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## ABSTRACT

Every year in the United States, 1.6 to 3.8 million concussions occur secondary to injuries sustained during sports and recreational activities. Major advances have been made in terms of identifying specific clinical profiles following concussion. Nevertheless, there are continued misunderstandings regarding this injury and variable clinical management strategies being employed that may result in protracted recovery periods for youth athletes. Therefore, it is essential that individualized treatment plans target the particular clinical profile(s) present following concussion. Further progress related to management of this injury depends on medical professionals working as part of multidisciplinary teams to provide appropriate education, accurate information, and treatments based on the identified clinical profiles. It is also important for medical professionals of all disciplines to stay vigilant toward future research and practice guidelines given the evolving nature of this injury.

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It was a great honor to receive an invitation to speak at the annual meeting of the American Pediatric Surgical Association, on behalf of the Journal of Pediatric Surgery. In addressing the growing public concerns regarding concussion, progress is often best achieved through multidisciplinary collaborations such as those between neuropsychology and

pediatrics. Concussion is a challenging injury for medical professionals of all disciplines to treat in isolation and therefore it is important for professionals to work together in establishing effective and targeted multidisciplinary care for this injury. Over time, we have made major advances in identifying specific clinical profiles following concussion and treatment options for each profile through research and clinical practice [1,2]. Nevertheless, treatment for concussion across the country remains unsatisfactory and further improvement depends on a better understanding of the pathophysiology, injury heterogeneity, clinical profiles, and treatment options as well as the development of multidisciplinary treatment centers nationwide.

This paper is divided into four main parts, beginning with a discussion regarding the public misperceptions of concussion. We will then review concussion in terms of the pathophysiology, injury heterogeneity, and risk factors for prolonged recovery. From there, we will discuss the components of a comprehensive clinical assessment for concussion. Finally, we will discuss the clinical profiles, importance of education during the recovery process, and home management strategies.

### 1. Public misperceptions of concussion

In April 2015, UPMC commissioned a survey by Harris Poll that included 2012 adults, aged 18 or older, residing within the United States. Figures for age, sex, race/ethnicity, education, and household income were weighted to account for actual population estimates. Of the 2012 adults surveyed, 948 were identified as parents. For the general public, the following misperceptions of concussion were endorsed: 1) 24% thought a concussion would change their life forever, 2) 72% felt the “damage” to the brain is permanent, 3) 80% believed you could only lessen symptoms and will never fully recover, and 4) 81%

**Abbreviations:** ADHD, Attention Deficit/Hyperactivity Disorder; BPPV, Benign Paroxysmal Positional Vertigo; CT, Computed Tomography; DTI, Diffuse Tensor Imaging; NPC, Near Point of Convergence; PTM, Post-Traumatic Migraine; SRC, Sport-Related Concussion; UPMC, University of Pittsburgh Medical Center; VMS, Visual Motion Sensitivity; VOR, Vestibular Ocular Reflex; VSR, Vestibulo Spinal Reflex.

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were not comfortable in knowing the steps to manage and treat a concussion. In addition to the general public, parents endorsed the following misperceptions: 1) 86% could not identify the definition of concussion, 2) 59% believed safety equipment could prevent most concussions, 3) 50% were under the impression that there is no cure for concussion, 4) 25% do not let their kids play sports because of fear of concussion, and 5) 12% thought that athletes should be allowed to return to play immediately after concussion. These percentages reflect the poor knowledge regarding concussion within the general public, including parents.

When considering treatment of sport-related concussion (SRC), medical professionals must be cognizant of the education, assessment, care, and recommendations they provide within context of the general public's poor knowledge as well as growing public concerns regarding this injury. Concussion is the focus of multiple news articles, media reports, and legislation each day. Although widespread focus on a particular injury can be helpful in terms of allocation of resources and advancing clinical practice, this must be done in a careful manner in order to convey proper messages and avoid fear responses. Unfortunately, the current focus on concussion, coupled with the evolving nature of this injury and poor knowledge has resulted in fear responses such as early retirement from professional sports, decreased participation in youth sports, and concerns regarding essential components of specific sports. Certainly more research is needed into the potential long-term effects of concussion, but currently it is our job as medical professionals to change the conversation and culture regarding concussion to one involving accurate understanding and appropriate management.

## 2. Understanding concussion

Every year in the United States, 1.6 to 3.8 million concussions occur secondary to injuries sustained during sports and recreational activities [1]. Concussion is caused by direct or indirect injury to the head or other parts of the body, as long as the injury force is transmitted to the head. Concussion has been interpreted as a functional injury resulting in transient neurological dysfunction secondary to a complex cascade of ionic shifts, metabolic changes, and impaired neurotransmission resulting in an “energy crisis” within the brain [3]. The primary elements of the energy crisis following concussion include release of excitatory neurotransmitters, neuronal depolarization, ionic shifts, changes in glucose metabolism, altered cerebral blood flow, cytoskeletal damage, and impaired axonal function [3]. These alterations can be correlated with a period of post-concussion vulnerability during which further injury or stress should be avoided to prevent more serious damage [3]. Concussion is undetectable with traditional imaging methods (e.g., computed tomography [CT]); however, advanced imaging techniques (e.g., diffusion tensor imaging [DTI]), show progress in identifying and tracking microstructural damage [3].

The duration of physical, cognitive, emotional, and sleep-related symptoms following concussion is highly variable across individuals, lasting from several minutes to days, weeks, months, or even longer in some cases. Previous studies have suggested that 80–90% of athletes recover from SRC within 7–14 days [4]; however, a recent study utilizing a comprehensive clinical assessment approach in high school athletes found recovery to take 3–4 weeks for memory, 4 weeks for symptoms, and 3 weeks for vestibular–oculomotor symptoms [5]. The different recovery periods for various areas of functioning and impairment reinforce the value of completing a comprehensive clinical assessment because of the heterogeneous nature of this injury. Results from this and previous studies have also demonstrated the role of certain risk factors including female gender, history of learning disability, history of attention-deficit/hyperactivity disorder (ADHD), young age, on-field dizziness, post-traumatic migraine (PTM), personal or family history of motion sickness, and sub-acute foginess in prolonged recoveries [5–12]. In particular, on-field dizziness and PTM have been shown to

result in a 6.3 and 7.3  $\times$  greater risk for protracted recovery, respectively [8,12].

When discussing prolonged recovery, it is also important to consider underreporting. Unfortunately, the “play through pain” culture in sport does not apply for brain injuries. SRC is a serious condition that needs to be treated immediately to avoid prolonged recoveries and potentially long-term effects. It was previously estimated that 40–60% of SRCs go unreported by reason of players not understanding the severity of the injury, not wanting to be withheld from competition, and lacking awareness regarding concussion [13]. Although there has been increased awareness and education since those estimates were obtained, this largely has not translated into behavior change. Specifically, recent data showed high rates of underreporting in college football, with a 27:1 ratio for general players in terms of six suspected concussions and 21 “dings” for every diagnosed concussion as well as a 32:1 ratio for rate of diagnosed concussions to suspected concussions and dings in offensive linemen [14]. These studies highlight the need for medical professionals to address the lack of understanding regarding this treatable injury, in youth and college athletes as well as adults.

## 3. Comprehensive clinical assessment of sport-related concussion

Concussion is a highly individualized injury resulting in a constellation of physical, cognitive, emotional, and sleep-related symptoms. Athletes are prone to experiencing different symptoms based on pre-injury risk factors, post-injury risk factors, the specific injury mechanism, personal characteristics, and the management approach. In terms of management, a “one size fits all” approach to SRC can result in a prolonged recovery because of non-specific and ineffective treatment strategies [1]. Therefore, a comprehensive clinical assessment is necessary to fully evaluate patients following SRC. The assessment should include measurement of post-concussion symptoms, neurocognitive functioning, vestibular/ocular motor dysfunction, tolerance of physical exertion, balance functioning, and cervical spine integrity (if necessary). This can be completed through a detailed clinical interview, neuropsychological assessment, vestibular/oculomotor screening, exertion screening, balance assessment, and a cervical evaluation with a certified physical therapist [1,2]. Results from the evaluation will be helpful in determining the diagnosis, prognosis, clinical profile(s), treatment options, and return-to-play expectations.

### 3.1. Neuropsychological assessment

Neuropsychological assessment is one component of the recommended comprehensive clinical assessment following SRC that assists in diagnosis, tailoring treatment recommendations (e.g., level of cognitive activity, type of academic accommodations), injury management, and return-to-play decisions [1,2]. Computerized neurocognitive tests (CNTs) have emerged as the primary tool utilized to obtain neuropsychological data for youth athletes because of the standardized administration/scoring, precise measurement of processing speed/reaction time, time efficiency, avoidance of practice effects, and ability to utilize estimates of baseline functioning [2,15]. Specifically, a baseline test can be completed prior to the season to obtain a pre-injury cognitive profile that can aid clinicians in identifying post-injury neurocognitive deficits through comparison of pre- and post-injury data (15). While the immediate post-concussion and cognitive testing (ImpACT) is the most widely used and researched CNT, other CNTs include the automated neurocognitive assessment metrics (ANAM), axon sports computerized cognitive assessment tool, concussion vital signs (CVS), and HeadMinder Concussion Resolution Index (CRI) [2,15]. In select cases, neuropsychologists will utilize a “hybrid” assessment approach that incorporates CNTs and traditional paper-and-pencil tests, as it can afford more flexibility in terms of assessing specific cognitive domains, obtaining behavioral observations, and assessing auditory-based processing/performance (as compared to visual-based with use of CNTs)

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