Abstract

To assess the effects of two sports-related concussions on neuropsychological functioning and symptom reporting, the Immediate Post-concussion Assessment and Cognitive Testing (ImPACT) was administered to 483 high school athletes. Three groups of athletes were determined based on the number of previous concussions: no concussion (*n*=409), one concussion (*n*=58), and two concussions (*n*=16). The results showed that the three groups did not differ in terms of their ImPACT composite scores (Verbal Memory, Visual Memory, Reaction Time, and Processing Speed) and the Total Symptom Score. As there are only a few studies that have reported the sequelae of two concussions in high school athletes, it is premature to declare that a repeated concussion does not have persistent neurocognitive effects on high school athletes.

Effects of Two Concussions on the Neuropsychological Functioning and Symptom Reporting of High School Athletes

A mild traumatic brain injury (mTBI) in sports is commonly referred to as a concussion. A vast number of concussions occurs among youth athletes on an annual basis. Between 2001 and 2005, about three in 1000 children ages 14 to 19 had an emergency department visit for a concussion sustained during organized team sport (Bakhos, Lockhart, Myers, & Linakis, 2010). According to a review of sports-related concussions in youth, high school football players suffer concussions at a rate of 11.2 concussions per 10,000 athletic exposures, a rate that is nearly twice that of college football players (Graham, Rivara, Ford, & Spicer, 2013). Fortunately, most high school athletes recover quickly and fully from a single concussion (Lovell, Collins, Iverson, Johnston, & Bradley, 2004; Meehan, d'Hemecourt, & Comstock, 2010; Pellman, Lovell, Viano, & Casson, 2006). A meta-analysis of 21 studies involving primarily high school athletes found no residual neuropsychological impairment when testing was done beyond seven days post-concussion (Belanger & Vanderploeg, 2005). However, some young athletes experience multiple concussions and may be at risk for long-term adverse effects.

Findings regarding the effects of two or more concussions among high school athletes on neurocognitive functioning have been inconsistent. A study utilizing the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) with high school athletes with no concussion history and with two or more concussion found that concussion history did not significantly affect the total RBANS score (Moser, Schatz, & Jordan, 2005). In a large-scale study of 413 high school and 454 college athletes, those with one or two previous concussions did not differ on baseline, preseason neuropsychological testing or symptom reporting from athletes with no previous concussion (Iverson, Brooks, Lovell, & Collins, 2006). In contrast, a report of 616 high school athletes indicated that those with a history of two or more concussions (*n*=105) showed significantly higher ratings of concussion-related symptoms than athletes with a history of one (*n*=260) or no previous concussion (*n*=251) (Schatz, Moser, Covassin, & Karpf, 2011). Collins et al. (2002) found that high school athletes with three or more prior concussions were more likely to experience loss of consciousness, anterograde amnesia, and confusion after a subsequent concussive event.

At the collegiate level, research findings regarding the effects of multiple concussions have been similarly mixed. In a small-scale study consisting of 24 college football players, the neurocognitive and neurobehavioral consequences of two concussions did not appear to be significantly different from those of one concussion in a 10-day assessment (Macciocchi, Barth, Littlefield, & Cantu, 2001). An investigation employing computerized neuropsychological testing found no differences in test performance between college athletes with a history of one or no concussion (*n*=310) and those with a history of two or more concussions (*n*=17) (Brown, Guskiewicz, & Bleiberg, 2007). When a computerized neuropsychological test battery was administered to 560 collegiate male athletes who reported no history of concussion in the previous six months, 196 athletes with a history of one concussion, 42 with a history of two concussions, and 60 with a history of three or more concussion, no significant association was found between concussion history and performance on verbal memory, visual motor speed, and reaction time measures (Bruce & Echemendia, 2009). However, an investigation involving college football players found long-term subtle neurocognitive deficits in those who had two or more concussions as compared to players who had no history of concussion (Collins et al., 1999). Other investigators found that college athletes with a history of two and three or more concussions performed significantly worse on verbal memory than athletes with no history of concussion (Covassin, Elbin, Kontos, & Larson, 2010).

In view of the unclear picture of the neuropsychological sequelae following two sports-related concussions, this research sought to examine further the effects of two concussions on the neurocognitive functioning and symptom reporting of high school athletes, utilizing the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) battery. ImPACT has been employed in several previous research of high school athletes following a concussion (Lovell, 2006).

Method

Test instrument

ImPACT is a computerized neuropsychological test instrument that evaluates verbal and visual memory, processing speed, reaction time, and impulse control, as well as post-concussion symptoms (Lovell, 2006). Research in the past decade has found that ImPACT is a reliable, valid, and practical approach to the neuropsychological assessment of mTBI in high school and collegiate athletes (Lovell et al., 2003; Maerlender et al., 2013; Schatz & Ferris, 2013)

Version 4.5 of ImPACT was administered and yielded four composite scores that were used for this research: Verbal Memory, Visual Memory, Processing Speed, and Reaction Time. ImPACT also included the Post-Concussion Symptom Scale consisting of 22 commonly reported symptoms (e.g., headache, dizziness), with a Total Symptom Score.

Participants

The data were derived from a retrospective archival search that involved 656 high school athletes who were administered the ImPACT during pre-season baseline testing. To maximize the number of concussed participants, 17 athletes who were tested after a concussion during the season, with results obtained after seven days post injury, were also included in the study. These in-season concussed athletes were tested, on average, 20.7 days (*SD*=16.8) after the head injury.

Application of the study inclusion and exclusion criteria resulted in 190 student athletes excluded from the study and 483 student athletes included in the study. The study included athletes who completed a valid ImPACT testing and who were not excluded based on the following exclusion criteria: (1) those who scored over 30 on the Impulse Control Composite score and thus, were deemed invalid (Lovell, 20012): (2) those whose primary language was not English; (3) those with a history of learning disability or special education; (4) those with three or more prior concussions; and (4) those who were tested fewer than seven days after a concussion. Seventy-two athletes were excluded because their ImPACT results contained a score over 30 on the Impulse Control Composite score and thus, were deemed invalid. Thirty seven athletes were excluded from the study because they indicated that English was not their primary language; 78

athletes were excluded because they had a history of learning disability or special education; 16 athletes were excluded because they took their ImPACT tests fewer than seven days post concussion. Two athletes were excluded because they reported three prior concussions, and one athlete was excluded because he reported four prior concussions. Of the 190 excluded athletes, 16 were excluded due to more than one exclusion criteria.

The study included 483 student athletes who met the inclusion and exclusion criteria. Participants reported on the ImPACT the number of prior concussions, if any, they sustained, and were classified into three groups based on the number of previous concussions: no previous concussion (n=409), one previous concussion (n=58), and two previous concussions (n=16). With 74 athletes with a history of concussion(s) out of 483 athletes, the study sample had an overall concussion rate of 15.3%.

The sports represented were football (n=218), soccer (n=97), wrestling (n=53), basketball (n=46), baseball (n=23), judo (n=23), cheerleading (n=10), volleyball (n=5), track (n=4), softball (n=1), field hockey (n=1), boxing (n=1), and paddling (n=1).

The database did not provide information as to the date of the previous concussions (except for the 17 with recent in-season concussions), nor the severity of the concussions.

Results

Data pertaining to the age, education, years of experience playing the sport, and gender appear in Table 1. The three concussion groups differed significantly in terms of age (p=0.004), education (p=0.006), and years of sport experience (p=0.001). As expected, athletes with a history of two concussions were, on average, older and with more years of education and sport experience than athletes with a history of no or one concussion.

The means and standard deviations of the four ImPACT composite scores and the Total Symptom Score are presented in Table 2, along with *p*-values based on one-way analyses of variance (ANOVA) comparing the three groups. The data showed that athletes with a history of no, one, or two concussions did not differ in terms of their four ImPACT composite scores (Verbal Memory, Visual Memory, Reaction Time, and Processing Speed) and the Total Symptom Score.

In view of the fact that the three groups differed in terms of age, and related to it, years of education and experience, we further conducted a multivariate analysis of covariance (MANCOVA) to compare the three groups in terms of their ImPACT scores while adjusting for age. These analyses confirmed the prior findings and showed no significant differences between the three concussion groups in terms of their ImPACT composite scores and Total Symptom Score when adjusted for age (*Wilks' Lambda*=0.984, *df*=10, *p*=0.639).

Discussion

This study examined the neuropsychological test performance and symptom reporting as measured by ImPACT of high school athletes who have a history of no, one, or two concussions. The results of this study indicated that the neuropsychological test performance and symptom reporting of high school athletes who have a history of no, one or two prior sports-related concussion were not statistically different. This finding held when the analyses were conducted to adjust for the athletes' ages.

The findings of this study were consistent with a previous large-scale study of high school and college athletes with one or two previous concussions who did not differ on neuropsychological test results and symptoms from athletes with no history of a prior concussion (Iverson et al., 2006). Moser et al. (2005) stated that high school athletes with two or more concussions exhibited significant neuropsychological deficits compared to athletes with no or one previous concussion, but their findings appeared equivocal in that they also found that athletes with one or two or more concussion did not differ from those with no concussion history on the total score of the RBANS computerized neuropsychological battery. The above research results tentatively suggest that a history of two self-reported concussions has little or no effect on the neurocognitive functioning of high school athletes.

Unlike the present investigation, the study by Schatz et al. (2011) found significantly more symptoms reported by high school athletes with two or more concussions compared to their peers with a history of one or no concussion. The inclusion of those with more than two concussions in the prior investigation probably underlies the disparity between the two studies.

The absence of group differences between athletes with and without concussion does not mean that the impact of two concussions is negligible. In their review of repeated concussions in sport, Henry and de Beaumont (2011) concluded that outcomes form multiple head injury could range from no consequences to subtle cognitive changes to mood symptoms and chronic traumatic encephalopathy. The results of repeated head trauma may be more difficult to identify in the brief career of youth athletes, but cumulative effects could be more likely with those who extend their participation in collegiate and professional sports.

The present data represent the results of 16 athletes who had two previous concussions. As such, our results are based on a limited sample of athletes who may not adequately represent the population of athletes who sustain two concussions. Moreover, a small n reduces the power of the statistics and lowers the probability of producing significant results.

While the use of self-report is prevalent in investigations of sports-related mTBI (e.g., Iverson et al., 2006; Moser et al., 2005; Bruce et al., 2009), the reliance on high school athletes accurately reporting that a concussion has occurred could pose a serious methodological flaw. Earlier reports indicate that high school and youth athletes are prone to under-report concussions because athletes often fail to recognize that a concussion has occurred (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). Young athletes also have concerns about a reported concussion preventing their return to participation in their sport (Williamson & Goodman, 2006). In a recent epidemiological report of over 3,000 high school athletes, the incidence rate of concussions based on athletic trainers' evaluations was 16.8% (Meehan et al., 2010). The cohort of athletes in this study reported a concussion rate of 15.3%, suggesting that underreporting of concussions may not have been a significant factor in the present research.

Other limitations in this retrospective research included: (1) the archival data of a convenience sample, yielding groups with significantly different ages, education, and years of sports experience; (2) the unverified severity or grade of the athlete's self-reported concussion(s); (3) the undetermined time of their previous concussion(s); (4) the unknown time interval between the head injury and the neuropsychological testing, and (5) the unknown time interval between concussions for those who sustained two concussions. These important factors limit the generalizability of the present findings and similarly designed investigations.

The present effort is one of the few that have focused on the neuropsychological sequelae of two concussions in high school athletes, and it is premature to be certain that a repeated concussion does not have lasting neuropsychological effects on high school athletes. Moreover, it should be kept in mind that youth athletes respond to mild concussion with more symptoms than adults and can suffer the persistent effects of a post-concussion syndrome (Moser, Fryer, & Berardinelli, 2011). Furthermore, a history of concussion in young athletes is a significant risk factor for future concussion, and is the basis for caution in releasing high school athletes to practice or play (Zemper, 2003). Given the current levels of sports participation by youths, and the fact that children and youths ages 5 to 18 have the highest rates of sports and recreation-related mTBI (Centers for Disease Control and Prevention, 2007), sports-related concussions become a matter that demands further research attention (Schatz & Moser, 2011).

References

Bakhos, L.L., Lockhart, G.R., Myers, R., & Linakis, J.G. (2010). Emergency department visits for concussion in young child athletes. *Pediatrics, 126,* e550-556. doi: peds.2009-3101 [pii] 10.542/peds. 2009-3101.

Belanger, H.G., & Vanderploeg, R.D. (2005). The neuropsychological impact of sports-related concussion: A metaanalysis. *Journal of the International Neuropsychological Society, 11,* 345-357.

Brown, C.N., Guskiewicz, K.M., & Bleiberg, J. (2007). Athlete characteristics and outcome scores for computerized neuropsychological assessment: A preliminary analysis. *Journal of Athletic Training, 42,* 515-523.

Bruce, J.M., & Echemendia, R.J. (2009). History of multiple self-reported concussions is not associated with reduced cognitive abilities. *Neurosurgery, 64,* 100-106.

Centers for Disease Control and Prevention. (2007). Non-fatal traumatic brain injuries from sports and recreation activities – United States, 2001-2005. *MMWR, 56,* 733-737.

Collins, M.W., Grindel, S.H., Lovell, M.R., Dede, D.E., Moser, D.J., Phalin, B.R…McKeag, D.B. (1999). Relationship between concussion and neuropsychological performance in college football players. *Journal of the American Medical Association*, 282, 964-970.

Collins, M.W., Lovell, M.R., Iverson, G.L., Cantu, R.C., Maroon, J.C., & Field, M. (2002). Cumulative effects of concussion in high school athletes. *Neurosurgery, 51,* 1175-1181.

Covassin, T., Elbin, R., Kontos, A., & Larson, E. (2010). *Journal of Neurology, Neurosurgery, and Psychiatry, 81*, 597-601.

Graham, R., Rivara, F.P., Ford, M.A., & Spicer, C.M. (Eds.) *Sports-related concussion in youth: Improving the science, changing the culture.* Washington, D.C.: The National Academies Press.

Henry, L.C., & de Beaumont, L. (2011). Effects of repeated concussive and subconcussive impacts in sport. In F.M. Webbe (Ed.) *The handbook of sport neuropsychology* (pp. 155-171). New York: Springer Publishing Company.

Iverson, G.L., Brooks, B.L., Lovell, M.R., & Collins, M.W. (2006). No cumulative effects for one or two previous concussions. *British Journal of Sports Medicine, 40,* 72-75.

Lovell, M.R. (2006). The ImPACT Neuropsychological Test Battery. In R.J. Echemendia (Ed.). *Sports Neuropsychology: Assessment and Management of Traumatic Brain Injury* (pp. 193-215). New York: Guilford Press.

Lovell, M.R. (2012, January). *Clinical Interpretation Manual.* Retrieved from ImPACT Website. http://www.impacttest.com/interpretation.php.

Lovell, M.R., Collins, M.W., Iverson, G.L., Field, M., Maroon, J.C., Cantu, R…Fu, F.H. (2003). Recovery from mild concussion in high school athletes. *Neurosurgery, 98,* 296-301.

Lovell, M.R., Collins, M.W., Iverson, G.L., Johnston, K.M., & Bradley, J.P. (2004). Grade 1 or "ding" concussions in high school athletes. *American Journal of Sports Medicine, 32,* 47-54.

Macciocchi, S.N., Barth, J.T., Littlefield, L., & Cantu, R.C. (2001). Multiple concussions and neuropsychological functioning in collegiate football players. *Journal of Athletic Training, 36,* 303-306.

Maerlender, A., Flashman, L., Kessler, A., Kumbhani, S., Greenwald, R., Tosteson T., et al. (2013). Discriminant construct validity of ImPACT™: A companion study. *The Clinical Neuropsychologist, 27,* 290-299.

McCrea, M., Hammeke, T., Olsen, G., Leo, P., & Guskiewiez, K. (2004). Unreported concussion in high school football players: Implications for prevention. *Clinical Journal of Sport Medicine, 14,* 13-17.

Meehan, W.P., III, d'Hemecourt, P., & Comstock, R.D. (2010). High school concussions in the 2008-2009 academic year. *The American Journal of Sports of Medicine, 38*, 2405-2409.

Moser, R.S., Fryer, A.C., & Berardinelli, (2011). Youth sport concussion: A heads up on the growing public health concern. In F.M. Webbe (Ed.). *The handbook of sport neuropsychology* (PP. 187-207). New York: Springer Publishing Company.

Moser, R.S., Schatz, P., & Jordan, B.D. (2005). Prolonged effects of concussion in high school athletes. *Neurosurgery, 57,* 300-306.

Pellman, E.J., Lovell, M.R., & Viano, D. (2004). Concussion in professional football: Neuropsychological testing – part 6. *Neurosurgery, 55*, 1303-1305.

Schatz, P., & Ferris, C.S. (2013). One-month test-retest reliability of the ImPACT Test Battery. *Archives of Clinical Neuropsychology, 28,* 499-504.

Schatz, P., & Moser, R.S. (2011). Current issues in pediatric sports concussion. *The Clinical Neuropsychologist, 25,* 1042-1057.

Schatz, P., Moser, R.S., Covassin, T., & Karpf, R. (2011). Early indicators of enduring symptoms in high school athletes with multiple previous concussions. *Neurosurgery, 68,* 1562-1567.

Williamson, I.J.S. & Goodman, D. (2006). Converging evidence for the under-reporting of concussion in youth ice-hockey. *British Journal of Sports Medicine, 40,* 128-132.

Zemper, E.D. (2003). Two-year prospective study of relative risk of a second cerebral concussion. *American Journal of Physical Medicine and Rehabilitation, 82*, 653-659.

Table 1

Characteristics of study participants (n=483)

	No concussion n=409	One concussion n=58	Two concussion n=16	p-value
Age	15.84±1.17	16.19±1.04	16.62±0.94	0.004
Years of sports experience	1.49±1.87	1.98±1.79	3.06±2.14	0.001
Years of education	9.47±1.22	9.83±1.09	10.25±0.93	0.006
Gender:				0.890
Male	290 (70.9%)	40 (69.0%)	12 (75.0%)	
Female	119 (29.1%)	18 (31.0%)	4 (25.0%)	

Note: p-values are based on one-way ANOVA analyses for age, years of sports experience, and years of education; and chi-square tests for gender.

Table 2

Comparison of ImPACT scores for the three groups (n=483)

	No concussion n=409	One concussion n=58	Two concussion n=16	p-value
Verbal Memory	0.83±0.10	0.84±0.09	0.84±0.13	0.916
Visual Memory	0.72±0.14	0.72±0.14	0.76±0.09	0.560
Reaction Time	0.59±0.08	0.59±0.09	0.60±0.10	0.930
Processing Speed	35.57±7.39	35.33±6.52	38.59±7.23	0.252
Symptom Score	7.67±10.53	9.48±10.48	11.50±12.81	0.195

Note: p-values are based on one-way ANOVA analyses.