Recovery From Mild Concussion in High School Athletes

Journal of Neurosurgery 2003;98:295-301

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ABSTRACT

OBJECTIVE: The objective of this study was to evaluate memory dysfunction and self-report of symptoms in a group of concussed high school athletes utilizing a computerized neuropsychological test battery.
METHOD: Neuropsychological performance prior to and following concussion is compared with the test performance of an age-matched comparison group. Potentially important diagnostic markers of concussion severity are discussed and linked to recovery within the first week of injury.
CONCLUSIONS: Mildly concussed high school athletes demonstrated significant declines in memory processes relative to a non-injured comparison group. Statistically significant differences between pre-season and post-injury memory test results were still evident in the concussed group at 4 and 7 days post-injury. Self-reported neurological symptoms such as headache, dizziness and nausea resolved by day 4. Duration of on-field mental status changes such as retrograde amnesia and post-traumatic confusion was related to the presence of memory impairment at 36 hours, 4 days and 7 days post-injury and was also related to slower resolution of self reported symptoms. The results of this study suggest that caution should be exercised in returning concussed high school athletes to the playing field following concussion. On-field mental status changes appear to have prognostic utility and should be taken into account when making return to play decisions following concussion. Athletes who exhibit greater than 5 minutes of on-field mental status changes have longer-lasting post-concussive symptoms and memory decline.

INTRODUCTION

The management of sports-related mild traumatic brain injury (MTBI; e.g. concussion) has rightfully received recognition as a public health issue.[1,4,11] Of particular concern is competition at the high school level, where a minimum of 1.25 million athletes compete in contact sports. Recent data suggest that an estimated 62,816 cases of concussion occur annually at the high school level, with football accounting for about 63% of the cases.[22]

Currently, neuropsychological testing is mandated within the National Hockey League[14] and the majority of National Football League franchises are also routinely using this tool.[15] However, to date, neuropsychological testing has not been widely implemented at the high school level and there are no published studies that have systematically investigated recovery from concussion in high school athletes.

The lack of research with high school athletes is alarming for several reasons. First, based on participation levels, the largest majority of at-risk athletes are at the high school level or below. Second, at least 17 deaths related to second impact syndrome [2] (which results from a second concussive insult closely following the first) were reported in the scientific literature between 1992-1997,[3] and cases of second impact syndrome continue to be reported. The majority of victims have been high school athletes between the ages of 13-18, suggesting greater vulnerability to severe injury in children and adolescents. In addition, recent laboratory research with rodents has documented changes in brain metabolism that persist 7 days or more after mild injury. [10] This research has also raised concerns about the cumulative effects of concussion in humans.

The goals of this study were threefold: 1) to evaluate memory impairment following *mild* concussion in high school athletes and document recovery within the first week post-injury; 2) to evaluate the relationship between duration of on-field markers of concussion and recovery of memory processes within the first week post-injury and; 3) to evaluate the relationship of self-reported post-concussion symptoms to performance on neuropsychological testing.

MATERIALS AND METHODS

Subjects

Participants in the study were 64 concussed high school athletes and 24 non-concussed high school athletes, which made up the comparison group. The comparison group was included to provide information regarding the stability of the neuropsychological test results over time in a non-injured group of athletes. The concussed group consisted of 60 males and 4 females while the comparison group consisted of 16 males and 8 females. The concussed group was composed of football athletes (N=44), basketball athletes (N=8), soccer athletes (N=7) and 5 athletes from other sports. The comparison group was composed of 22 swimmers and 2 football players. Comparison group athletes were recruited from a single high school in Pennsylvania. All subjects were screened for learning disabilities and attention deficit disorder and were not included if there was a history of either. All athletes with any history of alcohol or drug abuse or dependence were excluded from the study.

The concussed group had a significantly more pronounced pre-study history of concussion than the comparison group ($\underline{X}^2 = 8.87$, $p=.003$), although the concussed group and the control group did not differ significantly on baseline memory testing ($F=2.67$, $p<.11$) or with regard to number of symptoms reported ($F=.086$, $p<.77$). The average time post-baseline to first follow-up for the concussion group was 51.3 days. The average time from injury to initial follow-up was 1.5 days. The average time from injury to second follow-up was 4.2 days and the time from injury to third follow-up was 7.6 days. These times represent average post-concussion evaluation times within our clinical program, which is designed to carefully evaluate athletes following concussion while minimizing time off the field. The comparison group underwent initial baseline evaluation followed by evaluations at 7 days post-baseline, 9 days post-baseline and 11 days post-baseline. These intervals were chosen to approximate the post-concussion testing intervals of the concussed group.

Protocol and Outcome Measures

Appropriate review for research with human subjects was granted to conduct this study. Administration of the ImPACT computerized neuropsychological test battery[19] was supervised by a team of clinical neuropsychologists, athletic trainers and/or physicians who were thoroughly trained in the administration of the measures. Training was completed at each site through a half-day seminar presented by two of the authors (MWC and MRL). Because ImPACT is a self-administered test battery, all subtests were administered in a standardized manner and the test was automatically computer scored.

Preseason Baseline Evaluation

Baseline data collection for the concussed sample was initiated prior to the 2000 and 2001 athletic seasons. Consistent with previous research with athletes [9,18], all baseline data were collected during the off-season (i.e. prior to pre-season contact drills). Regarding concussion history, a standardized concussion history questionnaire contained within the ImPACT test battery was administered with the supervision of the test administrator.

ImPACT is a computer administered neuropsychological test battery that consists of seven individual test modules that measure aspects of cognitive functioning including attention, memory, reaction time and information processing speed. Previous studies using ImPACT have demonstrated that reaction time deficits resolved by day 5 in a group of mildly concussed athletes [17] Given the focus of this paper on the relationship between on-field mental status changes (such as amnesia) and formal neuropsychological test performance, only performance on the memory composite index was included in this study. Tests that comprise the Memory Composite Index are listed in Table 1. A more thorough description of the ImPACT test battery and rationale for the development of the individual tests has been described in detail previously.[19]

Table 1. ImPACT memory assessment module

Test	Cognitive Ability Assessed
Word Memory (immediate)	Verbal recognition memory
Word memory (delayed)	Delayed verbal recognition memory
X's and O's	Visual topographical memory/working memory
Symbol match memory	Visual associative memory
Three letter memory (Trigrams)	Verbal working memory

ImPACT also yields a Post-Concussion Symptom Scale that is now being utilized throughout both amateur and professional sports.[18] This scale consists of 21 symptoms commonly associated with concussion (e.g. headache, dizziness, nausea, sleep disturbance) that are graded from 0 (asymptomatic) to 6 (severely symptomatic). This scale assesses the athlete's self-report of symptoms including both cognitive (e.g. attention deficit, perceived memory dysfunction) as well as non-cognitive symptoms such as headache, nausea, dizziness, sleep disturbance, emotional changes and photophobia.

Post-Concussion Evaluation

High school athletes who sustained a concussion were referred for post-injury serial neuropsychological evaluation conducted at 36 hours, 4 days and 7 days post-injury. These test intervals reflect the fact that many participants in this study are returned to play within one week of injury (if they are asymptomatic). Therefore, we do not routinely collect more long-term follow-up data on this group.

Concussions were diagnosed based of the following criteria: 1) any observable alteration in mental status/level of consciousness such as loss of consciousness, retrograde amnesia, post-traumatic amnesia, disorientations) and/or; 2) any self-reported symptoms following a collision such as "fogginess" or "grogginess", headache, nausea/vomiting, dizziness, balance problems, visual changes. Seven of the athletes in this sample experienced frank loss of consciousness and were subsequently dropped from further analysis. These athletes were not included because of our desire to focus on *mildly* concussed athletes. Thirteen athletes experienced retrograde amnesia and 19 experienced posttraumatic amnesia. Twenty-eight were disoriented on the field. Twenty-seven athletes did not display any mental status changes on the field but did display other non-cognitive symptoms that suggested a concussion and resulted in removal from the playing field. The initial diagnosis of concussion was made by certified athletic trainers or team physicians who were present on the sideline at the time of injury. Both the presence and duration of on-field mental status changes was documented. Structural brain imaging (CT scan of the brain) is not routinely undertaken in athletes. Therefore, only 3 of our patients underwent CT scanning following injury and all of these studies were read as normal. None of the participants in the study developed a structural brain lesion while participating in the program.

Data Analysis

Data from all participating high school institutions were pooled and analyzed using Statistical Package for the Social Sciences.[23] As outlined below, statistical comparisons were made utilizing repeated measures Analysis of Variance (ANOVA) techniques as well as non-parametric analyses, where appropriate.

RESULTS

Given the multi-site nature of the study, an analysis was first undertaken to evaluate the consistency of baseline memory and symptom data between contributing sites. Data from the individual sites were pooled into groups comprising three geographic regions and compared statistically; East (Pennsylvania, Maine), Midwest (Illinois, Michigan), and West (Oregon). No significant differences between regional groups were found in pre-season baseline memory testing ($F=.003$, $p<.=.996$) or total symptom score ($F=.81$, $p<.451$).

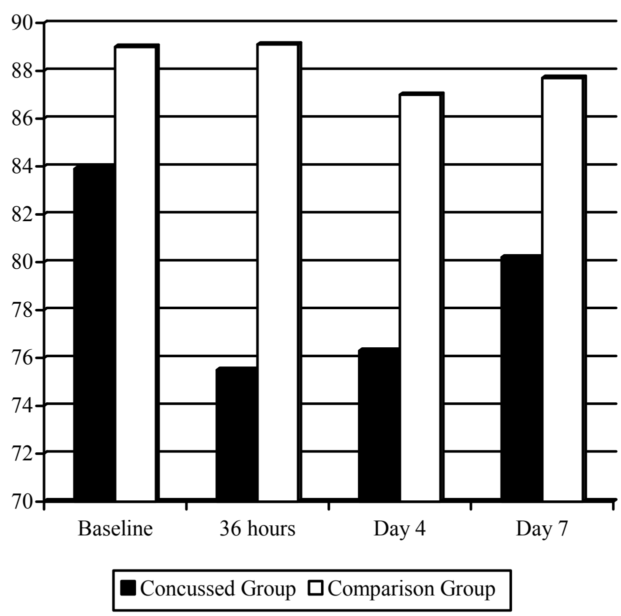
ImPACT baseline and follow-up memory composite and symptom total scores (and standard deviations) for the concussed and comparison groups are provided in Table 2. A graphic depiction of memory performance and symptom profiles of the concussion and comparison group is provided in Figures 1 and 2.

Table 2. Memory performance and symptoms for concussed and non-concussed high school athletes

Group / Variable	Baseline	Follow-Up 1	Follow-up 2	Follow-up 3
Comparison Group*				
Memory Composite	89.0 (6.2)	89.1 (8.6)	87.0 (7.4)	87.7 (9.9)
Postconcussion Symptoms Total**	3.4 (7.1)	1.4 (3.4)	1.3 (3.5)	1.4 (5.3)
Concussed Players	**Baseline**	**Follow-up 1**	**Follow-up 2**	**Follow-up 3**
Memory Composite	83.9 (8.6)	75.5 (14.2)	76.3 (13.5)	80.2 (13.1)
Postconcussion Symptoms Total	9.9 (12.9)	25.3 (23.8)	13.6 (19.8)	6.6 (13.9)

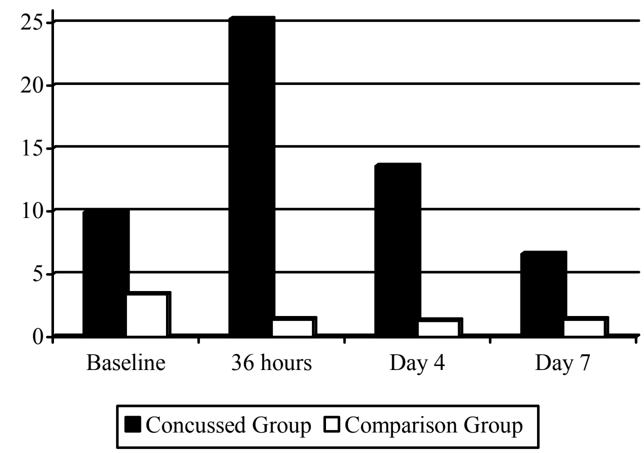
*The comparison group (n = 24) obtained higher memory scores and reported less symptoms than football players (n = 64) at the baseline assessment (Mann Whitney U test p's < .005).
**Baseline Postconcussion Symptom Total scores > All Follow-ups; p < .05.

Figure 1. ImPACT memory composite score for concussed and comparison groups.



Scores represent mean performance on the memory composite index of ImPACT. The performance of the comparison group did not differ significantly across the evaluation periods. Concussed athletes differed across the evaluation periods.

Figure 2. ImPACT symptom score for concussed and comparison groups.



Scores represent total symptom scores for the concussed and comparison groups. The comparison group demonstrated lower symptom scores at follow-up than at baseline. However, the concussed group displayed significantly higher symptom scores at follow-up

Comparison Group

The primary function of the comparison group in the study was to examine the effects of prior exposure or practice on memory test performance and symptom reporting. Repeated Measures ANOVAs revealed relatively equivalent memory scores for the comparison group across the four testing sessions ($F(2.6, 60.9) = .88$, $p = .445$) and therefore no significant practice effects. These findings provide the basis for comparison of post-concussion changes in the concussed groups. Regarding symptom reporting in the comparison group, all three follow-up symptom scores were significantly lower than the baseline score, based on a p<.05 criteria (p's range from .012 to .049). This indicates that comparison group subjects reported *less* symptoms at follow-up than at baseline.

Concussion Group

To evaluate recovery in the concussed group during the first week post-injury, change in memory and symptom scores were examined using the repeated measure ANOVA methodology described above. For the memory composite score, significant changes in performance were seen between preseason and post-concussion ($F(3, 189) = 12.6$, $p < .00001$). Furthermore, pairwise comparisons between memory scores revealed significantly lower memory scores at 36 hours, at day 4 and at day 7, compared to baseline (see Table 3).

Table 3. Documenting recovery of the concussion group through pairwise comparisons.

Pairwise Comparison	p value	Effect Size (d)	Effect Size Classification
Memory Composite			
Baseline – 36 hours	<.0001	.74[a]	Medium – Large
Baseline – Day 4	<.0001	.69	Medium – Large
Baseline – Day 7	< .017	.34	Small
Postconcussion Symptoms			
Baseline – 36 hours	< .000001	.84	Large
Baseline – Day 4	Ns	---	---
Baseline – Day 7	Ns	---	---

[a]Effect sizes represent the magnitude of difference between two groups in standard deviation units. This helps to establish the clinical relevance of statistically significant findings.

Regarding self-reported symptoms, there was also a significant difference in report of symptoms between pre-season baseline and at 36-hours post-concussion ($F(3, 171) = 25.2$, $p < .000000001$), with concussed athletes reporting more symptoms after concussion than they did during the pre-season. However, no significant differences in symptom reporting were found at days 4 and 7. The pairwise comparison results and associated effect sizes for the total symptoms score are presented in Table 3.

Comparisons of Athletes with Brief and Prolonged On-Field Symptoms of Concussion

To more closely examine the issue of concussion severity within this mildly concussed group, the concussed athletes were sorted into two groups based on *duration* of on-field symptoms. Athletes were classified into *more severe* and *less severe* concussion group, defined by duration of on-field markers of concussion. More severe concussions were defined as those presenting with (a) retrograde amnesia for greater than 5 minutes, *or* (b) post-traumatic amnesia greater than 5 minutes, *or* (c) disorientation greater than 5 minutes. The less severe concussion group either had no mental status changes or exhibited mental status changes that lasted less than 5 minutes. This classification scheme was utilized to allow the separation of transient post-concussive cognitive disturbance from longer lasting sequelae of the injury. The injury severity characteristics of these two groups are presented in Table 4.

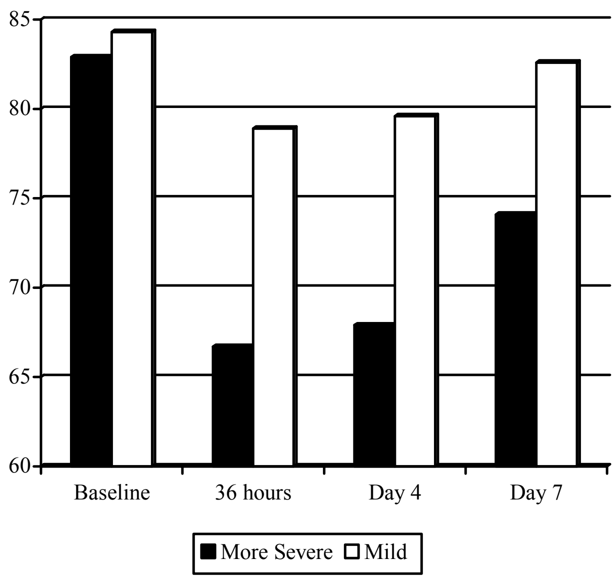
Average memory composite scores for the two concussion severity groups, are presented in Figure 3. An ANOVA revealed significant differences in memory performance between athletes with transient or more long-lasting on-field mental status changes ($F(1, 54) = 5.5$; $p < .024$). Self-report symptom profiles for the two groups are presented in Figure 4.

An additional analysis was conducted to assess differences across the three follow-up intervals and these data are presented in Table 5. Pairwise comparisons revealed significant declines in memory performance, relative to baseline, at all three follow-up intervals for concussed players with a longer duration of symptoms ($p < .017$, .004, and .037, respectively).

Table 4. Percentages of subjects by group with each injury severity characteristic.

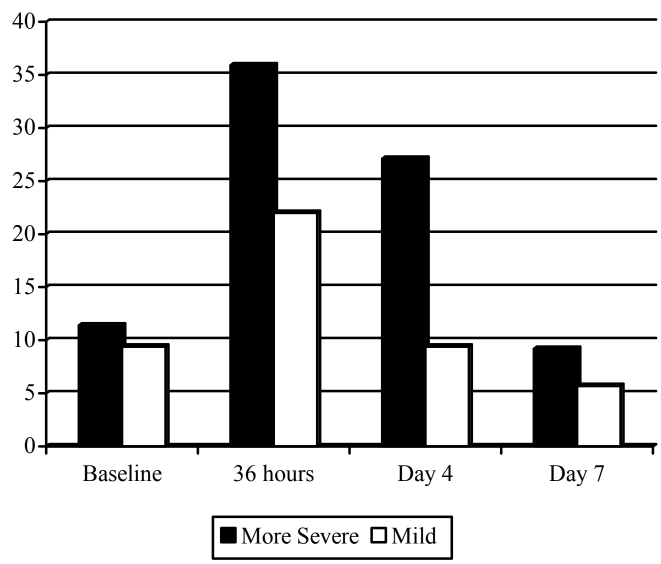
Retrograde Amnesia	**More Severe Concussion (n = 13)**	**Mild Concussion (n = 43)**
Yes	46.2	9.3
1 – 10 seconds	7.7	2.3
11 – 59 seconds	0	2.3
1 – 5 minutes	23.1	4.7
6 – 15 minutes	7.7	0
> 15 minutes	7.7	0
Anterograde Amnesia		
Yes	84.6	11.6
1 – 5 minutes	15.7	11.6
6 – 15 minutes	15.4	0
16 – 30 minutes	38.5	0
> 30 minutes	15.4	0
Disorientation		
Yes	76.9	34.9
10 – 59 seconds	7.7	0
1 – 5 minutes	0	34.9
6 – 30 minutes	38.5	0
> 30 minutes	30.8	0

Figure 3. **ImPACT memory composite scores by concussion severity**.



Scores represent mean performance on the memory composite index of ImPACT. Concussed athletes performed more poorly across time. Athletes with more severe injuries (as defined by on-field markers lasting longer than five minutes) displayed poorer performance compared to those with brief on-field difficulties.

Figure 4. ImPACT symptom total score by concussion severity.



Scores represent total symptom scores for the two severity groups. Concussed athletes performed significantly more poorly across time. A comparison between athletes with more severe and mild injuries (as defined by on-field markers of concussion lasting longer than five minutes) did not reach statistical significance, although there was a trend towards more symptom reporting in the more severe group.

Table 5. Recovery from concussion in more severe and less severe concussions based on duration of symptoms: pairwise comparisons.

Pair wise Comparison	p value	Effect Size (d)	Effect Size Classification
More Severe Concussion			
Memory Composite			
Baseline – 36 hours	.017	1.21	Very Large
Baseline – Day 4	.004	1.31	Very Large
Baseline – Day 7	.037	.67	Medium
Postconcussion Symptoms			
Baseline – 36 hours	.003	1.37	Very Large
Baseline – Day 4	.061	.81	---
Baseline – Day 7	ns	.03	---
Mild Concussion			
Memory Composite			
Baseline – 36 hours	.003	.47	Medium
Baseline – Day 4	.013	.43	Medium
Baseline – Day 7	ns	.17	---
Postconcussion Symptoms			
Baseline – 36 hours	.00007	.73	Large
Baseline – Day 4	ns	.01	---
Baseline – Day 7	ns	.27	---

[a]Effect sizes represent the magnitude of difference between two groups in standard deviation units. This helps to establish the clinical relevance of statistically significant findings.

For the group with a duration of symptoms lasting less than 5 minutes, pairwise within-group comparisons revealed significant declines in memory performance, relative to baseline, at 36 hours ($p < .003$) and at day 4 ($p <.013$) but not a 7 days post injury.

There was a trend towards differences in self-reported symptoms between shorter and longer duration groups with the longer duration group reporting more symptoms ($F\ (1, 49) = 2.9$; $p < .096$). As shown in Table 5, pairwise comparisons revealed a significant increase in symptoms from baseline to 36 hours for athtletes' whose on-field mental status changes were of longer duration ($p < .003$). There was a trend toward greater symptom reporting at day 4, relative to baseline ($p < .061$). For the mildly concussed players, pairwise within group comparisons revealed significantly greater symptoms from baseline to 36 hours ($p<.00007$). By day 4 and day 7, there were no significant differences compared to baseline.

The 13-point drop in memory performance displayed by the concussed group compared to their baseline and represents a major decline between preseason and immediate follow-up (i.e., greater than 1.5 standard deviation decline in performance). Furthermore, the athletes with longer duration of on-field mental status changes were 5.3 times more likely to demonstrate a major drop in memory performance at 36 hours than the athletes with mild concussions.

DISCUSSION

No area of sports medicine involves more clinical uncertainty and controversy than the management of concussion. Reasons for controversy in this area include an overall difficulty in accurately diagnosing the phenomenon, a current lack of understanding regarding the pathophysiology of mild concussion, and a lack of consensus regarding return to play guidelines. While the issue of sports-related concussion has become one of the most popular topics of discussion in sports medicine and has led to the publication of 2 recent journal issues covering the subject, [7,24] surprisingly little research has been published on high school age students. In fact, no studies have been published that investigate the recovery process in this age group utilizing formal neuropsychological testing.

In this study, we have provided data regarding the neuropsychological consequences of concussion in this younger group of athletes who have experienced what has traditionally been characterized as mild concussion. For the current study, we excluded athletes who experienced any degree of post-injury loss of consciousness and chose to focus on athletes with varying degrees of symptoms, disorientation, posttraumatic and/or retrograde amnesia. The exclusion of subjects who had lost consciousness was done for several reasons. First, concussions that involve a loss of consciousness almost always result in immediate removal from competition and restriction of return to play for at least one week. However, concussions that do not involve a loss of consciousness have historically been viewed as a more trivial injury and athletes have often returned to play during the same contest. In addition, although concussion *without loss of consciousness* is the most common type of sports-related head injury it is more difficult to detect and may be often be misdiagnosed by sports medicine practitioners.[5]

This study demonstrates that even in this more mildly injured group, there was pronounced memory decline in some concussed high school athletes that remained *at least* 7 days post-injury. Decline in memory functioning was clearly linked to concussive injury as a non-injured comparison group exhibited stable memory performance across similar testing sessions. Overall findings suggest the need for careful evaluation and monitoring of high school athletes sustaining a concussion of any severity.

In addition to evaluating decline in memory as a result of mild concussions, this study also evaluated overall symptom reporting during the first week of recovery. Self-reported symptoms generally resolved within 4 days of injury. Importantly, our findings suggest a lack of agreement between formal memory testing and self-report of symptoms with longer lasting memory decline and earlier resolution of symptoms. This finding is of concern given that most high schools do not utilize neuropsychological testing and athlete self-report is often the primary determinant of return to play. This study suggests that neuropsychological test results provide unique information to the sports medicine practitioner. These findings are also consistent with past research with college athletes that documented earlier resolution of somatic symptoms relative to neuropsychological test performance.[5,17] Differences between neuropsychological test performance and symptom self-report are common in concussed athletes and are likely to reflect both neurological and non-neurological (e.g. vestibular) aspects of the injury. Symptom self-report is also likely to be influenced by the expectations of the patient and other psychological processes.[21] In addition, some athletes are known to minimize symptoms in hopes of a faster return to the playing field, rink or court.[16] The use of neuropsychological testing helps to assure that the athlete is indeed recovered prior to returning to the playing field.

In addition to providing evidence of post-concussion memory decline and increased symptoms in mildly concussed high school athletes, this study also found a relationship between *duration* of initial on-field mental status changes and rate of recovery during the first week post-injury. Specifically, athletes with post-injury anterograde amnesia, retrograde amnesia or disorientation lasting *longer than* five minutes, as a group, did not fully recover by 7 days. In contrast, athletes with duration of on-field mental status changes lasting *less than* five minutes demonstrated a return to baseline within four days. In designing this study, 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. In employing this cutoff however, we do not wish to recommend its adoption as a new severity marker at the current time. Rather, we are hopeful that this study will spark more research aimed at the continued delineation of the acute recovery period following concussion.

Regarding the issue of possible age-related differences in recovery following concussion, existing research has failed to yield clinically useful data regarding potential age-related differences in recovery from concussion, although there is a considerable published literature addressing more severe traumatic brain injury.[12,13] To date, clinical research in the area of sports concussion has been limited to college and professional athletes. In these studies, neuropsychological recovery has been found to occur anywhere from 48 hours to 5 days post-injury. This current study provides evidence of memory deficits at least 7 days post-injury within a sample of high school athletes suffering "mild" concussions. Unfortunately, it was not possible to track athletes' beyond 7 days in this study. Given the persistence of memory dysfunction at 7 days post-injury, it would have been particularly useful to perform more long-term follow-up studies to document more long-lasting deficits in the athletes who had not shown complete recovery by day 7. Future studies of neuropsychological recovery completed within our program will track these athletes on a more long-term basis.

Finally, our finding of memory deficits 7 days post-injury is consistent with animal research demonstrating neurometabolic disruption 7 to 10 days for injury. [10] Animal research has also suggested that the brain may be more vulnerable to additional injury during this acute recovery period and that re-injury prior to complete recovery may result in additional (cumulative) deficits. More recently, preliminary research with High School athletes has also suggested that the effects of concussion may be cumulative. [6,] although this issue requires further evaluation. To better understand the relationship between brain metabolism and neuropsychological test performance our future research will involve functional brain imaging (fMRI) studies of athletes during the acute recovery process. This will allow simultaneous evaluation of both metabolic and neuropsychological markers of concussion recovery.

CONCLUSION

This is the first study to compare acute neurocognitive recovery after sports-related concussion in concussed and non-concussed high school athletes. Results suggest that there is measurable memory decline at least 7 days post-injury in a subgroup of athletes. Currently, formal neuropsychological baseline evaluations are routinely implemented at the professional and major college levels. Our results suggest that baseline/post-injury neuropsychological testing procedures should be considered at the high school level and that neuropsychological test results, in conjunction with other diagnostic information, can provide valuable information regarding return to play.

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