



NAN position paper

## Neuropsychological evaluation in the diagnosis and management of sports-related concussion<sup>☆</sup>

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### Abstract

A mild traumatic brain injury in sports is typically referred to as a concussion. This is a common injury in amateur and professional athletics, particularly in contact sports. This injury can be very distressing for the athlete, his or her family, coaches, and school personnel. Fortunately, most athletes recover quickly and fully from this injury. However, some athletes have a slow

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<sup>☆</sup> The working group of authors for this paper was comprised of neuropsychologists who are expert in this field, some of whom have researched and/or developed particular tests for use in sports concussion testing. The National Academy of Neuropsychology (NAN) and the authors of this position paper advocate the use of neuropsychological evaluation in the management of sports concussion. This paper, however, is not meant to advocate or recommend any particular neuropsychological test or vendor of neuropsychological testing. This paper has been peer-reviewed and edited by members of the NAN Policy and Planning Committee. The Policy and Planning Committee of the National Academy of Neuropsychology (NAN) is charged with writing position papers regarding important issues that impact the profession of Neuropsychology. Possible topics for the Position Papers are suggested by the NAN Board of Directors, members of the NAN Policy and Planning Committee, or individual Academy members. Primary authors are identified and approved by the NAN Policy and Planning Committee. These authors typically are experts on the topic and can come from within or outside the Policy and Planning Committee. Primary authors, Policy and Planning Committee members, and selected outside reviewers provide extensive peer review for all papers. All topics and the final paper submissions are reviewed and approved by the NAN Board of Directors.

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recovery, and there are reasons to be particularly concerned about re-injury during the acute recovery period. Moreover, some athletes who have experienced multiple concussions are at risk for long-term adverse effects. Neuropsychologists are uniquely qualified to assess the neurocognitive and psychological effects of concussion. The National Academy of Neuropsychology recommends neuropsychological evaluation for the diagnosis, treatment, and management of sports-related concussion at all levels of play.

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## 1. Concussions are common injuries in athletics

The Centers for Disease Control and Prevention (CDCP) reported that at least 300,000 athletes per year suffer concussions within the context of sports in the United States alone (CDCP, 1997; Sosin, Sniezek, & Thurman, 1996). This incidence rate is conservative and likely seriously under-estimates the true incidence because: (a) the CDCP based its statistics only on those athletes who lost consciousness, and (b) players and coaches tend to lack awareness or minimize symptoms of concussion. Typically, concussions do not cause a loss of consciousness (LOC). In fact, approximately 90% of concussions in sports occur without LOC (Guskiewicz, Weaver, Padua, & Garrett, 2000; Macciocchi, Barth, Alves, Rimel, & Jane, 1996; McCrea et al., 2003).

Because most concussions lack the dramatic on-field nature of those with LOC, they are typically more difficult to detect and can be under-diagnosed (Collins et al., 1999). Delaney, Lacroix, Leclerc, and Johnston (2002) found that 70% and 63% of football and soccer players, respectively, reported symptoms consistent with concussion, although only 23% and 20% realized they had, in fact, sustained a concussion. This partially explains why some injuries appear to go unrecognized or unreported by the athlete. However, in reporting the outcome of a confidential survey of more than 1500 high school football players regarding their concussion history, McCrea, Hammeke, Olsen, Leo, and Guskiewicz (2004) noted that more than 40% believed that they were concussed but deliberately did not reveal this information for fear of losing playing time.

Football is one of the most frequently studied sports with respect to concussion risk. Powell and Barber-Foss (1999) reported that concussions comprised 5.5% of the injuries in high school football players. That finding was consistent with collegiate data collected over a 3-year period by Covassin, Swanik, and Sachs (2003) in which 6.2% of total injuries were concussions. Concussion rates in high school and college football have ranged from approximately 3–4% (McCrea, Kelly, Randolph, Cisler, & Berger, 2002; Powell & Barber-Foss, 1999) to 7–9% (Covassin et al., 2003; Macciocchi et al., 1996). In a systematic review of published literature, Koh, Cassidy, and Watkinson (2003) identified ice hockey as having the highest incidence of concussion compared to football, soccer, and taekwondo/boxing for high school, college, and amateur adult males. However, out of all high school sports, Powell and Barber-Foss (1999) identified football as having the highest inherent risk among males, and soccer as having the highest inherent risk among females.

The NCAA utilizes an injury surveillance system to track injuries sustained in practice versus games across sports. Injury rates are combined for body parts, such as ankle ligament sprains, knee internal derangements, upper leg muscle-tendon strains, and shoulder injuries. When considering all injuries sustained in competition, concussions account for approximately 4–10% (with the exception of women's ice hockey). For men, concussions account for the following percentages of injuries sustained in games: (a) ice hockey = 9.0% (Agel, Dompier, Dick, & Marshall, 2007), (b) football = 6.8% (Dick, Ferrara, et al., 2007), (c) soccer = 5.8% (Agel, Evans, Dick, Putukian, & Marshall, 2007), (d) lacrosse = 8.6% (Dick, Romani, Agel, Case, & Marshall, 2007), and (e) basketball = 3.6% (Dick, Hertel, Agel, Grossman, & Marshall, 2007). For women, concussions account for the following percentages of injuries sustained in games: (a) ice hockey = 21.6% (Agel, Dick, Nelson, Marshall, & Dompier, 2007), (b) lacrosse = 9.8% (Dick, Lincoln, et al., 2007), (c) soccer = 8.6% (Dick, Putukian, Agel, Evans, & Marshall, 2007), (d) field hockey = 9.4% (Dick, Hootman, et al., 2007), and (e) basketball = 6.5% (Agel, Olson, et al., 2007). The high incidence of concussion in women's ice hockey is of great concern; additional research is needed to better understand how this injury rate can be reduced.

## 2. Concussions result in physical, psychological, and cognitive symptoms

A concussive injury to the brain follows a blow to the skull or an action that generates abrupt acceleration and deceleration of the brain within the skull. The acceleration/deceleration forces may lead to linear and/or rotational movement of the brain whereby brain tissue moves against itself inside the skull, increasing the risk for neurocognitive and neurobehavioral deficits (Barth, Freeman, Broshek, & Varney, 2001). Under the vast majority of circumstances, concussions in sports do not result in macroscopic damage to the brain visible with static neuroimaging techniques, such as CT or MRI. However, structural damage can occur, especially in sports such as equestrian and auto racing.

The vast majority of concussions in athletes fall at the mild end of the mild traumatic brain injury severity continuum. Loss of consciousness typically is not present, and post-traumatic amnesia is typically brief. This injury is likely associated with low levels of axonal stretch resulting in temporary changes in neurophysiology. Giza and Hovda (2004) described the complex interwoven cellular and vascular changes that occur following concussion as a multilayered neurometabolic cascade. The primary mechanisms include ionic shifts, abnormal energy metabolism, diminished cerebral blood flow, and impaired neurotransmission. Fortunately, for the vast majority of affected cells, there appears to be a reversible series of neurometabolic events.

The most common symptoms of sports-related concussion include headache, dizziness, confusion, nausea, memory difficulties, “mental fogging,” fatigue, balance problems, attention and concentration difficulties, sleep disturbances, and “nervousness” (Erlanger, Kaushik, et al., 2003; Iverson, Gaetz, Lovell, & Collins, 2004a; McCrory & Johnston, 2002). Many athletes with concussions have neurocognitive decrements detectable using traditional paper–pencil or computerized neuropsychological tests in the initial hours, days, and potentially weeks post-injury (Barr & McCrea, 2001; Collins et al., 1999; Delaney, Lacroix, Gagne, & Antoniou, 2001; Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Erlanger, Feldman, et al., 2003; Erlanger et al., 2001; Guskiewicz, Ross, & Marshall, 2001; Macciocchi et al., 1996; Makdissi et al., 2001; Matser, Kessels, Lezak, & Troost, 2001; McCrea, Kelly, Randolph, Cisler, & Berger, 2002; Warden et al., 2001). In group studies (considering aggregated data), athletes tend to recover in terms of perceived symptoms and neuropsychological test performance within 2–14 days (Bleiberg et al., 2004; Lovell, Collins, Iverson, Johnston, & Bradley, 2004; Macciocchi et al., 1996; McCrea et al., 2003; McCrea et al., 2002; Pellman, Lovell, Viano, Casson, & Tucker, 2004). It is important to note, however, that a minority of athletes who remain symptomatic at more than one or two weeks post-injury can be obscured in group analyses (Iverson, Brooks, Collins, & Lovell, 2006; Iverson, Brooks, Lovell, & Collins, 2006). The majority of athletes appear to recover fully within one-month post-injury (Collins, Lovell, Iverson, Ide, & Maroon, 2006), but some athletes can have lingering problems.

## 3. Baseline and post-injury neuropsychological testing is preferred

Neuropsychological testing provides unique information that can be invaluable not only in diagnosing the injury but also in tracking recovery over time. The basic baseline and post-concussion assessment paradigm that has been developed for the neuropsychological assessment of athletes was pioneered by Barth et al. (1989) at the University of Virginia. This model of concussion assessment has now been extended to large groups of athletes throughout professional (Lovell, 2006), collegiate (Collins et al., 1999; Echemendia et al., 2001; McCrea et al., 2003), and high school athletics (Lovell et al., 2004; Moser, Schatz, & Jordan, 2005).

The model of neuropsychological assessment utilized in sports is distinctly different from more traditional models of neuropsychological evaluation that utilize extensive, time-consuming test batteries. Sports concussion assessment and management models are designed to promote the screening of large numbers of athletes in order to establish an individual standard for each athlete. The baseline evaluation is not meant to represent a comprehensive assessment but is targeted to assess cognitive domains that are most often affected by concussion, such as memory, attention, speed of mental processing, and reaction time. Baseline neuropsychological testing is usually conducted prior to the sports season. If an athlete is concussed, serial evaluations are conducted post-injury to determine the point at which neurocognitive deficits and clinical symptoms are no longer present. It is considered standard practice that an athlete's neurocognitive performance must return to baseline or better before returning to play, in order to avoid the possibility of more serious, cumulative injury during the vulnerable recovery period. Although there is variability across sports concussion management programs regarding the administration of neuropsychological tests, the *interpretation* of neuropsychological test data should be conducted by a clinical neuropsychologist who is uniquely qualified to translate the test data into recommendations for clinical management.

#### 4. Most athletes recover from a concussion within one month

There is accumulating and converging evidence that isolated concussions in sports are often self-limiting injuries that are not associated with long-term cognitive or neurobehavioral problems (Belanger & Vanderploeg, 2005; Bleiberg et al., 2004; Carroll, Cassidy, Holm, Kraus, & Coronado, 2004; Iverson, 2005; Lovell et al., 2003; Lovell et al., 2004; Macciocchi et al., 1996; McCrea et al., 2003; McCrea et al., 2002; Pellman, Lovell, et al., 2004). The pathophysiology of concussion appears to be predominately neurometabolic and reversible, although under certain circumstances a small number of cells might degenerate and die (Buki & Povlishock, 2006; Giza & Hovda, 2004; Iverson, 2005; Iverson, Lange, Gaetz, & Zasler, 2007). It is reasonable, however, to assume that the vast majority of neurometabolic pathophysiology will undergo dynamic restoration in the hours and days following the injury. This dynamic restoration proposed in animal models Giza & Hovda (2004) seems to fit the recovery curves that have been reported repeatedly in studies with athletes (Bleiberg et al., 2004; Echemendia et al., 2001; Lovell et al., 2003, 2004; Macciocchi et al., 1996; McCrea et al., 2002, 2003; Pellman, Lovell, et al., 2004).

There is some research that suggests that professional football players recover more quickly than younger athletes (Pellman, Lovell, Viano, & Casson, 2006; Pellman, Lovell, et al., 2004; Pellman, Viano, Casson, Arfken, & Powell, 2004). In a large-scale prospective study, the vast majority of college football players recovered within seven days (McCrea et al., 2003, 2005). There is evidence suggesting that high school football players take longer to recover than university and professional athletes (Collins et al., 2006; Field, Collins, Lovell, & Maroon, 2003; Pellman et al., 2006). The majority of high school football players appear to recover within one month post-injury (Collins et al., 2006). Although the recovery rate for most athletes is reasonably well understood, much additional research is needed to identify reliable predictors of rapid versus slow recovery and to better appreciate the effects of multiple injuries.

#### 5. Concussions should be managed conservatively and individually

Consensus guidelines for general management and return to play have been available for several years (Aubry et al., 2002; McCrory et al., 2005). First, the athlete should be asymptomatic at rest. Then, the athlete is progressed through increasing non-contact physical exertion, until he or she has demonstrated asymptomatic status with non-contact physical exertion and non-contact sport-specific training.

When neuropsychological testing is available, the athlete should demonstrate full recovery of neurocognitive function prior to returning to play. Neurocognitive recovery is inferred when the athlete's performance either returns to baseline levels or, in the absence of a baseline, is consistent with pre-injury estimates of functioning when the test data are compared to normative values (clinicians should utilize test batteries that have athlete-specific norms). Although the preferred interpretation of post-injury test scores involves a comparison to baseline test scores, it is important to underscore that neuropsychological testing may be quite useful in the absence of baseline test data, particularly in the case of protracted or unusually severe symptoms.

The timing of the final neuropsychological evaluation has not been determined through consensus nor through empirical research. It is considered prudent, however, to withhold the athlete from contact practice until he or she has recovered neurocognitively. Importantly, some clinicians, especially those working with youth, cautiously prefer to withhold the athlete from any exercise until she or he has recovered from a neurocognitive perspective.

It is recommended that standardized symptom scales, such as the Post-Concussion Scale (Lovell et al., 2006), be used serially throughout recovery. The Post-Concussion Scale has normative data and information regarding interpreting change. If the athlete's report of asymptomatic status is suspected to be false, a careful discussion of the importance of reporting all symptoms should be undertaken. If there are others who are present during the athlete's evaluation (e.g., parents, athletic trainers, or teammates), asking these collateral informants about the athlete's previous or current symptom complaints can be helpful.

#### 6. Children may need to be managed differently

Some researchers have reported slower and differential recovery patterns for high school athletes as compared to college-aged and professional athletes (Collins et al., 2006; Field et al., 2003; Lang, Teasdale, Macpherson, & Lawrence, 1994). Although the mechanisms are poorly understood, there is reason to be concerned that more severe forms of concussion could have lasting effects on complex neurochemical and anatomical events that are occurring

in the developing brain (Giza & Hovda, 2001, 2004). Unfortunately, there is limited research on concussion in young athletes, with very little research extending to pre-high school years. Treatment of concussion and knowledge of return-to-play guidelines for young athletes appears to be limited. The recognition of possible critical differences between children and adults in injury outcome and in differential recovery patterns has prompted an international consensus conference to call for increasing research on concussion in children (McCrory, Collie, Anderson, & Davis, 2004).

In one retrospective study, 70% of concussed youth visiting the emergency room received inappropriate discharge instructions (Genuardi & King, 1995). Bazarian, Veenema, Brayer, and Lee (2001) reported that medical practitioners correctly identified specific return to play criteria in only 8–56% of hypothetical cases. In spite of the vulnerability of this population, individuals caring for concussed youth athletes are not uniformly familiar with guidelines for identification, treatment, and management of concussions. Moreover, youth athletic contests represent the venue *least* likely to have qualified medical professionals or paraprofessionals in attendance.

## 7. Concussions carry some risk for cumulative effects

Once concussed, an athlete is at a statistically increased risk for a future concussion. The reasons for the increased risk are unclear. Guskiewicz et al. (2003) reported that previously concussed athletes are four to six times more likely to experience a second concussion, even if the second blow is relatively mild. High school football players with a prior history of loss of consciousness, as reported by their coaches, had a four times greater risk of loss of consciousness than players without a prior history (Gerberich, Priest, Boen, Straub, & Maxwell, 1983). In a more recent two-year prospective study of high school and collegiate football players, Zemper (2003) reported a six times greater relative risk for individuals with a history of concussion than for individuals with no history. Results of research on professional football players reveal mixed results, although Canadian Football League players with a history of concussion were found to have increased risk of future concussion (Delaney, Lacroix, Leclerc, & Johnston, 2000).

Athletes, their families, coaches, athletic trainers, and sports medicine professionals are concerned about possible lingering effects, or permanent brain damage, resulting from multiple concussions. The literature regarding the persistent effects of two previous concussions is mixed. With regards to possible long-term effects, some researchers have reported statistically significant adverse effects (Collins et al., 1999; Moser & Schatz, 2002; Moser et al., 2005), and others have not (Gaetz, Goodman, & Weinberg, 2000). In a large-scale study, athletes with one or two previous concussions did not differ on neuropsychological testing or symptom reporting from athletes with no previous concussion on baseline, preseason testing (Iverson, Brooks, Collins, et al., 2006; Iverson, Brooks, Lovell, et al., 2006). Research on the effects of prior concussion on recovery time from an athlete's next concussion also has revealed mixed results. Guskiewicz et al. reported that some athletes with two previous concussions have slower recovery times (Guskiewicz et al., 2003). In contrast, Iverson (2007) reported that concussion history was unrelated to recovery time in high school athletes.

There is accumulating evidence that a history of *three or more* concussions is associated with changes in neurophysiology (Gaetz et al., 2000), subjective symptoms (Gaetz et al., 2000; Iverson, Gaetz, Lovell, & Collins, 2004a), and neuropsychological test performance (Iverson et al., 2004a) in some athletes. Furthermore, some athletes with three or more concussions are likely at increased risk of sustaining a future concussion (Guskiewicz et al., 2003), experiencing worse on-field presentations of their next concussion (Collins et al., 2002), having a greater likelihood of slowed recovery (Guskiewicz et al., 2003), and experiencing more severe, acute changes in memory performance on neuropsychological testing (Iverson et al., 2004a). More research is needed to examine recovery rate in relation to concussion history.

An extraordinarily rare and tragic outcome of concussion can be catastrophic brain swelling leading to severe disability or death. This has been described as second impact syndrome (Cantu, 1998), and over the past 20 years a number of cases have been reported. In theory, sustaining a second brain injury during a period of increased vulnerability, while the athlete is recovering from the first injury, has been linked to second impact syndrome. The pathophysiology of second impact syndrome is thought to be cerebrovascular congestion or a loss of cerebrovascular autoregulation leading to considerable brain swelling (Cantu, 1998; Kelly & Rosenberg, 1997). Most cases of second impact syndrome have been reported in children (e.g., Bruce et al., 1981) or adolescents (Kelly et al., 1991; McQuillen, McQuillen, & Morrow, 1988).

## 8. Conclusions

Neuropsychologists have made substantial professional and scientific contributions toward understanding the nature, course, and treatment of sports-related concussion. Neuropsychologists are uniquely qualified to apply this empirically gained knowledge to assess the neurocognitive and psychological effects of concussion. The objective evaluation of neurocognitive functioning and self-reported symptoms can be accomplished in a time- and cost-effective manner. Neuropsychologists interpreting neuropsychological test data assist athletes by identifying and tracking post-concussion symptoms and sequelae, lending valuable information for managing return to play decisions, and focusing on the best interests of the athlete. Neuropsychologists possess the background knowledge and training to understand brain-behavior relationships and are specialists in the identification and treatment of cognitive impairment. Neuropsychologists are trained to choose, administer, and interpret neuropsychological tests and to consider such test results in the context of the individual's history and presentation, especially if there has been a prior diagnosis of a learning, attentional, or developmental disorder, past or present psychiatric condition, or other brain trauma or disease process in the athlete (Echemendia, 2006). For these reasons, it is our position that neuropsychological evaluation is recommended for use in the diagnosis, treatment, and management of sports-related concussion at all levels of play.

## References

- Agel, J., Dick, R., Nelson, B., Marshall, S. W., & Dompier, T. P. (2007). Descriptive epidemiology of collegiate women's ice hockey injuries: National collegiate athletic association injury surveillance system, 2000–2001 through 2003–2004. *Journal of Athletic Training, 42*(2), 249–254.
- Agel, J., Dompier, T. P., Dick, R., & Marshall, S. W. (2007). Descriptive epidemiology of collegiate men's ice hockey injuries: National collegiate athletic association injury surveillance system, 1988–1989 through 2003–2004. *Journal of Athletic Training, 42*(2), 241–248.
- Agel, J., Evans, T. A., Dick, R., Putukian, M., & Marshall, S. W. (2007). Descriptive epidemiology of collegiate men's soccer injuries: National collegiate athletic association injury surveillance system, 1988–1989 through 2002–2003. *Journal of Athletic Training, 42*(2), 270–277.
- Agel, J., Olson, D. E., Dick, R., Arendt, E. A., Marshall, S. W., & Sikka, R. S. (2007). Descriptive epidemiology of collegiate women's basketball injuries: National collegiate athletic association injury surveillance system, 1988–1989 through 2003–2004. *Journal of Athletic Training, 42*(2), 202–210.
- Aubry, M., Cantu, R., Dvorak, J., Graf-Baumann, T., Johnston, K., Kelly, J., et al. (2002). Summary and agreement statement of the First International Conference on Concussion in Sport Vienna 2001. Recommendations for the improvement of safety and health of athletes who may suffer concussive injuries. *British Journal of Sports Medicine, 36*(1), 6–10.
- Barr, W. B., & McCrea, M. (2001). Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion. *Journal of the International Neuropsychological Society, 7*, 693–702.
- Barth, J. T., Alves, W., Ryan, T., Macciocchi, S., Rimel, R. W., Jane, J. J., et al. (1989). Mild head injury in sports: Neuropsychological sequelae and recovery of function. In H. Levin, J. Eisenberg, & A. Benton (Eds.), *Mild head injury* (pp. 257–275). New York: Oxford University Press.
- Barth, J. T., Freeman, J. R., Broshek, D. K., & Varney, R. N. (2001). Acceleration-deceleration sport-related concussion: The gravity of it all. *Journal of Athletic Training, 36*(3), 253–256.
- Bazarian, J. J., Veenema, T., Brayer, A. F., & Lee, E. (2001). Knowledge of concussion guidelines among practitioners caring for children. *Clinical Pediatrics (Philadelphia), 40*(4), 207–212.
- Belanger, H. G., & Vanderploeg, R. D. (2005). The neuropsychological impact of sports-related concussion: A meta-analysis. *Journal of the International Neuropsychological Society, 11*(4), 345–357.
- Bleiberg, J., Cernich, A. N., Cameron, K., Sun, W., Peck, K., Ecklund, P. J., et al. (2004). Duration of cognitive impairment after sports concussion. *Neurosurgery, 54*(5), 1073–1078. Discussion 1078–1080.
- Bruce, D. A., Alavi, A., Bilaniuk, L., Dolinskas, C., Obrist, W., & Uzzell, B. (1981). Diffuse cerebral swelling following head injuries in children: The syndrome of "malignant brain edema". *Journal of Neurosurgery, 54*(2), 170–178.
- Buki, A., & Povlishock, J. T. (2006). All roads lead to disconnection?—Traumatic axonal injury revisited. *Acta Neurochirurgica (Wien), 148*(2), 181–193. Discussion 193–184.
- Cantu, R. C. (1998). Second-impact syndrome. *Clinical Sports Medicine, 17*(1), 37–44.
- Carroll, L. J., Cassidy, J. D., Holm, L., Kraus, J., & Coronado, V. G. (2004). Methodological issues and research recommendations for mild traumatic brain injury: The WHO Collaborating Centre Task Force on mild traumatic brain injury. *Journal of Rehabilitation Medicine, 43*(Suppl.), 113–125.
- CDCP. (1997). Sports-related recurrent brain injuries – United States. *Morbidity & Mortality Weekly Report, 46*, 224–227.
- Collins, M. W., Grindel, S. H., Lovell, M. R., Dede, D. E., Moser, D. J., Phalin, B. R., et al. (1999). Relationship between concussion and neuropsychological performance in college football players. *Journal of the American Medical Association, 282*(10), 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*(5), 1175–1179. Discussion 1180–1181.
- Collins, M. W., Lovell, M. R., Iverson, G. L., Ide, T., & Maroon, J. (2006). Examining concussion rates and return to play in high school football players wearing newer helmet technology: A three year prospective Cohort study. *Neurosurgery, 58*(2), 275–286.
- Covassin, T., Swanik, C. B., & Sachs, M. L. (2003). Epidemiological considerations of concussions among intercollegiate athletes. *Applied Neuropsychology, 10*(1), 12–22.

- Delaney, J. S., Lacroix, V. J., Gagne, C., & Antoniou, J. (2001). Concussions among university football and soccer players: A pilot study. *Clinical Journal of Sport Medicine*, 11(4), 234–240.
- Delaney, J. S., Lacroix, V. J., Leclerc, S., & Johnston, K. M. (2000). Concussions during the 1997 Canadian football league season. *Clinical Journal of Sport Medicine*, 10(1), 9–14.
- Delaney, J. S., Lacroix, V. J., Leclerc, S., & Johnston, K. M. (2002). Concussions among university football and soccer players. *Clinical Journal of Sport Medicine*, 12(6), 331–338.
- Dick, R., Ferrara, M. S., Agel, J., Courson, R., Marshall, S. W., Hanley, M. J., et al. (2007). Descriptive epidemiology of collegiate men's football injuries: National collegiate athletic association injury surveillance system, 1988–1989 through 2003–2004. *Journal of Athletic Training*, 42(2), 221–233.
- Dick, R., Hertel, J., Agel, J., Grossman, J., & Marshall, S. W. (2007). Descriptive epidemiology of collegiate men's basketball injuries: National collegiate athletic association injury surveillance system, 1988–1989 through 2003–2004. *Journal of Athletic Training*, 42(2), 194–201.
- Dick, R., Hootman, J. M., Agel, J., Vela, L., Marshall, S. W., & Messina, R. (2007). Descriptive epidemiology of collegiate women's field hockey injuries: National Collegiate athletic association injury surveillance system, 1988–1989 through 2002–2003. *Journal of Athletic Training*, 42(2), 211–220.
- Dick, R., Lincoln, A. E., Agel, J., Carter, E. A., Marshall, S. W., & Hinton, R. Y. (2007). Descriptive epidemiology of collegiate women's lacrosse injuries: National collegiate athletic association injury surveillance system, 1988–1989 through 2003–2004. *Journal of Athletic Training*, 42(2), 262–269.
- Dick, R., Putukian, M., Agel, J., Evans, T. A., & Marshall, S. W. (2007). Descriptive epidemiology of collegiate women's soccer injuries: National collegiate athletic association injury surveillance system, 1988–1989 through 2002–2003. *Journal of Athletic Training*, 42(2), 278–285.
- Dick, R., Romani, W. A., Agel, J., Case, J. G., & Marshall, S. W. (2007). Descriptive epidemiology of collegiate men's lacrosse injuries: National collegiate athletic association injury surveillance system, 1988–1989 through 2003–2004. *Journal of Athletic Training*, 42(2), 255–261.
- Echemendia, R. J. (2006). *Sports neuropsychology: Assessment and management of traumatic brain injury*. New York: Guilford Press.
- Echemendia, R. J., Putukian, M., Mackin, R. S., Julian, L., & Shoss, N. (2001). Neuropsychological test performance prior to and following sports-related mild traumatic brain injury. *Clinical Journal of Sport Medicine*, 11(1), 23–31.
- Erlanger, D., Feldman, D., Kutner, K., Kaushik, T., Kroger, H., Festa, J., et al. (2003). Development and validation of a web-based neuropsychological test protocol for sports-related return-to-play decision-making. *Archives of Clinical Neuropsychology*, 18(3), 293–316.
- Erlanger, D., Kaushik, T., Cantu, R., Barth, J. T., Broshek, D. K., Freeman, J. R., et al. (2003). Symptom-based assessment of the severity of a concussion. *Journal of Neurosurgery*, 98(3), 477–484.
- Erlanger, D., Saliba, E., Barth, J., Almquist, J., Webright, W., & Freeman, J. (2001). Monitoring resolution of post-concussion symptoms in athletes: Preliminary results of a web-based neuropsychological test protocol. *Journal of Athletic Training*, 36(3), 280–287.
- Field, M., Collins, M. W., Lovell, M. R., & Maroon, J. (2003). Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *Journal of Pediatrics*, 142(5), 546–553.
- Gaetz, M., Goodman, D., & Weinberg, H. (2000). Electrophysiological evidence for the cumulative effects of concussion. *Brain Injury*, 14(12), 1077–1088.
- Genuardi, F. J., & King, W. D. (1995). Inappropriate discharge instructions for youth athletes hospitalized for concussion. *Pediatrics*, 95(2), 216–218.
- Gerberich, S. G., Priest, J. D., Boen, J. R., Straub, C. P., & Maxwell, R. E. (1983). Concussion incidences and severity in secondary school varsity football players. *American Journal of Public Health*, 73(12), 1370–1375.
- Giza, C. C., & Hovda, D. A. (2001). The neurometabolic cascade of concussion. *Journal of Athletic Training*, 36(3), 228–235.
- Giza, C. C., & Hovda, D. A. (2004). The pathophysiology of traumatic brain injury. In M. R. Lovell, R. J. Echemendia, J. T. Barth, & M. W. Collins (Eds.), *Traumatic brain injury in sports* (pp. 45–70). Lisse: Swets & Zeitlinger.
- Guskiewicz, K. M., McCrea, M., Marshall, S. W., Cantu, R. C., Randolph, C., Barr, W., et al. (2003). Cumulative effects associated with recurrent concussion in collegiate football players: The NCAA concussion study. *Journal of the American Medical Association*, 290(19), 2549–2555.
- Guskiewicz, K. M., Ross, S. E., & Marshall, S. W. (2001). Postural stability and neuropsychological deficits after concussion in collegiate athletes. *Journal of Athletic Training*, 36(3), 263–273.
- Guskiewicz, K. M., Weaver, N. L., Padua, D. A., & Garrett, W. E., Jr. (2000). Epidemiology of concussion in collegiate and high school football players. *American Journal of Sports Medicine*, 28(5), 643–650.
- Iverson, G. L. (2005). Outcome from mild traumatic brain injury. *Current Opinion in Psychiatry*, 18, 301–317.
- Iverson, G. L. (2007). Predicting slow recovery from sport-related concussion: The new simple–complex distinction. *Clinical Journal of Sport Medicine*, 17, 31–37.
- Iverson, G. L., Brooks, B. L., Collins, M. W., & Lovell, M. R. (2006). Tracking neuropsychological recovery following concussion in sport. *Brain Injury*, 20(3), 245–252.
- 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(1), 72–75.
- Iverson, G. L., Gaetz, M., Lovell, M. R., & Collins, M. W. (2004a). Cumulative effects of concussion in amateur athletes. *Brain Injury*, 18(5), 433–443.
- Iverson, G. L., Gaetz, M., Lovell, M. R., & Collins, M. W. (2004b). Relation between subjective foginess and neuropsychological testing following concussion. *Journal of the International Neuropsychological Society*, 10, 904–906.
- Iverson, G. L., Lange, R. T., Gaetz, M., & Zasler, N. D. (2007). Mild TBI. In N. D. Zasler, H. T. Katz, & R. D. Zafonte (Eds.), *Brain injury medicine: Principles and practice* (pp. 333–371). New York: Demos Medical Publishing.
- Kelly, J. P., Nichols, J. S., Filley, C. M., Lillehei, K. O., Rubinstein, D., & Kleinschmidt-DeMasters, B. K. (1991). Concussion in sports, guidelines for the prevention of catastrophic outcome. *Journal of the American Medical Association*, 266(20), 2867–2869.
- Kelly, J. P., & Rosenberg, J. H. (1997). Diagnosis and management of concussion in sports. *Neurology*, 48(3), 575–580.

- Koh, J. O., Cassidy, J. D., & Watkinson, E. J. (2003). Incidence of concussion in contact sports: A systematic review of the evidence. *Brain Injury*, 17(10), 901–917.
- Lang, D. A., Teasdale, G. M., Macpherson, P., & Lawrence, A. (1994). Diffuse brain swelling after head injury: More often malignant in adults than children? *Journal of Neurosurgery*, 80(4), 675–680.
- Lovell, M. R. (2006). Neuropsychological assessment of the professional athlete. In R. J. Echemendia (Ed.), *Sports neuropsychology: Assessment and management of traumatic brain injury* (pp. 176–190). New York: Guilford Press.
- Lovell, M. R., Collins, M. W., Iverson, G. L., Field, M., Maroon, J. C., Cantu, R., et al. (2003). Recovery from mild concussion in high school athletes. *Journal of Neurosurgery*, 98(2), 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(1), 47–54.
- Lovell, M. R., Iverson, G. L., Collins, M. W., Podell, K., Johnston, K. M., Pardini, D., et al. (2006). Measurement of symptoms following sports-related concussion: Reliability and normative data for the post-concussion scale. *Applied Neuropsychology*, 13(3), 166–174.
- Macciocchi, S. N., Barth, J. T., Alves, W., Rimel, R. W., & Jane, J. A. (1996). Neuropsychological functioning and recovery after mild head injury in collegiate athletes. *Neurosurgery*, 39(3), 510–514.
- Makdissi, M., Collie, A., Maruff, P., Darby, D. G., Bush, A., McCrory, P., et al. (2001). Computerised cognitive assessment of concussed Australian rules footballers. *British Journal of Sports Medicine*, 35(5), 354–360.
- Matser, J. T., Kessels, A. G., Lezak, M. D., & Troost, J. (2001). A dose–response relation of headers and concussions with cognitive impairment in professional soccer players. *Journal of Clinical and Experimental Neuropsychology*, 23(6), 770–774.
- McCrea, M., Barr, W. B., Guskiewicz, K., Randolph, C., Marshall, S. W., Cantu, R., et al. (2005). Standard regression-based methods for measuring recovery after sport-related concussion. *Journal of the International Neuropsychological Society*, 11(1), 58–69.
- McCrea, M., Guskiewicz, K. M., Marshall, S. W., Barr, W., Randolph, C., Cantu, R. C., et al. (2003). Acute effects and recovery time following concussion in collegiate football players: The NCAA concussion study. *Journal of the American Medical Association*, 290(19), 2556–2563.
- McCrea, M., Hammeke, T., Olsen, G., Leo, P., & Guskiewicz, K. (2004). Unreported concussion in high school football players: Implications for prevention. *Clinical Journal of Sport Medicine*, 14(1), 13–17.
- McCrea, M., Kelly, J. P., Randolph, C., Cisler, R., & Berger, L. (2002). Immediate neurocognitive effects of concussion. *Neurosurgery*, 50(5), 1032–1040.
- McCrory, P., Collie, A., Anderson, V., & Davis, G. (2004). Can we manage sport related concussion in children the same as in adults? *British Journal of Sports Medicine*, 38(5), 516–519.
- McCrory, P., Johnston, K., Meeuwisse, W., Aubry, M., Cantu, R., Dvorak, J., et al. (2005). Summary and agreement statement of the 2nd International Conference on Concussion in Sport Prague 2004. *British Journal of Sports Medicine*, 39(4), 196–204.
- McCrory, P. R., & Johnston, K. M. (2002). Acute clinical symptoms of concussion. *The Physician and Sportsmedicine*, 30., 43–47.
- McQuillen, J. B., McQuillen, E. N., & Morrow, P. (1988). Trauma, sport, and malignant cerebral edema. *American Journal of Forensic Medicine and Pathology*, 9(1), 12–15.
- Moser, R. S., & Schatz, P. (2002). Enduring effects of concussion in youth athletes. *Archives of Clinical Neuropsychology*, 17(1), 91–100.
- Moser, R. S., Schatz, P., & Jordan, B. D. (2005). Prolonged effects of concussion in high school athletes. *Neurosurgery*, 57(2), 300–306. Discussion 300–306.
- Pellman, E. J., Lovell, M. R., Viano, D. C., & Casson, I. R. (2006). Concussion in professional football: Recovery of NFL and high school athletes assessed by computerized neuropsychological testing—part 12. *Neurosurgery*, 58(2), 263–274. Discussion 263–274.
- Pellman, E. J., Lovell, M. R., Viano, D. C., Casson, I. R., & Tucker, A. M. (2004). Concussion in professional football: neuropsychological testing—part 6. *Neurosurgery*, 55(6), 1290–1305.
- Pellman, E. J., Viano, D. C., Casson, I. R., Arfken, C., & Powell, J. (2004). Concussion in professional football: Injuries involving 7 or more days out—part 5. *Neurosurgery*, 55(5), 1100–1119.
- Powell, J. W., & Barber-Foss, K. D. (1999). Traumatic brain injury in high school athletes. *Journal of the American Medical Association*, 282(10), 958–963.
- Sosin, D. M., Sniezek, J. E., & Thurman, D. J. (1996). Incidence of mild and moderate brain injury in the United States 1991. *Brain Injury*, 10(1), 47–54.
- Warden, D. L., Bleiberg, J., Cameron, K. L., Ecklund, J., Walter, J., Sparling, M. B., et al. (2001). Persistent prolongation of simple reaction time in sports concussion. *Neurology*, 57(3), 524–526.
- Zemper, E. D. (2003). Two-year prospective study of relative risk of a second cerebral concussion. *American Journal of Physical Medicine & Rehabilitation*, 82(9), 653–659.