Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes

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Abstract

Objectives- Sports related concussion is common in children and adults. However age-related differences have never been studied. In this study we evaluate post-concussion recovery patterns between high school and college athletes.

Study Design- 371 college and 183 high school athletes underwent baseline neuropsychological evaluation between 1997 and 2000. Individuals sustaining a concussion during athletic competition underwent serial neuropsychological evaluation following injury. Main outcome measures included structured interview, four memory measures, and Concussion Symptom Scale ratings. These were statistically evaluated using multiple analysis of variance analyses.

Results- Concussed high school athletes demonstrated prolonged memory dysfunction compared to concussed college athletes. High school athletes performed significantly worse than age-matched controls at 7 days post-injury ($F=2.90$; $p<.005$). College athletes, despite suffering more severe in-season concussions, displayed commensurate performance with matched control subjects by day 3 after concussion. Self-report of post-concussion symptoms by student athletes was not predictive of poor performance on neuropsychological testing.

Conclusions- Caution and more systematic evaluation should be undertaken before returning concussed high school athletes to competition. Sole reliance on the self-report of the athlete may be inadequate. Current adult concussion guidelines may not provide the best standard for making return-to-play decisions in high school athletes.

Abbreviations

AAN - American Academy of Neurology
BVMT-R - Brief Visual Spatial Memory Test-Revised
CT - computed tomography
EAA - excitatory amino acids
GPA – grade point average
HVLT - Hopkins Verbal Learning Test
LD - learning disabilities
LOC - loss of consciousness
MANOVA - multiple analysis of variance analyses
MRI – magnetic resonance imaging
MTBI – mild traumatic brain injury
NMDA - N-methyl-D-aspartate
TBI – traumatic brain injury

The diagnosis, recovery, and management of sports-related mild traumatic brain injury (MTBI; e.g. concussion) has rightfully received recognition as a major public health concern.[1] A minimum of 1.5 million high school and college athletes compete in contact sports. Recent data suggest an estimated 62,816 cases of MTBI occur annually at the high school level, with football accounting for about 63% of the cases.[2] At the college level, a multi-center study found 34% of college football players had experienced one concussion in their past, whereas 20% had experienced multiple concussions.[3] The latter study also revealed associated neuropsychological impairment (e.g. speed of information processing, problem solving) in the multiple concussion group, with learning disability found to be an associated risk factor. Colleagues from the Netherlands have similarly revealed neuropsychological impairment (e.g. planning, memory) in a group of adult amateur soccer players.[4] In addition to these systematic research efforts, the National Hockey League mandates baseline neuropsychological evaluation for all athletes and the majority of National Football League organizations have implemented neuropsychological testing to help with clinical decision-making following concussion.[5]

Though systematic research and clinical efforts have been fruitful and are underway with many college and professional teams, there has been a paucity of systematic or published research examining the acute recovery of adolescent and high school athletes following concussion. In fact, there are no published studies that have systematically investigated recovery from concussion in high school athletes, utilizing formal neuropsychological testing. Published studies with older athletes that incorporated baseline and post-injury neuropsychological evaluation have revealed cognitive and symptom deficits (relative to controls) within 2 days of injury that generally resolve within 5 days post-injury.[6,7] For example, Echemendia and his colleagues examined concussed college athletes and found deficits in memory and reaction time that persisted at 48 hours post-injury and were actually more pronounced at 48 hours post-injury than at 2 hours post-injury.[8]

The lack of research in the younger athlete is concerning for many reasons. First, 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 (which results from a second concussive insult closely following the first) were reported in the scientific literature between 1992-1997.[9] The majority of reported victims were children between the ages of 13-18. Finally, existing return-to-play management "guidelines" assume a standard use for all age groups (i.e. high school, college, and professional athletic levels) and are based on adult concussive experiences. Unfortunately, no current study has examined whether there are differing vulnerabilities to concussive injury at different ages. Given the serious outcomes associated with concussion, recognition and management of the injury are of paramount importance. At least 19 different concussion scales have been published since 1973, all of which have disparate criteria for grading severity and return-to-play options. The reason for this variability is secondary to a lack of evidenced-based data in constructing these guidelines, thus resulting in an arbitrary delineation of return-to-play and management parameters.[10]

Recently, the American Academy of Pediatrics outlined the clinical pathway for managing general minor traumatic brain injury.[11] These parameters primarily address ruling out serious intracranial pathology (e.g. skull fracture, developing hematoma) and also stress the importance of ongoing research in the area of MTBI in children. One such area delineated by the Academy is to foster appropriate diagnostic techniques that help to differentiate the risk status of children with or without symptoms of MTBI. It is important to note, however, that standard neurodiagnostic procedures such as Computed Tomography (CT) scan or Magnetic Resonance Imaging (MRI) are not typically sensitive to the subtle impairments associated with concussion.

The current prospective study was undertaken to compare pre-season (i.e. baseline) to post-concussion neuropsychological and symptom recovery patterns in high school and college athletes. Baseline data can often vary dramatically from athlete to athlete making objective post-concussive neurocognitive and symptom recovery difficult to interpret without a knowledge of the pre-injury state. Such an approach is of paramount importance to the eventual construction of evidence-based concussion management strategies.

METHODS

Subjects

Study subjects were comprised of college and high school athletes. The college sample consisted of 370 male football and 23 female soccer players from four Division 1A programs: Michigan State University, East Lansing; the University of Utah, Salt Lake City; the University of California, Berkeley; and Arizona State University, Tempe. The high school sample consisted of 161 varsity male football players and 22 varsity male soccer players from five high schools in Shiawassee County, Michigan.

Program Protocol and Outcome Measures

All athletes in the sample participated in the "Concussion Safety Program." This voluntary ongoing clinical and research program implements the use of neuropsychological tests to assist team medical staff in making objective decisions for return-to-play following the occurrence of sports-related concussion. All athletes in the program are individually administered neuropsychological tests during the pre-season which then become the standard of comparison if the athlete is injured. Athletes are not financially compensated for participation in the program.

Preseason Baseline Evaluation

Appropriate review for research with human subjects was granted separately from the four college institutions. Each college participant was provided written informed consent for voluntary participation. Parental consent for participation was also obtained for each athlete in the high school sample. Data collection for all athletes were completed by a research team of clinical neuropsychologists, team physicians, or athletic trainers who were formally trained in the administration of the measures. Each examiner was required to attend a 2-hour workshop and was supervised during test administration (by MWC) to facilitate the appropriate standardized administration of the test battery. All measures were administered and scored in a standardized manner to minimize differences between test administrators and institutions/high schools. Project investigators trained in neuropsychological assessment completed all data scoring.

Baseline data collection for the college sample was initiated prior to the 1997/98 athletic season and continued yearly up until the 2000/2001 season. High school baseline data collection was completed prior to the 1999/2000 and 2000/2001 seasons. All baseline data were collected during the off-season (e.g. prior to pre-season contact drills). At the baseline session, the following self-reported data were collected: age, playing position, college board examination scores (if applicable), grade point average, history of diagnosed learning disability, neurological history (e.g., epilepsy, brain tumor), psychiatric history (e.g. depression, mania), and history of concussion. The standardized concussion history form was administered to gather information regarding specific incidences of concussion in the athletes' past. Concussion history information collected included: year of concussion, description of event, presence/length of confusion, loss of consciousness, anterograde amnesia (memory loss after the hit), retrograde amnesia (memory loss prior to the hit), and results of neuroimaging procedures (if any).

Concussions were defined and graded according the American Academy of Neurology Practice Parameter.[12] Thus, players experiencing a traumatically-induced alteration in mental status, not necessarily resulting in loss of consciousness, were defined as having experienced a concussion. According to the AAN guidelines, a grade 1 concussion occurs when mental status changes resolve in less than 15 minutes post-trauma. A grade 2 event occurs when mental status changes persist for greater than 15 minutes post-trauma. A grade 3 concussion occurs when there is an associated loss of consciousness (either brief or prolonged) following the trauma.

During the baseline session, all athletes were administered a Post-Concussion Symptom Scale that is now being utilized throughout amateur and professional sports.[13] This Likert scale consists of 20 symptoms commonly associated with concussion (e.g. headache, dizziness, nausea, sleep disturbance) that are graded from 0 (asymptomatic) to 6 (severely symptomatic) in terms of severity.

After completing the Post-Concussion Symptom Scale, all athletes were administered a 25-minute battery of neuropsychological tests. Tests included the Hopkins Verbal Learning Test (HVLT; verbal learning and memory); Digit Span Test (attention/concentration); Symbol Digit Modalities Test (speed of information processing); Trailmaking Test, Forms A and B (visual scanning and executive functioning), and Controlled Oral Word Assocation Test (word fluency). High school athletes were also administered the Brief Visual Spatial Memory Test-Revised (BVMT-R; visual memory). This test was added to the high school battery for the 1999/2000 season since more time was available with this sample. A more thorough description of the specific cognitive tests and rationale for testing has been described in detail previously.[13]

Based on previous work with college athletes suggesting acute and demonstrable impairments of memory processes after concussion[3], this study utilized memory tests as dependent measures. We also chose to focus on memory due to the primary importance of amnesia to virtually all current concussion management guidelines. Thus, our two dependent measures included the HVLT and BVMT-R. Each of these tests has a learning component to verbal or visual stimuli (3 consecutive immediate recall trials) and a delayed memory component (20 minutes after learning trial).

Post-Concussion Evaluation

Although in-season concussions were graded based on AAN criteria, the diagnosis of concussion was made based upon the on-field presentation of one or more of the following symptoms after a blow to the head or body: 1) any observable alteration in mental status or consciousness; 2) a constellation of self-reported symptoms, such as post-traumatic headache, "fogginess," nausea/vomiting, dizziness, etc and/or 3) the presence of loss of consciousness, disorientation, PTA, or retrograde amnesia as identified by on-field examination. This was accomplished utilizing an athlete concussion history form as well as a post-concussion symptom scale. Initial diagnosis of concussion was made by sports medicine practitioners who were present on the sideline at the time of injury.

Sports medicine practitioners at the participating institutions carefully documented information pertaining to post-concussion markers of injury. At the aforementioned training seminars, athletic trainers and/or physicians were trained to identify the on-field markers of concussion, including disorientation, PTA, retrograde amnesia, and LOC. On-field disorientation 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). Athletes presenting with *any* level of on-field disorientation in this regard were classified in the positive disorientation group. On-field PTA was assessed through immediate and delayed (e.g. 0, 5, 15 minute) memory for three words (e.g. girl, dog, green). PTA was subsequently 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 PTA. On-field retrograde amnesia was assessed by having the athlete recall events occurring just prior to trauma (e.g. memory for play or plays preceding trauma, events in previous quarter, etc). Retrograde amnesia was subsequently 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 positive presence of retrograde amnesia. Loss of consciousness 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 PTA (i.e. loss of memory for the duration of the unconscious state). For the purposes of this study, athletes with *any* degree of LOC were categorized in the positive LOC group. If the athlete sustained an additional period of PTA, they were also categorized in the positive PTA group.

High school and college athletes sustaining concussion from within the sample were referred for serial neuropsychological evaluation following injury. Athletes were assessed within 24 hours of injury and at days 3, 5, and 7 post-injury to determine "recovery curves" for both cognitive and self-report symptomatology. Concussion diagnoses and referrals were at the discretion of the respective athletic trainers or team physicians. A structured description of the concussive event was provided at the time of injury. Specifically, information was gathered about the nature of the "hit" as well as presence/duration of loss of consciousness (LOC), anterograde amnesia, retrograde amnesia, and post-traumatic confusion. The neuropsychological tests and self-report inventory used in the post-concussion evaluation were identical to those used at the baseline evaluation. Available alternate forms of the HVLT and BVMT-R were administered to attempt to minimize the learning effects associated with the measures.

Control Subjects

College and high school athletes from the baseline sample served as control subjects. Control subjects were matched according to sport, age, high school grade point average (for high school athletes), college board examination scores (for college athletes), history of diagnosed learning disability, and history of previous concussion. Within the context of these criteria, it was possible for controls to be matched to more than 1 athlete with concussion. Control subjects for both high school and college samples were evaluated serially following their respective athletic seasons. No control subject experienced concussion during the course of the study.

Data Analysis

Data from all participating high school and college institutions were analyzed with Statistica, 5.1 statistical software for Windows. To allow an analysis of change in post-concussion test performance relative to baseline performance, a series of difference scores were calculated for each subject to reveal recovery (or lack thereof) compared to his/her own baseline performance. Scores were constructed so that a negative value signified a decline from baseline while a positive number signified an improvement in performance from baseline. These change scores were calculated for the 24 hours post-injury period as well as for the 3, 5 and 7 days post-injury periods. Recovery patterns for the high school and college samples were compared to their respective control groups at each time post-injury. A series of multiple analysis of variance analyses (MANOVA) were performed with scores on standardized memory testing (difference scores) representing the dependent variables. For both the high school and college groups, the total words and delayed recall difference scores of the HVLT were utilized. At the high school level, the BVMT-R difference scores were also used as a dependent measure. These latter data are presented in this study, even though no direct comparison between high school and college athletes is possible.

RESULTS

Demographic Data

The patient population in this study included both high school (n=39) and college (n=53) student athletes. High school and college athletes who had suffered concussions (high school, n = 19; college, n = 35) were compared directly to matched control groups (high school, n=20 ; college, n=18) at their respective level of participation. Ninety-five percent of the high school sample was Caucasian (n=37), and five percent non-Caucasion (one African American and one Asian American). At the college level, 66% were European American (n=35), 25% African American (n=13) and 9% were of either Hispanic, Asian or Polynesian American ancestry (n=5). In the high school sample, 90% (n=35) of the athletes were football players and approximately 10% (n=4) soccer players. At the college level, 96% (n=51) of the athletes were male football players and 2 (4% of sample) were female soccer players.

The mean age of the high school group was 15.9 years (range=14-18 years) while the college sample had a mean age of 19.9 years (range= 17-25 years). The mean age difference between these groups was statistically significant (t = -11.60; p = .0001). The mean age of the pooled concussion group (18.4) was similar to the control group (18.3) and this difference was not statistically different (t = .04; p = .961). The concussed and control groups did not differ significantly with regard to traditional achievement measures. At the high school level, GPA between the two groups was not significantly different (t = -1.70; p = .10). Likewise, academic score differences between concussed and control groups at the college level were not significantly different [SAT scores (t = .41; p = .70), ACT scores (t = -.29; p = .82), high school GPA (t = -.74; p = .50)].

The prevalence of learning disabilities (LD) in the study population was 5.4% (n=5). There was no significant difference between the high school and college groups (χ^2 = 1.09; p.= .297). The concussed and control groups also did not differ significantly with regard to LD prevalence. (χ^2 = .014; p = .906).

Prior Concussion History:

Fifty-three percent of the pooled high school and college athletes in this study had a lifetime history of at least one prior concussion. The high school and college groups did not differ significantly with regard to their report of suffering one concussion in their past (χ^2= 1.11; p=.292). The college group, however, reported a significantly higher rate of multiple concussions in their past (36% of college sample versus 7.7% of high school sample)(χ^2 = 9.79; p = .002) and a significantly higher number of total concussions (t = -2.60; p = .01) compared to the high school group. The severity of concussive events for both the high school and college groups generally fell within the mild range with only 14 of 92 subjects (15%) reporting a history of LOC. The high school and college samples did not vary with regard to history of prior LOC (χ^2 = .750; p = .688). When the high school concussion group was compared directly to their matched control group, there was no significant difference with regard to a history of one concussion (χ^2 = 1.25; p= .263) or mean number of concussions experienced (t = -.35; p = .80). However, the college concussion and control groups did vary significantly, with the concussed college sample having a higher incidence of previous concussion than the control group (χ^2 = 3.78; p = .054) as well as a higher mean number of concussions (t = 2.85; p = .007). With regard to a history of multiple concussions, the injured high school group did not differ from their control group (χ^2 = .419; p = .517), though the concussed college sample did have a higher incidence of multiple concussions compared to their control group (χ^2 = 7.25; p = .007).

Within Study Concussion Severity:

The majority of concussions occurring within this study were mild, falling within the Grade 1 or Grade 2 classification of the American Academy of Neurology guidelines.[12] The overall percentage of athletes in the total concussed sample that suffered a loss of consciousness during the study was 26%. College athletes had a higher rate of LOC (34%) while only 2 (11%) of the high school sample experienced a LOC during the study period (χ^2 = 3.62; p = .057). High school and college groups did not differ significantly with respect to presenting symptoms of confusion (χ^2 = .081; p = .796) or retrograde amnesia (χ^2 = 2.55; p = .278).

Recovery Patterns of high school and college athletes

The comparison between concussed and control athletes is presented for both the high school and college samples. Verbal learning and memory (HVLT) recovery patterns are presented for the college and high school samples in Figure 1 and Figure 2, respectively. Visual learning and memory learning recovery patterns (BVMT-R) are presented for high school athletes in Figure 3. Raw data (means and standard deviations) for the concussed and control groups across all testing sessions for both the high school and college groups are presented in Table 1 and Table 2, respectively.

At 24 hours post-injury, the MANOVA for memory performance was statistically significant for high school (F = 3.88; p < .01) and college groups (F = 6.45; p < .004). In the high school group, an analysis of univariate main effects revealed significant differences between the concussed and control athletes for HVLT total words (F = 10.13; p < .003), BVMT-R total figures (F = 11.50; p < .002), and BVMT-R delayed figure recall (F = 11.11; p < .002). At the college level, significant differences were found for both HVLT total words (F = 10.65; p < .002) and HVLT delayed recall (F = 11.05; p < .002).

At 3 days post-injury, the MANOVA was significant for the high school sample (F = 3.43; p < .02) but not for the college group (F = .100; p < .905). Differences in test performance between concussed high school athletes and respective controls approached significance for HVLT total words (F = 3.55; p < .07) and were more robust for BVMT-R total figures (F = 11.34; p < .002) and BVMT-R delayed recall (F = 6.00; p < .02).

At 5 days post-injury, comparisons of test performance between concussed and control high school athletes were significant for differences in BVMT-R total figures (F = 8.20; p < .008). HVLT total words recalled approached significance for the college groups (F = 3.76; p < .06).

At 7 days post-injury, the MANOVA comparing concussed and control high school athletes was significant (F = 2.90; p < .04). Further univariate analysis revealed that differences between the HVLT total score was significant in these groups (F = 9.37; p < .005), while BVMT-R total figures approached but did not reach statistical significance (F = 3.16; p < .09) in the high school student/athletes. There were no significant differences between the college concussion or control groups on either HVLT total words or HVLT memory at 7 days post-injury (F = .48; p < .70).

The BVMT-R was not administered to the college sample, therefore, a direct comparison of high school and college athletes' performance on this test was not possible. However, an additional analysis of variance between high school and college samples on the Hopkins Verbal Learning test was completed to further investigate differences in rate of recovery on this test. At baseline, the college and high school groups did not differ on the HVLT total (F=3.07, p<.10) and Delayed Recall scores (F=2.2, p<.15). At the time of first post-injury follow-up, significant differences between the High School and college athletes groups was also not evident. However, a comparison of these groups at 3 days post injury did indicate significantly poorer performance for the High School group for both HVLT total (F=8.65, p<.005) and HVLT Delay (F=5.72, p.<02).

This finding suggests a more protracted rate of recovery for the High School group. This performance difference was no longer evident at day 5 or day 7.

Concussion Symptoms

Figure 4 reveals self-report of post-concussive symptoms relative to baseline. Concussed athletes at the high school level reported a significant increase in post-concussive symptoms relative to controls 24 hours post-injury ($F = 16.7$; $p < .0002$), 3 days post-injury ($F = 5.8$; $p < .02$) and 5 days post-injury ($F = 4.1$; $p < .05$). At the college level, significant differences were evident at 24 hours ($F = 8.4$; $p < .006$) and at day 3 ($F = 5.7$; $p < .02$) but not at days 5 or 7. It is important to note that both the high school and college athletes who had suffered concussions actually reported a net *decrease* in post-concussive symptoms from baseline at days 5 and 7, raising the possibility of underreporting of symptoms in both of these groups.

DISCUSSION

No area of sports medicine involves more clinical uncertainty and controversy than the management of concussion. Reasons for concern in this area include an overall difficulty in measuring the phenomenon (CT scan and MRI are insensitive to injury), the enigmatic and complex pathophysiological processes underlying concussion, and a failure to create evidence-based standards for return-to-play. Based upon prevailing standards of care (i.e. existing guidelines), it is assumed that the speed of recovery from injury is standard for all age groups and athletic levels. In this study, we have attempted to test this assumption. Studies have demonstrated age-related differences in response to more moderate or severe TBI. However, depending on the particular study reviewed, the degree of immaturity can be either a favorable or detrimental factor.[14-18]

Results of this study suggest that high school athletes may demonstrate slower acute neuropsychological recovery following sports-related concussion when compared to a sample of college athletes. Specifically, following “mild” concussion, high school football and soccer participants, when compared to matched controls, revealed significant memory impairment *at least* 7 days following injury. Conversely, college football/soccer athletes from a multi-center sample revealed significant memory deficits only within the first 24 hours following injury.

The underlying mechanisms resulting in these apparent age-related differential responses to MTBI identified in this study remain largely enigmatic as such mechanisms are likely quite complex and have yet to be clearly elucidated even in the severe TBI literature. However, the observation that a diffuse and more prolonged cerebral swelling can occur after TBI in children relative to adults, suggests that children may be at a greater risk for secondary intracranial hypertension and ischemia. A more diffuse and prolonged cerebral swelling could also lead to a delayed recovery period and may make the adolescent more susceptible to a permanent or severe neurological deficit should they be re-injured during this recovery period.[17,19-22] A second hypothesis, derived from the developmental animal literature, is that the immature brain may be up to 60 times more sensitive to glutamate mediated N-methyl-D-aspartate (NMDA) excitotoxic brain injury.[23,24] Such NMDA hypersensitivity may make the developing adolescent more susceptible than the young adult to the ischemic and injurious effects of excitatory amino acids (EAA) after brain trauma.[25,26] In fact, recent human studies have suggested that the delayed metabolic dysautoregulation found to occur after mild head injury is caused by EAA induced ionic shifts with increased Na/K ATPase activation and resultant hyperglycolysis.[27-31] The decreased cerebral blow flow that occurs with post-traumatic dysautoregulation, however, is not well understood. Such dysautoregulation may not be seen until 2-3 days after the initial injury and can often persist for greater than a week.[32-38] It has also been postulated that metabolic dysregulation may make the brain more vulnerable to a second insult until fully resolved.[6,39] Thus, our results may reflect the more pronounced and prolonged secondary physiological effects of brain injury seen in the developing brain relative to the young adult brain.

The popular concept of cortical plasticity would alternatively anticipate that high school athletes make a better neurocognitive recovery than collegiate athletes after mild head injury. For example, animal studies comparing functional outcome after hemispherectomy found younger animals to have a more complete recovery than older ones.[16] This finding supported previous clinical evidence of marked synaptic excess in children, relative to adults, allowing for neural pathway rerouting during recovery and functional plasticity in the developing brain.[40] If our study evaluated the long-term effects of mild concussion (i.e. six months to 1 year post-injury), it is possible that high schools athletes might demonstrate a more complete recovery than collegiate athletes as suggested by the theories of cortical plasticity. Clearly, longitudinal studies of this nature are indicated. Of primary concern, however, is acute response to injury since return-to-play issues are usually the most clinically germane from a management perspective. Although only 92 athletes experienced concussive events during this study period, the findings raise concerns regarding existing return-to-play criteria for the concussed athlete. First, only 11% of our high school sample as compared to 34% of college athletes experienced a loss of consciousness following injury. Based upon this information, one would traditionally assume much poorer acute outcome for the college athletes. All existing return-to-participation guidelines grade severity of injury based upon the loss of consciousness construct. Our data question the validity of this assumption and are consistent with recent data examining recovery from MTBI in a group of concussed non-athletes.[41] A second common assumption is that recovery from concussion is a linear phenomenon and that presentation is most severe immediately following injury. Our data reveal significant memory deficits in high school athletes 7 days post-injury whereas functioning is more commensurate with control data at days 3-5. These data suggest a more delayed progression of cognitive deficit and "clearing" an athlete to play using brief sideline assessment tools may place that individual at profound neurological risk. Thus, on-going and repeated examination of the concussed athlete is clearly indicated to determine if he/she has fully recovered from injury.

Another concern is that current guidelines assume a standard implementation for all age groups (e.g. high school, college, professional). Our data support more conservative management and comprehensive assessment of the high school athlete. Unfortunately, too many high schools do not employ a full-time athletic trainer or team physician who is on-site for all practices and contests as the majority of colleges do. This lack of daily qualified medical coverage increases the likelihood that high school concussion goes unidentified, thus predisposing the athlete to serious injury and poor outcome. Further, cursory evaluation of the athlete is common and return-to-participation is most often based upon self-report and symptom based parameters. Our data suggest that this standard may be inadequate since self-report of symptoms resolved within 3 days post-injury with significant cognitive deficits evidenced *at least* 7 days from the event. In addition, concussed athletes in both our high school and college groups actually reported *less* symptoms at 5-7 days post-injury than they did at baseline, raising the strong possibility of under-reporting of symptoms. Self-report of symptoms by the athlete can be influenced by a general naivete of the potential severity of the injury, desire to return-to-action, or by the belief that one must "play through" injury to be successful, even at the high school level.

Finally, the findings of this study suggest that age-related differences exist between high school and collegiate athletes with regards to recovery from concussion. Based on these findings, the importance of age stratification in future studies as well as studies including younger children at risk for concussion cannot be underemphasized. The results of such research will help to generate safe, objective, and scientifically sound guidelines and management protocols for return to play after sports-related concussion for all age groups in the future. Further research studying the role of gender, position or sport played, ethnicity, and type of symptoms/deficits experienced as related to concussion and recovery is clearly indicated but could not be addrssed in this current study. Although we would have liked to study the effect of gender, ethnicity, and sport on recovery from concussion, the small number of females relative to males, number of soccer players relative to football players, and number of Caucasians relative to African Americans or Asian Americans precluded us from being able to perform relevant statistical analyses to adequately address these variables and potential confounders. Since no other current research has suggested a role for these variables as related to concussion recovery, prospective studies addressing these issues will be significant contributions to the field.

CONCLUSION

This is the first study to evaluate differences in neurocognitive recovery after sports-related concussion between high school and college athletes. Results suggest that differences may exist in acute recovery rates between the two groups and that future studies are needed to further validate or refute current practice guidelines. Clearly, more comprehensive, objective, and evidenced-based return-to-participation parameters are needed for sports concussion management, especially in children and teenagers. Currently, formal neuropsychological baseline evaluations are routinely implemented at the professional and major college levels[3]. Our results suggest that baseline/post-injury neuropsychological testing procedures should be more readily available at the high school level, as well. Since the implementation of these individualized procedures with younger athletes has been significantly limited by cost and the labor-intensive nature of the protocols the recent advent of brief computerized neuropsychological testing procedures may help to circumvent these issues.[42] Such technology can allow a more sensitive approach to become more readily available for high school athletes. Finally, this study provides the first evidence that recovery from sports-related concussion may be age dependent and suggests that further studies are needed in children of all ages before current adult based return to play “management guidelines” are implemented in high school and other adolescent related sports.

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Table 1. Demographic and Neuropsychological Results for Concussed and Control High School Athletes

	Baseline		24 hours		Day 3		Day 5		Day 7	
	Concus	Contrl	Concus	Contrl	Concus	Contrl	Concus	Contrl	Concus	Contrl
Total subjects	35	18	---	---	---	---	---	---	---	---
Age	19.85	20.06	---	---	---	---	---	---	---	---
GPA	3.36(.51)	3.54 (.51)	---	---	---	---	---	---	---	---
ACT	20.4(4.0)	21.0 (3.37)	---	---	---	---	---	---	---	---
SAT	1052(135.0)	1010(99.0)	---	---	---	---	----	---	---	---
Mean Number of revious Concussion	1.48(1.28)	.56(.70)	---	---	---	---	---	---	---	---
Symptoms	14.1(14.5)	8.9(8.5)	28.3(24.5)	7.9(12.8)	13.0(15.7)	.73(1.3)	8.2(13.5)	.70(.78)	4.6(5.6)	.14
HVLT Total	25.6(3.9)	25.8(4.9)	22.5(4.3)	27.3(4.0)	25.8(3.9)	27.0(3.3)	24.3(4.4)	27.9(4.4)	26.3(3.4)	26.7(9.7)
HVLT Delay	8.7(1.9)	9.1(2.0)	6.5(2.7)	9.3(1.9)	8.1(2.5)	8.9(1.7)	8.2(4.0)	8.7(2.8)	8.5(2.3)	8.5(3.7)

	Baseline		24 hours		Day 3		Day 5		Day 7	
	Concus	Contrl	Concus	Contrl	Concus	Contrl	Concus	Contrl	Concus	Contrl
Total subjects	19	20	---	---	---	---	---	---	---	---
Age	15.2 (.98)	16.6 (.98)	---	---	---	---	---	---	---	---
GPA	2.96 (.63)	3.27 (.44)	---	---	---	---	---	---	---	---
Mean Number f Previous oncussions	.56 (.70)	.63 (.60)	---	---	---	---	---	---	---	---
Symptoms	5.4(6.40)	8.7(11.9)	19.8(16.0)	3.8(5.7)	10.5(13.3)	4.6(7.4)	4.1(6.7)	1.6(3.2)	.70(.95)	1.4(3.1)
HVLT Total	25.4(3.8)	23.0(3.9)	23.3(4.0)	25.1(5.3)	22.1(5.0)	22.6(4.5)	23.1(4.6)	21.9(3.9)	26.1(3.8)	27.8(4.8)
HVLT Delay	8.4(1.7)	8.1(2.5)	7.3(2.4)	8.4(2.7)	6.2(2.8)	6.8(2.4)	7.5(2.6)	7.3(1.9)	8.4(2.1)	9.2(1.9)
BVMT-R otal	27.6(4.4)	22.9(7.5)	25.7(7.0)	31.0(3.9)	27.6(4.3)	29.2(5.2)	25.9(4.4)	27.2(7.2)	29.6(3.9)	29.9(4.5)
BVMT-R elay	10.2(1.5)	9.4(2.5)	8.9(2.9)	11.2(1.6)	9.8(2.1)	10.7(2.1)	9.8(2.2)	10.1(2.7)	10.6(1.7)	11.3(1.4)

Table 2. Demographic and Neuropsychological Results for Concussed and Control College Athletes

Figure 1. Recovery Pattern of Concussed and Control College Athletes -Verbal Learning and Memory. Scores reflect the mean difference of subjects relative to their baseline performance. A lower score reflects poorer performance compared to baseline. Learning and memory scores represent performance on the Hopkins Verbal Learning Test (HVLT). *Concus-*

learn: Mean Concussed Athlete Score for Verbal Learning, *Control-learn*: Mean Control Athlete Score for Verbal Learning, *Concus-Mem*: Mean Concussed Athlete Score for Verbal Memory, *Control-Mem*: Mean Control Athlete Score for Verbal Memory

Figure 2. Recovery Pattern of Concussed and Control High School Athletes -Verbal Learning and Memory. Scores reflect the mean difference of subjects relative to their baseline performance. A lower score reflects poorer performance compared to baseline. Learning and memory scores represent performance on the Hopkins Verbal Learning Test (HVLT).). *Concus-learn:* Mean Concussed Athlete Score for Verbal Learning, *Control-learn*: Mean Control Athlete Score for Verbal Learning, *Concus-Mem*: Mean Concussed Athlete Score for Verbal Memory, *Control-Mem*: Mean Control Athlete Score for Verbal Memory

Figure 3. Recovery Pattern of Concussed and Control High School Athletes - Visual Memory and Learning. Scores reflect the mean difference of subjects relative to their baseline performance. A lower score reflects poorer performance compared to baseline. Learning and memory scores represent performance on the Brief Visuo-spatial Memory Test-Revised.). *Concus-learn:* Mean Concussed Athlete Score for Visual Learning, *Control-learn*: Mean Control Athlete Score for Visual Learning, *Concus-Mem*: Mean Concussed Athlete Score for Visual Memory, *Control-Mem*: Mean Control Athlete Score for Visual Memory

Figure 4. Symptom Self-Report of Concussed and Control Athletes - High School and College. Scores reflect the mean difference of subjects relative to their baseline report of symptoms. A positive score reflects more symptoms compared to baseline on the Post-Concussion Scale-Revised. A negative score indicates less symptoms compared to baseline.). *HS-CONC*: Concussed High School Athletes, *HS-CONT*: Control High School Athlete, *COLL-CONC*: Concussed College Athlete, *COLL-CONT*: Control College Athlete