been posited (14); however, this relationship has not yet been investigated in younger populations.

Participation in youth sports is at an all-time high, and athletic participation is often mandatory in preparatory schools. Youth athletes are at risk, and their coaches, parents, and health care providers are frequently unaware or ignorant of the dangers of concussion. What was particularly striking in the present study was the surprise and lack of knowledge that parents and athletes exhibited during the interviews. Many athletes described concussive events without ever having realized that concussions had been sustained. Parents frequently seemed embarrassed and alarmed listening to their children describe, for the first time, a mild hit that resulted in confusion, disorientation, "seeing stars," and headache. It is likely that many professional athletes who are identified as having received their "first" concussion as a young adult have actually experienced numerous unidentified concussions throughout their lifetime.

Although the current study offers a glimpse into the possible long-term effects of concussion in youth, it is not without its limitations. Factors such as severity or grade of concussion were not examined, and concussion history was based on self-report of student athletes and their parents. Studies investigating the accuracy of self-report of concussion history have demonstrated that awareness of symptoms related to concussion is more readily reported than having experienced a concussion (9). The RBANS is a screening measure designed to determine the neuropsychological status of individuals with neurological injury or disease, such as stroke, head trauma, or dementia. As such, items are relatively straightforward, sensitive to neurological insult, and quite simple for otherwise healthy individuals. In spite of possible threats that could have masked these test findings, the present study was still able to demonstrate negative effects of repeated concussion using three independent measures. Using volunteers may have resulted in a self-selected sample of individuals who chose to participate because of concussion concerns, thus explaining the statistically significant results. As well, the incidence of previous concussion reported in our sample was 63%, which is consistent with the recent concussion literature, in which the incidence ranges from 53% (6, 11) to 85% (9) when relying on self-report of concussion history. Finally, the generalizability of this sample of academically competitive boarding school youth athletes to the greater youth athlete population may be limited. However, in a more diverse population of students, where there is less of a restricted range of academic and intellectual functioning, the neuropsychological effects of concussion may be even more clearly evident.

The importance of baseline screening for intraindividual pre- and postconcussion comparison is a diagnostic necessity and cannot be underestimated. Without a baseline, one must rely on "the average performance" or group norms and compare the individual with what is considered within the norm for his or her age level. Inclusion of concussion history in an initial evaluation seems to be crucial to understanding a particular high school athlete's strengths and weaknesses on baseline evaluations (6) as well as to identifying on-the-field vulnerabilities and potential markers in the event of concussion (11). Generally, youth sports teams do not possess the luxury of on-site consulting physicians and athletic trainers. The current state of assessment and management of sports-related concussion in youth athletes has become too great a risk; the same protocols for preseason baseline testing, education, prevention, and assessment currently available to professional athletes should be inherent in youth athletics programs. Effective and efficient modes of assessment that can be easily implemented and youth education programs regarding the identification and effects of concussion should also be developed and implemented. The current study supports the notion that despite what many coaches, parents, health care providers, athletic personnel, and athletes believe, even a history of mild concussion in "healthy" youth athletes can have long-term effects.

REFERENCES

1. Aldrich EF, Eisenberg HM, Saydjari C, Luerssen TG, Foulkes MA, Jane JA, Marshall LF, Marmarou A, Young HF: Diffuse brain swelling in severely head-injured children: A report from the NIH Traumatic Coma Data Bank. **J Neurosurg** 76:450–454, 1992.
2. Alves WM, Rimel RW, Nelson WE: University of Virginia prospective study of football-induced minor head injury: Status report. **Clin Sports Med** 6:211–218, 1987.
3. American Academy of Neurology: Practice parameter: The management of concussion in sports (summary statement)—Report of the Quality Standards Subcommittee of the American Academy of Neurology. **Neurology** 48:581–585, 1997.
4. Barth JT, Alves W, Ryan T, Macciocchi S, Rimel RW, Nelson W: Mild head injury in sports: Neuropsychological sequelae and recovery of function, in Levin HS, Eisenberg HM, Benton AL (eds): *Mild Head Injury*. New York, Oxford University Press, 1989, pp 257–275.
5. Bruce DA, Alavi A, Bilaniuk L, Dolinskas C, Obrist W, Uzzell B: Diffuse cerebral swelling following head injuries in children: The syndrome of "malignant brain edema." **J Neurosurg** 54:170–178, 1981.
6. Collins MW, Grindel SH, Lovell MR, Dede DE, Moser DJ, Phalin BR, Nogle S, Wasik M, Cordry D, Daugherty KM, Sears SF, Nicolette G, Indelicato P, McKeag DB: Relationship between concussion and neuropsychological performance in college football players. **JAMA** 282:964–970, 1999.
7. Collins MW, Lovell MR, Iverson GL, Cantu RC, Maroon JC, Field M: Cumulative effects of concussion in high school athletes. **Neurosurgery** 51:1175–1181, 2002.
8. Collins MW, Lovell MR, McKeag DB: Current issues in managing sports-related concussion. **JAMA** 282:2283–2285, 1999.
9. Delaney JS, Lacroix VJ, Leclerc S, Johnston KM: Concussions among university football and soccer players. **Clin J Sport Med** 12:331–338, 2002.
10. Echemendia RJ, Putukian M, Mackin S, Julian L, Shoss N: Neuropsychological test performance prior to and following sports-related mild traumatic brain injury. **Clin J Sports Med** 11:23–31, 2001.
11. Field M, Collins MW, Lovell MR, Maroon J: Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. **J Pediatr** 142:546–553, 2003.
12. Gerberich SG, Priest JD, Boen JR, Straub CP, Maxwell RE: Concussion incidences and severity in secondary school varsity football players. **Am J Public Health** 73:1370–1375, 1983.
13. Giza CC, Hovda DA: The neurometabolic cascade of concussion. **J Athl Train** 36:228–235, 2001.
14. Jordan BD, Relkin NR, Ravdin LD, Jacobs AR, Bennett A, Gandy S: Apolipoprotein E $\epsilon 4$ associated with chronic traumatic brain injury in boxing. **JAMA** 278:136–140, 1997.
15. Kelly JP: Traumatic brain injury and concussion in sports. **JAMA** 282:989–991, 1999.
16. Lovell MR, Collins MW: Neuropsychological assessment of the college football player. **J Head Trauma Rehabil** 13:9–26, 1998.
17. Maroon JC, Lovell MR, Norwig J, Podell K, Powell JW, Hartl R: Cerebral concussion in athletes: Evaluation and neuropsychological testing. **Neurosurgery** 47:659–672, 2000.
18. McCrory PR, Bercovic SF: Second impact syndrome. **Neurology** 50:677–683, 1998.
19. Moser RS, Schatz P: Enduring effects of concussion in youth athletes. **Arch Clin Neuropsychol** 17:91–100, 2002.
20. Pellman EJ: Background on the National Football League's research on concussion in professional football. **Neurosurgery** 53:797–798, 2003.

21. Pellman EJ, Lovell MR, Viano DC, Casson IR, Tucker AM: Concussion in professional football: Neuropsychological testing—Part 6. **Neurosurgery** 55:1290–1305, 2004.
22. Pellman EJ, Powell JW, Viano DC, Casson IR, Tucker AM, Feuer H, Lovell M, Waeckerle JF, Robertson DW: Concussion in professional football: Epidemiological features of game injuries and review of the literature—Part 3. **Neurosurgery** 54:81–96, 2004.
23. Pellman EJ, Viano DC, Casson IR, Arfken C, Feuer H: Concussion in professional football: Players returning to the same game—Part 7. **Neurosurgery** 56:79–92, 2005.
24. Pellman EJ, Viano DC, Casson IR, Arfken C, Powell J: Concussion in professional football: Injuries involving 7 or more days out—Part 5. **Neurosurgery** 55:1100–1119, 2004.
25. Pellman EJ, Viano DC, Casson IR, Tucker AM, Waeckerle JF, Powell JW, Feuer H: Concussion in professional football: Repeat injuries—Part 4. **Neurosurgery** 55:860–876, 2004.
26. Pellman EJ, Viano DC, Tucker AM, Casson IR: Concussion in professional football: Location and direction of helmet impacts—Part 2. **Neurosurgery** 53:1328–1341, 2003.
27. Pellman EJ, Viano DC, Tucker AM, Casson IR, Waeckerle JF: Concussion in professional football: Reconstruction of game impacts and injuries. **Neurosurgery** 53:799–814, 2003.
28. Powell JW, Barber-Foss KD: Traumatic brain injury in high school athletes. **JAMA** 282:958–963, 1999.
29. Rabadi MH, Jordan BD: The cumulative effect of repetitive concussion in sports. **Clin J Sport Med** 11:194–198, 2001.
30. Randolph C: *Repeatable Battery for the Assessment of Neuropsychological Status*. San Antonio, The Psychological Corp., 1998.
31. Reitan R, Wolfson D: *Halstead-Reitan Neuropsychological Test Battery: Theory and Clinical Interpretation*. Tucson, Neuropsychology Press, 1993.
32. Snoek JW, Minderhoud JM, Wilmink JT: Delayed deterioration following mild head injury in children. **Brain** 107:15–36, 1984.

COMMENTS

This article provides compelling evidence for residual neurocognitive difficulties in a sample of high school students. Although cognitive deficits in high school athletes have been demonstrated in previous studies, this article presents important corroborative information regarding several controversial issues. First, the issue of whether multiple concussions result in significant morbidity in athletes has been a hot topic for debate over the past 5 years. Although some studies have not suggested residual difficulties, others have. One of the most interesting and important findings in this current study is that symptom-free athletes with a history of two or more concussions performed similarly to athletes who had recently suffered an injury. These data support the hypothesis that these (younger) athletes are possibly at risk for long-term cognitive dysfunction after injury. This study adds to a growing body of work (see recent series by Pellman et al. in this journal) that suggests that there may be differences in recovery patterns for school-aged athletes and older, professional athletes. The second important implication of this article has to do with the "value added" issue of conducting neuropsychological testing in athletes. Specifically, this highlights the inadequacy of reliance on self-reported symptoms as the sole criterion for return to play.

Mark R. Lovell
Neuropsychologist
Joseph C. Maroon
Pittsburgh, Pennsylvania

This study by Moser et al. is an attempt to further delineate the long-term consequences of concussion in high school athletes, and particularly to study the differences between various concussion histories. They measured the neuropsychological and clinical responses in 238 high school athletes, including 82 who had never experienced a concussion, 56 who had sustained a remote concussion more than 6 months before and were asymptomatic, 45 who had had two or more previous concussions but were asymptomatic, and 40 who had experienced a concussion within 1 week before testing. This last group was known as the "recent concussion" group. Their data showed that high school athletes with recent concussion had significantly reduced performance on neuropsychological assessment including tests of attention, concentration, processing speed, and mental flexibility, when compared with those with no history of concussion or one previous concussion. In addition, the group of athletes who had sustained two or more previous concussions but were asymptomatic were comparable to those athletes who had suffered a recent concussion within the past week. Many athletes would describe a head impact which constituted a concussive effect, but did not realize that cerebral concussion had occurred, a phenomenon also unrecognized by parents. Independent measures confirmed these deleterious effects of repeated concussion.

Although this study does have limitations, it emphasizes several important points. First, as it intuitively seems, it is almost certain that many contact athletes have had undiagnosed or unappreciated concussions in their playing career, which were likely mischaracterized as confusion, disorientation, positive visual phenomena, or headache, frequently referred to as being "dinged." Athletes with two or more concussions had a longer exposure to contact sports, which correlates to an increased risk of chronic traumatic brain injury. There is also the suggestion that academic performance may be negatively affected by multiple concussions; this needs more investigation, but seems to be a logical trend. This research thus supports the theory that repetitive sports-related concussion may have long-lasting effects. Also, there may be a threshold number of concussive events that will have an additive and long-term permanent effect on intellectual and cognitive function. Further study is needed to better define the long-term effects of sports-related traumatic brain injury. In the interim, we realize that a history of concussion in youth athletes may have long-term consequences and that proper identification and management by athletic trainers and healthcare personnel is mandatory.

Julian E. Bailes
Morgantown, West Virginia

Essentially the authors have amassed a convenience sample using retrospective data and have found clever ways to use those data to address important questions. Because the authors are forthright in describing what they have done, and are proportionately modest and cautious regarding their conclusions, the present study has value because it suggests, but does not conclusively demonstrate, that repeated concussions in student athletes can have long-lasting consequences.

As a foundation for discussing the differences across groups owing to concussion, the authors equate the groups on the basis of self-reported standardized academic testing scores. They posit that concussion may have lasting effects on academic performance and present an alternative explanation, that children with lower grade point averages could be more prone to concussion. However, the authors do not fully address the possibility that lower pre-existing cognitive performance could influence the results on neuropsychological measures, and they attribute differences in neuropsychological measures to concussion and concussion history. Aside from the above methodological concern, the paper is admirably succinct and parsimonious without excluding important details that qualify the findings. The authors have explained with clarity the analyses of their concussion groups, and have openly stated the weaknesses of their study.

Joseph Bleiberg
Neuropsychologist
Washington, District of Columbia