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Current Issues in the Identification, Assessment, and Management of Concussions in Sports-Related Injuries

Catherine K. McKeever
Department of Psychology, Drexel University, Philadelphia, Pennsylvania, USA

Philip Schatz
Department of Psychology, Saint Joseph's University, Philadelphia, Pennsylvania, USA

The recent literature has focused on the need for appropriate identification, assessment, and management of sports-related concussion. This article addresses current issues in the prevalence and assessment of sports-related concussion. Despite a paucity of research on female athletes and youth athletes, there is evidence that female athletes are at higher risk for injury than males and that concussions may affect children and young adolescents differently than older adolescents and adults. Sideline, baseline, and postconcussion assessments have become prevalent in documenting preinjury and postinjury performance, tracking recovery rates, and assisting return-to-play decisions. New computerized assessment procedures are growing in popularity and use. Future directions in the assessment and management of sports-related concussion include increased research on prevalence rates and effects of concussions for females and youth athletes, educating parents of youth athletes as well as family physicians on the importance of baseline and postconcussion cognitive assessments, and further validation of computerized assessment measures.

Key words: concussion, sports-related injury, mild traumatic brain injury, neuropsychological assessment, athletes, computerized assessment, baseline assessment, sideline assessment

Assessment of sports-related concussion has received considerable attention within the field of neuropsychology over the past decade. Specific research and applications have focused on a mechanism and pathophysiology of injury, the grading of concussions and recovery rates, return-to-play guidelines, and the development and validation of neuropsychological assessment measures. Important issues, such as the scarcity of research on the incidence of concussions in youth and female athletes, and the recent trend toward standardized and computerized assessment measures are, however, not as well represented in the current literature. It is the intention of this article to focus on neuropsychology's contributing role in the identification, assessment, and management of these emergent issues.

Prevalence of Sports-Related Concussions

Sports-related injuries represent approximately 20% of the estimated 1.54 million head injuries that occur yearly in the United States. Nine percent of all sports injuries are thought to be concussions (Erlanger, Kutner, Barth, & Barnes, 1999), and between 2% and 10% of all athletes are at risk for sustaining a concussion (Ruchinskas, Francis, & Barth, 1997). It is estimated that 10% of all college and 20% of all high

Requests for reprints should be sent to Philip Schatz, Department of Psychology, Saint Joseph's University, Philadelphia, PA 19131, USA. E-mail: pschatz@sju.edu

school football injuries will be head injuries, which amounts to approximately 250,000 annually. Collins, Grindell, et al. (1999) found that 34% of 393 college football players had sustained at least one concussion and 20% reported a history of two or more concussions while on the team. During the 1997–1998 and 1998–1999 football seasons, 21% of football players were found to have had concussions, the majority of which were mild or Grade 1 according to the American Academy of Neurology (AAN) severity grading guidelines (Kelly & Rosenberg, 1997).

Although concussion in professional and college athletes is widely reported in the literature, concussion in high school athletes has only recently begun to receive similar attention. Powell and Barber-Foss (1999) estimated the number of concussions in high school varsity athletics to be 63,000. During a 3-year time span, 5.5% of all sports-related injuries reported among 235 high schools were concussions. Sports-related head injuries are most likely to occur among adolescents playing football (Baker & Patel, 2000). Powell and Barber-Foss (1999) found that 63.4% of sports-related injuries in high school football were concussions. Other activities in which youth athletes sustain sports-related concussions include wrestling, soccer, basketball, softball, baseball, field hockey, and volleyball.

Incidence of sports-related concussion appears to be increasing as a function of the number of the total sports activities, the number of previous sports years of the youth athlete, the recentness of the study, and the level of athletic participation (e.g., high school vs. college). Barth et al. (1989) reported that 10% of college football players in the Virginia football study sustained concussions each year, and 42% of their sample had sustained at least one previous concussion. Since then, incidence of previous concussion appears to have increased for collegiate athletes. Similarly, high school athletes appear to be sustaining concussions at a greater rate, as compared to collegiate athletes participating in the same sport. For example, concussion rates among college soccer players are estimated to be approximately 1 per 3,000 athletic exposures (AE; Green & Jordan, 1998). In contrast, concussion rates among high school soccer players have been reported to be higher at 1 per 2000 playing hours (Boden, Kirkendall, & Garrett, 1998). Between 7% and 11% of all sports-related injuries sustained by Canadian amateur hockey players aged 15 to 20 (over the 1998–1999 and 1999–2000 seasons) were concussions; 60% of these reported having sustained at least one concussion during either a game or practice (Goodman, Gaetz, & Meichenbaum, 2001). Moser and Schatz (2002) recently reported that 97% of athletes age 14 to 19 years, sampled from a boarding school with mandatory sports participation requirements and who had participated in numerous sports over a period of many years, had sustained at least one previous sports-related concussion.

Younger athletes appear to be at increased risk for concussions. Giza and Hovda (2001) discussed the potential vulnerability of youth athletes who sustain concussions during critical stages in brain development, especially during a time of increased plasticity. They hypothesize that concussions in the developing brain may ultimately impair this plasticity; however, it is not yet clear whether this impairment is permanent or temporal. It is possible that participants in the initial Virginia football study represented youth athletes from a different culture or with a different history of athletic participation. College athletes from the mid-1980s would have been participating in little league and club sports in the 1970s, whereas high school athletes in the late 1990s were participating in such sports activities in the late 1980s and early 1990s. Although there is no empirical data available on this specific variable, Moser and Schatz's (2002) sample was comprised of youth athletes with an average of 5 to 7 previous years of participation, as well as current participation in multiple sports. It is unlikely that athletes from the 1980s were being shuttled from soccer to lacrosse to baseball practice by era-equivalent "soccer moms." Thus, it appears that there may be a higher chance of sustaining concussive injuries when an athlete participates in more sports, has played for a higher number of years, and competes during high school years or earlier.

Additionally, the higher incidence of concussion rates in adolescents may simply be the result of younger, more susceptible brains. Although overall survival from severe head injury may be more likely in the pediatric population than in adults (Tepas, DiScala, Ramenofsky, & Barlow, 1990), traumatic brain injury in children and adolescents can lead to persistent cognitive dysfunction, even when no initial effects are observed (Giza & Hovda, 2001). Increased susceptibility to concussion in children and adolescents, as compared to adults, has been attributed to decreased myelination, a greater head-to-body ratio, and thinner cranial bones, all which provide less protection to the developing cortex.

The number of sports-related concussions appears to be increasing, and they are prevalent in all levels of sports participation. With the pervasive nature of sports-related concussion comes the need for appropriate identification by professionals, such as neuropsychologists, who are trained to investigate such injuries in a systematic and useful manner. Neuropsychologists have a knowledge base, which can contribute to an understanding of the susceptibility of sports-related concussion and different rates of recovery among disparate age groups. Integrating knowledge of the plasticity and repairing mechanisms of the brain, along with a comprehensive understanding of cognitive functions, neuropsychologists can provide unique insight to identifying and managing sports-related injuries in children, adolescents, young adults, and older adults.

Gender Differences

The National Athletic Trainers' Association study was the first major research effort delineating at-risk concussion differences between male and female athletes (Powell & Barber-Foss, 1999). In this study, female athletes were consistently found to be at higher risk for sustaining concussions than male athletes participating in the same high school sport: 1.14 concussions (per 100 player-seasons) in girls soccer versus .92 in boys soccer, 1.04 in girls basketball versus .75 in boys basketball, and .46 in girls softball versus .23 in boys baseball. These gender disparities represent approximate female-to-male concussion ratios of 5:4 for soccer, 4:3 for basketball, and 2:1 for softball and baseball. Similarly, Dick (1999) presented data from the National Collegiate Athletic Association (NCAA) Injury Surveillance System in which female athletes were at nearly twice the risk for concussion than male athletes playing soccer (.578 vs. .348 injuries per 1,000 AE) and lacrosse (.618 vs. .334 per 1,000 AE).

These trends do not appear to carry over to all sports or to athletes of all age ranges. Concussion rates in college soccer players (0.31 per 1,000 AE for male athletes and 0.33 per 1,000 AE for female athletes; Green & Jordan, 1998) and basketball players (36.8% of males, 31.3% of females; Echemendia, 1997) were found to be nearly identical for both genders. Barnes et al. (1998), however, observed that 78% of head injuries incurred by female athletes in Olympic soccer matches were the result of a collision with another player, as compared to 65% of head injuries for male athletes. Differences in brain chemistry and other as yet under-investigated neuroanatomical differences may account for this disparity; nevertheless, it is not yet clear why female athletes are at higher risk for sustaining concussions than male athletes.

Contrary to these findings, Boden et al. (1998) postulate that participants in boys soccer tend to represent a higher incidence of head injuries than girls soccer, perhaps due to boys' greater willingness to engage in risk-taking behaviors. This trend toward increased risk-taking may explain why 89% of male versus 43% of female Olympic soccer players reported a prior history of concussion (Barnes et al. 1998).

Even if female athletes are sustaining concussions at the same rate as male athletes, there is a lack of data, research, and focus on female concussions. Although many research efforts focus on NCAA Division I football, a uniquely male sport, the overwhelming majority of studies representing sports such as soccer, rugby, basketball, and lacrosse are based primarily on male participants. An ideal manner by which to address this need can be met by neuropsychological research, which offers the unique opportunity to investigate the potentially different neuroanatomical and neurochemical elements that contribute to the distinct rates of sports-related concussions sustained by female athletes versus male athletes. Neuropsychological investigation into the possible disparities between female performance and male performance on neurocognitive tests can be used not only to detect impairment following concussion but also provide insight into the potentially higher risk for concussion in females (see also Covassin, Swanik, & Sachs, this issue).

Assessment of Concussion

More than a decade after the publication of the Virginia football study (Alves, Rimel, & Nelson, 1987; Barth, et al. 1989), researchers continue to refine assessment protocols and add to the current literature in the areas of neuropsychology, sports medicine, and athletic training. Recent publications focus on guidelines for immediate postconcussion sideline assessments (McCrea, 2001), implementation of testing programs (Randolph, 2001), the sensitivity and specificity of standardized measures (Barr & McCrea, 2001), and statistical methods for documenting postconcussion changes (Daniel et al. 1999; Hinton-Bayre, Geffen, Geffen, McFarland, & Friis, 1999). The literature is replete with comprehensive reviews of historical aspects of and emergent trends in the assessment of sports-related concussion (Bleiberg, Halpern, Reeves, & Daniel, 1998; Echemendia & Julian, 2001; Grindel, Lovell & Collins, 2001; Lovell & Collins, 1998; Ruchinskas et al., 1997). Current research trends reflect the importance of sideline assessments, the inclusion of baseline assessments in concussion management and assessment, and the introduction and utility of computerized assessment batteries.

Sideline assessment of concussion. The Standardized Assessment of Concussion (SAC) was developed in accordance with guidelines set forth by the AAN and in response to the recommendation for the development of a standardized tool with which concussion could be immediately evaluated on the sidelines (McCrea, Kelly, Kluge, Ackley, & Randolph, 1997). The SAC is comprised of four components: orientation, immediate memory, concentration, and delayed recall. Benefits include ease and brevity of administration and scoring and alternate forms for follow-up assessment and tracking recovery. Validation studies reveal the SAC to be accurate in classifying concussed athletes from nonconcussed controls with 95% sensitivity and 76% specificity (Barr & McCrea, 2001; McCrea, 2001).

More recently, Erlanger, Feldman, and Kutner (1999) developed the eSAC, which is essentially an electronic version of the SAC that can be used to administer sideline assessments using a Palm handheld or equivalent personal digital assistant. As with the original version of the SAC, alternate test forms are available to monitor postconcussion progress and recovery. The eSAC also stores information about athletes that may be useful to athletic trainers on the sideline, such as a roster of all athletes, their emergency contact numbers, and pertinent medical information.

Concussed athletes have displayed deficits in immediate memory and delayed recall, as well as significantly decreased performance on postconcussion test trials in comparison to individual baseline test performance on the SAC (McCrea et al., 1998). As such, McCrea (2001) recommended that the SAC not be used as a stand-alone tool and that optimal evaluation of sports-related concussion occurs with information from the SAC, additional comprehensive neuropsychological test measures, physical examinations, and the player's self-report of postconcussive symptoms. Further, Collins, Lovell, and McKeag (1999) stated that sideline assessments provide only gross indications of the injured athlete's cognitive abilities and deficits, and return-to-play decisions should not be determined based solely on these results.

Nevertheless, the usefulness of a sideline assessment tool, such as the SAC or the eSAC, to immediately and accurately detect mental status changes related to sports-related concussion will assist in the diagnosis and management of this complex injury. Further neuropsychological research into the identification of concussion utilizing such measures will lead to better delineation of the acute effects of sports-related concussive injuries.

Baseline and serial postconcussion assessment. Assessments used to document preconcussion and postconcussion performance tend to be more detailed and include more complex tasks than either sideline assessments or other screening measures that may take only 5 to 10 min to complete. Baseline assessments provide a vital experimental control for individual differences among players. Those individuals who, relative to other athletes, perform poorly on baseline measures cannot be classified as injured due to poor subsequent performances on the tests. Knowledge of an athlete's premorbid level of functioning is important (Bernhardt, 2000), especially when attempting to determine whether an impairment seen on postconcussion cognitive testing is due to the effects of a recent concussion compared to an individual's relative weakness in that cognitive domain.

Researchers have employed brief batteries of specific tests (Barth et al., 1989) as well as more comprehensive neuropsychological test batteries (Echemendia & Julian, 2001; Lovell & Collins, 1998) to assess sports-related concussive injuries. In contrast to brief test batteries or sideline assessments, more comprehensive neuropsychological test batteries are typically reserved for cases in which there is a question of permanent cognitive impairment, a history of multiple concussions, or when repetitive baseline tests may have confounded results due to practice effects (Randolph, 2001). Formal neuropsychological assessment tools have been shown to be both reliable and valid in the detection of concussion, and they have been used to provide specific scientific data to determine the presence of a concussion, document an injured athlete's fitness to return to play, track recovery curves, and protect against catastrophic injuries related to either multiple concussions or second-impact syndrome (Barth, Freeman, Broshek, & Varney, 2001).

Completion of baseline neuropsychological testing has been universally recommended for the purposes of comparison with postconcussion assessment data. The aforementioned Virginia football studies (Alves et al., 1987; Barth et al., 1989) were the first published studies to incorporate formal neuropsychological assessment measures in detecting residual effects of concussion in collegiate football players. In this study, serial assessment, for which the injured athlete was matched with an uninjured athlete to control for practice effects, occurred at 2 hr, 48 hr, 1 week, and 1 month postinjury to track recovery and to determine the concussed athlete's fitness to return to play. Serial assessments can demonstrate gradual improvement or deterioration in mental status over time, allow for better differentiation of cognitive deficits, and assist in treatment and management of concussions. This original pattern of serial assessment allowed for the determination of the time when an athlete's concussion symptoms were resolved, which was found to occur between 5 and 10 days postinjury. Since that time, various test measures and schedules for postconcussion serial assessments have been employed, each contributing differently to the understanding of the postconcussion recovery trajectory for various sports or preinjury conditions. Selected studies demonstrating various schedules of serial postconcussion assessment and test batteries are presented in Table 1. As can be seen from Table 1, there is little agreement regarding the schedule of serial testing to evaluate symptom resolution of concussed athletes, nor is there conformity on the neuropsychological procedures used to document the cognitive changes. Although the diversity of test measures and assessment schedules has provided an increased understanding of postconcussion recovery patterns, these between-study differences preclude collaborative data sharing or cross-comparisons at specific time intervals.

Preconcussion and postconcussion testing by neuropsychologists provides a comprehensive approach to identifying a concussion and documenting the effects on cognition. Most importantly, testing provides the opportunity to use objective data of symptom resolution in making return-to-play decisions (see also Echemendia & Cantu, this issue). Without the use of baseline and subsequent serial testing, there is no assurance that a concussed athlete is neuropsychologically fit to return to athletic participation where reaction time and decision-making capabilities are critical not only for skilled participation but also for protection against further injury.

Computerized assessment. Evaluations of entire athletic teams or programs have been identified as being both time- and labor-intensive, thus burdening financial resources and creating potential reluctance on the part of the school or facility (Maroon et al., 2000). Brief screening batteries, comprised of carefully selected measures may, in part, help lessen these burdens (Lovell & Collins, 1998). However, any repetitive or serial assessment will expose athletes to test measures over multiple sessions, thereby creating unwanted and often confounding practice effects. Such practice effects can introduce error into assessment data, obscure the effects of concussion, and, ultimately, compromise the reliability of the assessment (Hinton-Bayre et al., 1999). Additionally, practice effects have been shown to vary from test to test and across serial assessment intervals (Heaton et al., 2001), further complicating and compromising the reliability and interpretation of postconcussion test data.

Cerebral concussions have been shown to cause subtle deficits in speed and quality of information processing (Moser & Schatz, 2002). Tests that measure attention, concentration, reaction time, psychomotor coding, and working memory are most commonly utilized in baseline and postconcussion evaluations (Barth et al., 1989; Collins, Lovell, et al., 1999; Echemendia & Julian, 2001; Lovell & Collins, 1998). Concussed individuals have been shown to differ significantly from otherwise healthy controls on tests of reaction time by margins of 110 ms or less (Bleiberg et al., 1998), and such measurement accuracy cannot be achieved with the traditional means of examiners using stopwatches.

A fully computerized battery may be the best approach to assessing sports-related concussions for several reasons (Randolph, 2001). First, the comprehensive battery can offer an objective approach to administration and scoring of test protocols. Second, time and cost constraints and the availability of personnel can be practically accommodated. Third, if a player moves from one team to another, as is often the case in professional sports, baseline data and any subsequent testing trials can easily be transferred from one database to another. Research efforts have focused on computerizing specific tests for the purpose of test validation (Hatfield, Laforce, Lapland, & Barite, 2001) or for use in assessment of sports-related concussion (Schatz & MacNamara, 2001). To date, however, only three computerized test batteries have been developed: the Immediate Measurement of Performance and Cognitive Testing (Lovell, Collins, Podell, Powell, & Maroon, 2000), the Concussion Resolution Index (Erlanger, Feldman, et al., 1999), and CogSport (CogState, 1999). Each of these batteries has been used effectively in the assessment of sports-related concussion (see also Schatz & Zillmer, this issue).

In sum, neuropsychologists can utilize computerized batteries in a time- and cost-efficient manner to effectively identify the presence of even the mildest of concussive injuries. Further, the results of such assessments can provide a sensitive vehicle by which to track recovery curves that can lead to comprehensive and realistic recommendations regarding an athlete's return to play.

Future Directions

As awareness of sports-related concussions is increasing, this issue has the potential to become a public health concern. There have been a number of studies examining the effects of concussion on both college and professional athletes, yet few studies incorporate

Table 1. *Comparison of Postconcussion Assessment Schedules*

	Schedule of Serial Postconcussion Assessments							
	Hours		Days					
Study	**1–2**	**24–48**	**3**	**5**	**7**	**10**	**30**	**Measures Used**
NCAA–Multiple sports (Echemendia et al., 2001)	2	24			7		30	PC, HVLT[a], SDMT, Stroop Test, Trails[b], VIGIL/W[c], Digit Span, PSU, COWAT
NCAA–Football (Collins et al., 1999)	1		3	5	7			HVLT[a], Trails[b], Digit Span, SDMT, COWAT, Pegboard[d]
NCAA–Football (Barth et al., 1989)		24		5		10		SDMT, Trails[b], PASAT
Prof. Hockey Players (Echemendia, 2001)		24		5[e]	7[e]			PC, HVLT[a], SDMT, Trails[f], PSU, COWAT, BVMT–R
Prof. Football Players (Lovell & Collins, 1998)		24		5				HVLT[a], SDMT, Trails[b], Digit Span, COWAT, Pegboard[d]
Prof. Rugby Players (McCrory et al., 1997)	1			5				SDMT, Choice RT[g], Memory[h], Orientation[h]
Prof. Rugby Players (Hinton-Bayre et al., 1999)			3[i]		7[i]		35[i]	SDMT, Digit Symbol[j], Speed of Comprehension[h]

Note: PC = Postconcussion Checklist; SDMT = Symbol Digit Modalities Test; PSU = Penn State University Cancellation Task; COWAT = Controlled Oral Word Association Test; PASAT = Paced Auditory Serial Addition Test; BVMT–R = Brief Visuospatial Motor Test–Revised.

[a]Postconcussion Checklist. [b]Trail Making Test A & B. [c]Continuous Performance Task. [d]Grooved Pegboard Test. [e]Athletes tested 5 to 7 days postconcussion. [f]Color Trail Making Test. [g]Symbol Digit Modalities Test (with incidental memory testing). [h]Unspecified. [i]Athletes tested 1 to 3 days, 1 to 2 weeks, 3 to 5 weeks postconcussion. [j]Digit Symbol subtest of the Wechsler Adult Intelligence Scale–Revised.

high school athletes, and even fewer address female athletes. More research is needed to investigate the high prevalence of concussion and its potentially detrimental effects in youth athletes, a population engaging in more and more athletic activities at increasingly younger ages. Investigations examining the neuroanatomical differences and mechanisms of injury in child and adolescent athletes could also provide important information to physicians, athletic trainers, neuropsychologists, and parents. Such research may yield needed age-appropriate protective equipment, concussion-grading scales, return to play guidelines, and rules changes, such as those that have been introduced in the National Football League in the recent past.

Although neuropsychologists and athletic trainers appear to have an understanding of the potentially dangerous impact of concussions, there needs to be more widespread understanding of and support for these issues. Family physicians and pediatricians may or may not already be aware of the potential physical, emotional, and cognitive sequelae of concussion in athletes. These physicians can serve to educate parents about the risks involved in athletic activity and the need to seek professional services when sports-related injuries occur, especially when youth athletes are participating in athletic programs not mediated by sports-concussion management programs. Practicing neuropsychologists should recognize that parents and coaches are potentially the best resource for knowledge of the premorbid functions of the child athlete and in recognizing postinjury changes. To this end, parents are best suited to observe subsequent changes in their child off the field and thus seek professional help. Similarly, the education of coaches on the effects of concussion, and the importance of cognitive assessment after injury is essential. Together, physicians, parents, and coaches can help fulfill some of the roles now standard in many collegiate concussion management programs.

Assessment of neuropsychological sequelae following sports-related concussion and the recognition and management of symptoms are key to understanding the short- and long-term effects of concussion. Formal concussion management programs should be in place for every professional, semi-professional, college, high school, club team, little league, and youth sports program. Such programs are needed to identify physical and cognitive symptoms, to appropriately determine the need for more comprehensive neuropsychological assessment, to assist in determining fitness for returning to play, and to protect athletes against further concussion and second impact syndrome. Specifically, baseline, sideline, and serial assessment following concussion can allow athletic programs to determine the severity of injury and safely return an athlete to play by formally tracking recovery rates.

Despite the considerable research on the cognitive effects of concussion, there is no common postconcussion assessment protocol currently in use. A core battery of tests that is both reliable and valid in identifying concussion, grading concussions more carefully, and tracking recovery rates more precisely is needed in the research investigating the appropriate assessment of concussion. Further, such research should collect data at common postconcussion time frames to allow for cross-sample comparisons and collaborative data sharing. Recently developed computerized assessment tools appear to provide significant gains, with respect to both cost and time efficiency, while providing useful and unique response-time data and test-retest reliability not available using traditional measures. The initial validation research regarding the psychometrics of these computerized measures is promising, and continued validation should result in widespread adoption of computerized concussion management programs at all levels.

In conclusion, we make the following recommendations. Increase research on sports-related concussion in youth athletes at the pee-wee, little league, club sport, grade school, junior high, and high school level. Increase research on sports-related concussion in female athletes competing at all age levels and in all sports categories. Establish universal protocols utilizing common baseline, sideline, and serial postconcussion measures and assessment schedules. Implement comprehensive concussion management programs involving players, coaches, trainers, athletic directors, and team physicians. And involve parents and pediatricians in concussion education programs promoting mandatory baseline assessments for all youth athletes who are at risk.

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