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ORIGINAL ARTICLE

The Management of Sport-Related Concussion: Considerations for Male and Female Athletes

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Abstract Sport-related concussion continues to be a centerpiece of attention in the field of sports medicine. The benefit to using neurocognitive testing when managing concussion will be documented in this review. In addition to providing critical objective information on the neurocognitive status of the concussed athlete, research data will be provided on the pre- and post-concussion neurocognitive profiles of concussed male and female athletes. Specifically, an overview of research will be presented on the epidemiology of male and female concussion rates, as well as concussion outcomes including symptoms and cognitive function post-injury. Finally, a clinician's perspective on managing sports-related concussion will be presented focusing on three factors regarding sex differences: risk factors, clinical presentation, and management.

Keywords Concussions · Sex differences · Neurocognitive function · Clinical assessment

Sport-related concussion continues to be a centerpiece of attention in the field of sports medicine. In particular, the assessment and management of this injury has evolved from "outdated" grading scales to the currently recommended multifaceted approach that includes symptom, cognitive, and balance/vestibular assessment tools. Of the varying number of clinical assessments and tools endorsed for the management of concussion, neurocognitive testing has been reported to add increased objectivity [1] to the inherent subjective reports of concussion symptoms, which are often minimized and underreported [1]. Thus current consensus statements recommend neurocognitive testing as a cornerstone of the multifaceted approach to managing concussion [2].

Researchers and practitioners have highlighted the importance and value of baseline testing, as this approach provides a benchmark for comparing post-concussion neurocognitive performance to athletes' "normal" preinjury scores (e.g., prospective design methodology) [3]. One of the advantages of employing baseline testing is the increased ability to control certain demographic factors (e.g., age and sex) that may confound post-injury test interpretation when only relying on normative data. In addition, employing baseline testing allows the sports medicine professionals to take an individual's cognitive strength and weakness into account so that post-injury deficits can be differentiated from pre-morbid weakness that is already existent [4]. Finally, baseline testing is believed to aid the sports medicine staff in weighing concussion severity, in addition to guiding a more informed return-to-play decision process [5].

Barth et al. [6] were among the first researchers to document the neurocognitive effects of concussion in a sample of collegiate football players using prospective methodology. Serial assessments used by Barth and colleagues [6] included the Trail Making Test, Gronwall's Paced Auditory Serial Addition Test, and the Symbol Digit Test. These paper-and-pencil tests were administered at 2 h, 48 h, 1 week, and 1 month post-injury. Barth and colleagues [6] documented increased post-concussion symptom reports, relative to baseline levels, for concussed athletes. These increases were significantly higher than symptom reports of a group of non-injured controls and a group of athletes with orthopedic injuries not including concussion. These researchers [6] concluded that neurocognitive changes do occur as a result of sport-related concussion and that symptoms specific to head

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injuries (i.e., dizziness, nausea, memory impairment) are unique to concussive injuries and not to general trauma (i.e., orthopedic injury) or the noninjured athlete population.

The prospective approach implemented by Barth and colleagues [6] was an important first step in estimating a timeframe in which concussion symptoms resolved, which was documented to occur between 5 and 10 days post-injury [7]. This study was the first to document the importance of using a prospective approach to utilizing neurocognitive testing for the management of sport-related concussion. These results have been supported by recent research that concludes that without the use of prospective neurocognitive testing, sports medicine professionals may be unclear as to when exactly a concussed athlete is the most cognitively fit to return to competition safely.

Given the benefit of prospective, serial neurocognitive testing, computerized forms of these batteries have become increasingly popular due to their time-saving nature, accurate assessment protocol (i.e., reaction time recorded in milliseconds), and sensitive ability to identify residual neurocognitive impairment [8]. Among the numerous forms of computerized testing, the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is one of the most widely used and studied computerized neurocognitive tests currently in use [9–12].

Researchers have documented the sensitivity and specificity of neurocognitive testing for the use of predicting recovery time following a sport-related concussion. Lau et al. [13] used ImPACT, post-concussion symptom clusters (i.e.., cognitive, physical, emotional, sleep), and total symptom scores to assist in determining prognostic ability used to predict recovery length following a concussive injury. Results revealed that using computerized neurocognitive testing along with symptom clusters results in improved sensitivity, specificity, positive predictive value (73.2 %), and negative predictive value (73.8 %) of recovery. Moreover, increased sensitivity of 24.4 % was also shown when using neurocognitive testing and symptom clusters together in comparison to using the total symptom scores on the Post-Concussion Symptom Scale alone. Lau and colleagues concluded that results from this study lend support to using neurocognitive tests and symptom clusters in tandem to aid the sports medicine team in more accurately predicting whether a concussed athlete may require a protracted recovery or not.

A similar study by Meehan et al. [14] examined the importance of computerized neurocognitive testing when assessing concussed high school athletes and described associations between using computerized neurocognitive tests, timing of return-to-play, and medical provider managing the athlete. These researchers reported that approximately 40 % of high schools in the USA used a computerized neurocognitive test when managing sport-related concussions. In addition, athletic trainers and physicians, but not neuropsychologists, most often interpret the neurocognitive test results. Moreover, computerized neurocognitive tests were significantly associated with the return-to-play guidelines that are implemented with each concussed athlete individually.

The benefit to using neurocognitive testing when managing concussion is well documented. In addition to providing critical objective information on the neurocognitive status of the concussed athlete, these data have also provided an opportunity for researchers to examine differences in neurocognitive outcomes across various demographic subgroups of injured athletes. More specifically, examining the pre- and post-concussion neurocognitive profiles of concussed male and female athletes has recently been documented.

Sex Differences in the Incidence of Sport-Related Concussion

Title IX as part of the Equality in Education Act of 1972 triggered significant increase for women to participate in sports, and its rise in participation has steadily increased over the past few decades. The National Collegiate Athletic Association (NCAA) reported women's sport participation increased 80 % between 1988 and 2004, while men's sport participation increased by only 20 % [15]. During the 2010–2011 academic year, 191,131 and 3,173,549 female athletes participated in NCAA and high school sports [16, 17]. Considering these record-setting participation rates for high school and collegiate athletes [18, 19], it is expected that the annual incidence of sport-related concussion will continue to rise relative to these increases in sport participation [20].

Epidemiological studies have been conducted in order to understand sex differences between female and male athletes with respect to sport injury incidence and prevalence. General trends have shown that female athletes at both the collegiate and high school levels are at a greater risk for incurring a concussion compared to male athletes [15, 21–24]. In a recent study by Marar et al. [23] that compared injury trends among male and female high school sports (e.g., soccer, basketball, softball, swimming and diving, and track and field) revealed that girls had a higher incidence of concussions than boys. A similar trend was reported by Lincoln et al. that examined injury rates in a sample of 25 high schools over an 11-year period (1997–2008) [24]. Lincoln and colleagues [24] reported that girls had a higher ratio rate of concussion in soccer (6.0), basketball (2.8), and softball (1.8) compared to boys soccer (3.1), basketball (1.8), and baseball (1.0). These data suggest that there are differences for the risk of concussion between males and females at the high school level, with female athletes having a higher risk of incurring a concussion.

Sex differences in risk of concussion have also been explored in collegiate populations. In one of the first studies reported on the NCAA Injury Surveillance System (ISS) data, Covassin and colleagues [22] compare sex differences in the prevalence of concussions among collegiate athletes during the 1997–2000 academic years. Similar to high school concussion data, female collegiate athletes reported a higher prevalence of concussions compared to male collegiate athletes. Specifically, concussions represented a greater portion of total injuries for women's lacrosse (13.9 vs. 10.1 %), soccer (11.4 vs. 7.0 %), and basketball (8.5 vs. 5.0 %) compared to comparable male sports [22]. Recently, Hootman and colleagues [15] summarized 16 years (1988–2004) of NCAA ISS date in 15 NCAA sports. The researchers reported a greater prevalence of concussions in women's sports compared with their male counterpart: lacrosse (6.3 vs. 5.6 %), soccer (5.3 vs. 3.9 %), basketball (4.7 vs. 3.2 %), and softball/baseball (4.3 vs. 2.5 %). The data clearly suggest that female athletes have a higher risk of incurring a concussion compared to male athletes.

There are several possible reasons why female athletes may be at a greater risk for sustaining a concussion compared to male athletes. Female athletes tend to have weaker neck muscles and smaller neck girth which may also predispose them to an increased risk of concussion [25]. Tierney and colleagues [25] found that sex differences exist in head–neck segment dynamic stabilization during head angular acceleration (similar to concussive acceleration/deceleration forces). Females exhibited significantly greater head–neck segment peak acceleration and displacement than males. These authors concluded that females' heads are susceptible to higher speeds of acceleration and greater displacement following an externally applied force [25]. Finally, female soccer athletes have a larger ball-to-head size ratio than male athletes possibly predisposing them to concussions [26, 27].

Sex Differences in Concussion Symptoms and Neurocognitive Function

The male and female brain differs in structure and function. In relation to cognitive function, females have been found to perform better than males on verbal memory and perceptual motor speed [28–30], while males perform better in visual–spatial task, mental rotation, and quantitative problem solving compared to females [30–32]. These disparities in cognitive function may contribute to differences in concussion symptoms and neurocognitive performance following a concussion. These inherent differences in cognitive ability among males and females have prompted the empirical investigation of post-concussion outcomes in males and females.

One of the first studies to examine sex differences in concussion outcomes was published by Broskek and colleagues [33] in 2005. The authors administered 2,350 baseline Concussion Resolution Index tests (computerized neurocognitive test battery) to male and female athletes at both the high school and collegiate levels. One hundred and seventeen males and 38 female athletes incurred a concussion during the study period. Results revealed female concussed athletes reported more concussion symptoms compared to male athletes and more severe declines in simple and choice reaction time compared to their baseline measures. Moreover, female concussed athletes were 1.7 times more cognitively impaired than male concussed athletes.

In a similar study by Covassin and colleagues [16], another computerized neurocognitive test battery (ImPACT) was administered to 41 male and 39 female concussed athletes. Female concussed athletes were found to take longer to recover on visual memory compared to male concussed athletes. When considering the role of sex and recovery from a soccer-related concussion, Colvin and colleagues [34] found that female concussed soccer athletes (n=141) had slower reaction time and more total concussion symptoms compared to male concussed soccer athletes.

Finally, in a recent study published in 2012 by Covassin and colleagues [35], a larger cohort of concussed high school and collegiate athletes (209 males, 93 females) were administered the ImPACT, Balance Error Scoring System (BESS), and concussion symptoms scale. Again, females were found to be impaired on visual memory and self-reported more concussion symptoms compared to male athletes. In addition to cognitive impairments, male high school concussed athletes scored more balance errors on the BESS compared to male collegiate concussed athletes. The reverse findings were found in female athletes with female collegiate concussed athletes scoring more balance errors than female high school concussed athletes.

There are several possible reasons why females may report more symptoms and have cognitive impairments following a concussion. Specifically, sex differences have been attributed to neuroanatomical cerebral blood flow, sex hormonal estrogen, and sport environment/social differences between males and females [33]. Considering differences in neuroanatomy, females have a greater area of unmyelinated neuronal processes, while males have a greater number of cortical neuronal densities [36]. In regards to cerebrovascular differences, researchers have suggested that females have a higher cerebral blood flow rate, coupled with a higher basal rate of glucose metabolism which may exacerbate the neurometabolic cascade [37]. Finally, researchers have differing conclusions regarding the potential protective or detrimental effect of estrogen on concussion outcome [38]. Nonetheless, continued research in this area is warranted. Despite the growing body of research on sex differences in concussion among athletes, the clinical management of concussion has been slow to recognize differences among males and females when sex differences are taken into account.

Clinical Management of Female and Male Concussed Athletes

The clinical evaluation and management of sports-related concussion consists of three parts: a detailed clinical interview (that identifies the mechanism of injury, acute/subacute symptoms, current symptoms, and relevant history), neurocognitive assessment, and a vestibular/balance screening. Based on the clinical experience of one of the co-authors of this paper (S.B.) and a search of evidence-based research, sex differences have not been observed or documented on vestibular screening measures. Regarding symptom reporting, Frommer et al. [39] reported that males traditionally endorse more symptoms related to cognitive difficulties, while females tend to focus more on neurobehavioral and somatic symptoms. Females also reported greater symptom severity and intensity [39]. Despite empirical evidence for sex differences among athletes in self-reported symptoms, the clinical care and management of concussion focuses on treatment of the direct symptoms reported by the individual athlete during a clinical evaluation. While differences in symptom typology and severity exist, clinicians treating concussion should tailor treatment to the specific symptoms reported by the injured athlete, despite the empirically supported differences among sexes.

Clinicians using ImPACT for the evaluation, management, and treatment of sports-related concussion in the clinical setting should be performing assessment of neurocognitive function on the basis of sex-corrected normative data. While other measures exist in the assessment of neurocognitive performance in athletes following concussion, using an assessment measure that takes sex differences into account reduces the risk of misinterpreting neurocognitive data on the basis of sex bias norms within the clinical setting. Sex differences have been reported in athletes on the basis of neurocognitive test performance [33, 35] and symptom endorsement [39]; however, clinical observation suggests that greater differences may exist.

The empirical findings on sex differences in sport-related concussion warrant clinical considerations when assessing concussion among male and female athletes. Clinicians managing sports-related concussion should consider three factors regarding sex differences: risk factors, clinical presentation, and management. Male and female athletes differ significantly in terms of concussion-related risk factors [40]. For example, female athletes are at a higher risk for migraine headaches [40], which may relate to worse post-concussion outcomes. A previous research has shown that the prevalence for personal or family history of migraine headaches may be as high as five times more likely in female athletes as opposed to male athletes [40]. Given this information, clinicians should consider that headache presentation may be more prevalent in female athletes than in male athletes which in turn will impact management of symptoms. In addition, course of treatment for concussion in female athletes may eventually require behavioral interventions regarding regulation of diet, sleep, hydration, exercise, and reducing stress when headache symptoms present as lingering sequelae of concussion.

Clinical observations and experiences have shown that female athletes may present with higher rates of anxiety and may take longer to recover from concussion when compared to males, which may in turn impact presentation and management of sports-related concussion. However, further research is needed to determine the extent or likeliness that these differences exist. Conversely, male athletes often present with higher rates of previous concussions or suspected prior events and may be less likely to report concussive injuries [41]. It is not surprising that, based on clinical anecdote, male athletes may underreport symptoms as well as symptom severity possibly in an effort to return to the desired sport. Implications in turn exist for presentation and management, as male athletes may attempt to present as less symptomatic or even asymptomatic in order to expedite return-to-play. Therefore, clinicians must consider this information when making concussion management as well as return-to-play decisions. Given that this information is based on clinical observation and experience, further research is necessary to develop tools and rating measures beyond self-report scales and neurocognitive data as a means of identifying the presentation of concussion.

While a significant amount of empirical literature exists regarding sex differences on risk and outcome following sports-related concussion, further research is needed to determine the extent to which sex differences have on the clinical presentation, management, and recovery from concussion. Finally, future clinical research is needed to close the gap between clinical and nonclinical studies on the differences between male and female concussed athletes.

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