Cumulative Effects of Concussion in High School Athletes

Michael W. Collins, Ph.D.[1]; Mark R. Lovell, Ph.D.[1]; Grant L. Iverson, Ph.D.[2]; Robert Cantu, MD[3]; Joseph Maroon, M.D.[4]; Melvin Field, M.D.[4]

1 University of Pittsburgh Medical Center; Pittsburgh, PA. (Dept. of Orthopaedic Surgery)
2 University of British Columbia; Vancouver, Canada (Dept. of Psychiatry)
3 Emerson Hospital; Concord, MA. (Dept. of Neurological Surgery)
4 University of Pittsburgh Medical Center; Pittsburgh, PA. (Dept. of Neurological Surgery)

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Contact: Michael W. Collins, Ph.D.
UPMC Sports Medicine Concussion Program
UPMC Center for Sports Medicine
3200 South Water St.
Pittsburgh, PA. 15203

Phone: (412) 432-3668
Email:collinsmw@msx.upmc.edu
Fax: (412) 432-3690

Abstract

Objective: It is a common assumption in sports medicine that prior history of concussion is predictive of lowered threshold and worse outcome following subsequent concussive injury. The current study was conducted to investigate the relationship between concussion history in high school athletes and the on-field presentation of symptoms following subsequent concussion.

Methods: 173 athletes experiencing sports concussion comprised the initial study group. Binary groups were subsequently created based upon concussion history. Sixty athletes with no prior concussion history were compared to 28 athletes with a history of three or more concussions. Groups were compared in terms of on-field presentation of symptoms following an in-study concussion. Dependent variables included the post-injury presence of loss of consciousness, anterograde amnesia, retrograde amnesia, and confusion.

Results: Athletes with three or more prior concussions were more likely to experience on-field positive loss of consciousness ($X^2 = 8.0$; $P = .005$), anterograde amnesia ($X^2 = 5.5$; $P = .019$), and confusion ($X^2 = 5.1$; $P = .024$) following a subsequent cerebral concussion. An odds ratio revealed that athletes with a history of three concussions were 9.3 times more likely to demonstrate 3-4 abnormal on-field markers of concussion severity.

Conclusion: This is the first study to suggest a cumulative effect of concussion in high school athletes. A more severe, on-field presentation of concussion markers is evidenced in high school athletes with a pronounced history of concussion. Findings highlight the need for more long-term outcome studies in high school athletes sustaining concussion.

Running Title: Cumulative Effects of Concussion

Key Words: Cerebral Concussion, Head Injury, Sports, High School, Anterograde Amnesia, Retrograde Amnesia, ImPACT

Introduction

It is a common assumption in sports medicine that prior history of concussion is predictive of lowered threshold and worse outcome following subsequent concussive injury. This idea may have its historical roots in an anecdotal approach utilized by Quigley in 1945 that was later referenced by Thorndike (21). Quigley suggested that an athlete suffering three cerebral concussions (with loss of consciousness) should retire for the season. No scientific data was outlined to support this claim. More recent studies in this area have been conducted via survey by both Gerberich and colleagues in 1983 (8) and Guskiewicz and colleagues in 2000 (10). In American football players, Gerberich and colleagues found that those with a history of a trauma-induced loss of consciousness (LOC) were four times more likely to sustain a second concussion involving LOC. Guskiewicz and colleagues found that high school and college football players who sustained a concussion were three times more likely to sustain a second concussion during the same season than those not sustaining a previous injury. These latter two works are widely referenced and promulgated, though neither have been expanded upon by examining the influence of multiple prior concussions on an athlete's presentation following a subsequent concussion. Moreover, Gerberich and colleagues focused only on LOC, which, at the time, was largely considered a requisite for cerebral concussion. More recent work, however, has highlighted the importance of other common markers of concussion, such as mental status change, anterograde amnesia, and retrograde amnesia (1, 2, 13, 14, 16).

The issue of reduced threshold for concussion is of considerable significance for many reasons. First, many athletes who participate in contact and collision sports are at risk for multiple concussive injuries throughout their careers (4, 7, 8, 10, 19). Second, return to sport participation following concussion is often predicated upon concussion history. In fact, all current concussion "guidelines" heavily weight this issue in return to play criteria (1, 5, 13). Though data in this area is scant, a number of high profile athletes have, in large part, based their retirement decision on perceived lowered threshold to concussive injury and more severe on-field presentation of symptoms after seemingly mild blows to the head or body.

The current study was designed to evaluate the relationship between concussion history and the on-field presentation of symptoms following a subsequent cerebral concussion. This study will specifically investigate the likelihood of developing on-field severity markers of concussion in high school athletes with a history of multiple concussions versus athletes sustaining their first concussion.

Methods

Program Protocol

Appropriate review for research with human subjects was granted through the University of Pittsburgh to conduct this study. All subjects in the study participated in the Sports Medicine Concussion Program at the University of Pittsburgh Medical Center. Athletes within the sample were included from high schools within the states of Pennsylvania, Michigan, Illinois, Oregon, and Maine. This ongoing clinical program implements the use of baseline/post-injury neuropsychological testing to assist team medical staff in making return-to-play decisions following the occurrence of sports-related concussion. The inventory utilized for the program is ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing)(18). ImPACT is a computer-based program designed specifically for the assessment of sports-related concussion. The program includes a demographic questionnaire, symptom inventory, injury evaluation form and 20-minute neuropsychological test battery. For the purposes of this study and as outlined below, ImPACT was the method by which data were collected regarding athletes' concussion history (independent variable) and on-field presentation of symptoms (dependent variables) following an in-study concussion.

As part of the UPMC Concussion Program, all athletes in the current study underwent a "baseline" or pre-injury evaluation and were administered ImPACT prior to the 2000 and 2001 athletic seasons. All baseline data were collected during the off-season (i.e. prior to pre-season contact drills). ImPACT is inclusive of a standardized demographic questionnaire that requires the athlete to document relevant educational, sport, and personal medical history. For the purposes of this study, we focused on the athletes' self-reported history of concussion.

Regarding concussion history, a standardized concussion history questionnaire contained within the ImPACT test battery was administered with the supervision of the test administrator. Prior to athletes

completing this section, test administrators communicated to the athletes that they were to document each prior episode of cerebral concussion that was formally diagnosed by a team physician or certified athletic trainer. Athletes also documented any prior concussion that resulted in loss of playing time. Test administrators were trained to define concussion as a "traumatically induced alteration in mental status that may or may not be accompanied by a loss of consciousness." This definition was based upon the standard American Academy of Neurology nomenclature (15). Non sports-related concussions were also included in the tally only if diagnosed by a physician. Based upon these criteria, athletes, under the supervision of the test administrator, entered in the total number of concussions experienced in their history.

Administration of the ImPACT computerized test battery was supervised by a team of clinical neuropsychologists, athletic trainers, and/or physicians who were thoroughly trained in the administration of the standardized inventory. Training was completed at each site through training seminars presented by two of the authors (MWC and/or MRL). Data accumulated during the administration process was automatically generated within ImPACT's clinical report and utilized for the current analysis.

Post-Concussion Evaluation

High school athletes within our sample experiencing a cerebral concussion during the 2000-2001 athletic seasons were referred for post-injury ImPACT evaluation within 72 hours of injury. In-season concussions were diagnosed based of the following criteria: 1) any observable alteration in mental status or consciousness on the field, rink or court, and/or; 2) the presence of LOC and/or presence of anterograde or retrograde amnesia as identified by an on-field examination, and/or; 3) any self-reported symptoms such as cognitive "fogginess", headache, nausea/vomiting, dizziness, balance problems, visual changes, etc. following a collision involving the head or body. Initial diagnosis of concussion was made by certified athletic trainers or team physicians who were present on the sideline at the time of injury.

Documentation of On-Field Signs of Concussion

Sports medicine practitioners at participating institutions carefully documented information pertaining to injury severity markers. At the aforementioned training seminars, athletic trainers and/or physicians were trained to identify the on-field markers of concussion, including confusion, anterograde amnesia, retrograde amnesia, and LOC. All staff members were also provided a standardized, on-field palm card outlining proper assessment of these severity markers of injury. Specifically, on-field confusion (e.g. disorientation to person, place, or time) was assessed by questioning the athlete's post-injury awareness and orientation to surroundings (e.g. name, current stadium, city, opposing team, current month/day). On-field anterograde amnesia was assessed via immediate and delayed (e.g. 0, 5, 15 minute) memory for three words (e.g. girl, dog, green). Anterograde amnesia was further documented at the post-injury follow-up evaluation by assessing the athlete's ability to recall all information subsequent to trauma. Any loss of memory in this latter regard indicated positive presence of anterograde amnesia. On-field retrograde amnesia was assessed by having the athlete recall events occurring just prior to trauma (e.g. memory for play preceding trauma, events in first quarter or earlier in practice). Retrograde amnesia was further documented at the post-injury evaluation by assessing the athlete's ability to recall information just prior to trauma. Any loss of memory in this latter regard indicated the positive presence of retrograde amnesia. LOC was documented when an athlete was unresponsive to external stimuli and in paralytic coma as reported by teammates and/or on-field evaluation. By definition, athletes experiencing LOC also experienced a concomitant anterograde amnesia. For the purposes of this study, athletes with any degree of LOC were categorized in the positive LOC group rather than the anterograde or retrograde amnesia group, regardless of the length of associated amnesia.

ImPACT contains a standardized post-injury evaluation form, which requires the test administrator to input the aforementioned collected data regarding the presence and duration of these specific concussion markers at the first post-injury evaluation. Such data is detailed and printed within the ImPACT clinical report that becomes part of the athletes' medical records. Data regarding the presence of confusion, anterograde amnesia, retrograde amnesia, and LOC were collected and served as the dependent variables for the current study.

Subjects

173 high school athletes participating in the UPMC Sports Concussion Program who sustained cerebral concussion during their respective 2000 and 2001 athletic seasons comprised the initial study group. All subjects had known concussion histories as determined by the pre-season baseline ImPACT evaluation and completion of the standardized concussion history form. The breakdown of number of previous concussions was as follows: none = 34.7%, 1 = 33.5%, 2 = 15.6%, 3 = 8.7%, 4 = 4.0%, 5 = 1.2%, 6 – 9 = 2.3%. Binary groups were created based on concussion history in order to study the possible effects of sustaining multiple concussions. The first group was composed of 60 athletes with no history of concussion. Their average age was 15.8 (SD = 1.1) years, and 92% were male. The second group was composed of 28 athletes with a history of three or more concussions. Their average age was 16.1 (SD = 1.2), and 82% were male. Thus, a total of 88 athletes comprised the final study group.

Results

To evaluate the relationship between prior history of concussion and the presence of acute, on-field presentation of concussion severity markers, high school concussed athletes with no history of concussion were compared to high school concussed athletes with a history of 3 or more cerebral concussions. For those with no concussions in their past, 78% (n = 47) of the sample were participating in football at the time of their in-study concussion. Approximately 8% (n = 5) were participating in soccer and 5% (n = 3) were participating in basketball. Other represented sports included baseball (n = 1), ice hockey (n = 1), lacrosse (n = 1), cheerleading (n = 1), and wrestling (n = 1). For those with three or more concussions in their past, 54% (n = 15) were participating in football and 18% (n = 5) were soccer athletes. Other represented sports included basketball (n = 2), ice hockey (n = 2), lacrosse (n = 1), wrestling (n = 2), and volleyball (n = 1).

Statistical comparisons between concussion groups were conducted via Chi-square analyses with on-field markers of concussion severity as dependent variables. As seen in Table 1, athletes with a history of multiple concussions were significantly more likely to experience an initial on-field loss of consciousness ($\underline{X}^2$ = 8.0, p = .005), anterograde amnesia ($\underline{X}^2$ = 5.5, p = .019), and confusion ($\underline{X}^2$ = 5.1, p = .024) following a subsequent concussion. In fact, only 5% of athletes with no prior concussion experienced LOC following injury, whereas 26% of the multiple concussion group experienced LOC following a subsequent injury. The concomitant odds ratio suggests that athletes with three or more prior concussions are 6.7 times more likely to experience post-injury LOC subsequent to concussion as compared to those with no prior history of concussion.

Table 1: On-field Concussion Severity Markers by Concussion History Group.

Variable	N	No Previous Concussions	3 or More Previous Concussions	X^2	p	Odds Ratio
Positive LOC	87	5.0%	25.9%	8.0	.005	6.7
Retrograde Amnesia	73	11.1%	21.1%	1.2	.278	---
Anterograde Amnesia	74	14.8%	40.0%	5.5	.019	3.8
Confusion	60	44.2%	76.5%	5.1	.024	4.1
5+ Minutes Mental Status Change*	72	9.4%	31.6%	5.3	.021	4.4
3-4 Abnormal Markers	73	3.7%	26.3%	8.3	.004	9.3

Our total study sample consisted of 88 athletes. Varying degrees of missing data were present. The number of subjects who had each marker coded ranged from 60 to 87.
*Five or more minutes of retrograde amnesia, anterograde amnesia, or confusion.

A variable representing mental status change for five or more minutes was also created. Athletes were included in this group if they exhibited five or more minutes of confusion, anterograde amnesia, and/or retrograde amnesia. We chose a 5-minute time cutoff to differentiate transient from more severe injuries. This time cutoff was utilized because it represents a common unit of time that can be tracked relatively easily on the athletic playing field. Data pertaining to this variable was also entered directly into the ImPACT post-injury evaluation form. Only 9.4% of players with no history of concussion had prolonged post-injury mental status changes at the time of injury as compared to 31.6% of players with multiple concussions. Lastly, if the four primary on-field severity markers are considered simultaneously (positive loss of consciousness, anterograde amnesia, retrograde amnesia, and confusion), only 3.7% of athletes with no history of concussion evidenced 3 or 4 of these markers, whereas 26.3% of the multiple concussion group evidenced 3 or 4 severity markers. An odds ratio revealed that players with a history of three or more concussions are 9.3 times more likely to demonstrate 3-4 abnormal on-field markers of concussion severity.

Discussion

Over the past decade, the diagnosis and management of sports-related concussion has been a frequent topic of discussion and debate within sports medicine and neurosurgical journals. This focus has become particularly acute over the past two years as evidenced by two recent journal supplements covering the subject (3, 20). At present, there continues to be considerable debate regarding diagnosis of the injury and when it is safe to return the concussed athlete to the playing field, rink, or court. Return to play decisions are complicated by the fact that no two concussions are identical and individual variability appears to exist in terms of post-injury presentation and elapsed time before complete amelioration of symptoms (e.g minutes, days, weeks). Animal model research suggests that acute metabolic dysfunction may help to account for the mental status changes evidenced following cerebral concussion (9,11). Increased neuronal vulnerability may exist for minutes to days following injury secondary to a higher demand for glucose (which is increased after injury) and a paradoxical reduction in cerebral blood flow. Little is known regarding the influence of multiple concussions on this process. In regards to neurobehavioral presentation, a recent animal model study by DeRoss and colleagues (6) suggested that multiple concussions (10-14 day time period between insults) resulted in impaired spatial recognition in rats (Morris water maze), though increased deficits were not related to number of concussions sustained (presumably due to training effects associated with multiple exposures to the task).

All current concussion grading parameters, at least in part, base return to sport participation within the context of number of concussions in the athletes' past (1, 5, 13). As is the case with all sports concussion management directives, these recommendations are derived upon little to no scientific data. The current study is the first analysis to closely examine the influence of prior concussions on an athletes' immediate on-field presentation following a subsequent concussive insult. We chose to focus on high school athletes given that the majority of at-risk athletes are at the high school level and below. Somewhat disconcerting, however, is the fact that concussion management has been understudied within this population.

Our results suggest that a pronounced history of concussion appears to increase the susceptibility to the acute effects of a subsequent concussive injury. Specifically, high school athletes with a self-reported history of three prior concussions were over nine times more likely, relative to those with no prior concussion, to exhibit 3-4 on-field abnormal markers of injury when they experience a subsequent concussion. These traditionally accepted hallmarks of concussion severity include the presence of loss of consciousness, anterograde amnesia, retrograde amnesia, and confusion. Our findings might reflect a lowered concussion threshold in those who sustain repeated concussions. A second hypothesis is that individuals within our sample with a history of multiple concussions are selectively vulnerable to this injury. Though a paucity of research exists regarding this issue, recent long-term outcome studies have suggested that factors such as cognitive reserve (4) and possible genetic influences via the presence of the apolipoprotein 4 allele (12) may potentially be related to increased symptom presentation following concussion. Other potential moderating variables are unknown.

Debate certainly exists as to the relative importance of prior concussion history and its influence on both recovery from injury and potential effects on long-term functioning. Conflicting reports exist in the few retrospective analyses that have been conducted by examining this issue via the prior history of concussion as the independent measure and "baseline" neuropsychological testing as the dependent measure of outcome. One study in American college football players found that a history of two or more prior concussions predisposed

athletes to significantly reduced cognitive function (months to years after injury) in the areas of speed of processing and executive function (4). However, a smaller study (n = 12) found no pre-season to post-concussion neuropsychological test differences in athletes reporting prior multiple concussions as compared to those sustaining a single concussion (17). Prospective research is needed to better clarify if there are cumulative effects of concussive injury as it pertains to neuropsychological recovery from injury, attenuation in academic performance, susceptibility to post-concussion syndrome, and potential influences on long-term neurologic functioning.

There are two primary limitations of the current study. First, concussion history data were of a self-report nature, though were collected via a standardized questionnaire. Obviously, it would have been preferable to collect direct medical information confirming the historical accounts of the injuries. Unfortunately, however, concussion history is not typically presented in formal medical records and many concussions go unrecognized by athletic trainers or team medical staff. Thus, at the current time, reliance on medical records to ascertain concussion history is virtually impossible and a self-reported history is essential to conduct a study of this nature. A related issue is that some athletes may potentially minimize self-report history of concussion given a perception that this information may jeopardize their playing status. Hopefully, long-term prospective studies that are now in progress will allow us to more carefully document concussion history in the future.

Second, the severity of impact and the temporal proximity of prior concussions were not studied within our current analysis. Thus, the role of these factors, if any, is unknown. It is suggested that future studies carefully evaluate these factors. It may be that the number of concussions during any given season is a better predictor of subsequent response to concussion, rather than the absolute number of injuries. Along similar lines, the role of biomechanical forces in determining both immediate and long-term consequences of concussion is warranted.

Conclusions

In summary, current results should be considered preliminary for suggesting a cumulative effect of concussion in high school athletes. Results are consistent with the hypothesis of an increased vulnerability and/or lowered threshold with successive concussive injuries, though we cannot rule out the possibility that certain individuals are neurologically predisposed to have an increased incidence and more severe on-field presentation following concussive injury. Along similar lines, it is yet to be determined whether there is a cumulative effect of concussive injury as it relates to the time period necessary for a complete amelioration of post-injury sequlae (e.g. somatic symptoms and neurocognitive decrements) or to the potential association with poor long-term outcome. Until such information is gathered, management of concussion should be considered a clinical decision based upon individualized presentation following injury. While there is debate and variability regarding concussion return to play parameters, there is certainly agreement amongst clinicians that the athlete be completely symptom-free prior to resuming at-risk sport activity.

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