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Prognostic Factors in Pediatric Sport-Related Concussion

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Abstract

Purpose of Review Sport-related concussion (SRC) and mild traumatic brain injury (mTBI) have been thrust into the national spotlight, with youth athletes bearing the burden of this public health problem. The current review aims to provide a practical summary of pediatric SRC, including key terminology, return to play/school, and risk factors for post-concussion syndrome (PCS).

Recent Findings While the majority of youth athletes recover within 2 to 4 weeks, approximately 10% of athletes experience a protracted recovery with symptoms lasting months, impacting social, scholastic, and sporting activities.

Summary In the pediatric population, the strongest predictors of PCS are initial symptom burden and prior concussion, with mixed results behind the factors of gender, headaches, and learning disability. The role of psychiatric, family history, sports, and socioeconomic factors remain in their infancy.

Keywords Sport-related concussion · Traumatic brain injury · Post-concussion syndrome · Modifying factors · Prognosis

Introduction

In recent decades, sport-related concussion (SRC) has proven to be a major public health concern in young athletes. While media attention tends to focus on elite athletes, the 1.6 to 3.8 million yearly SRCs is a problem of our youth [1, 2]. The Institute of Medicine has called for research addressing the incidence, diagnosis, management, and prevention of youth sports concussion, in addition to the short- and long-term consequences of concussions and repetitive "sub-concussive" head impacts [3].

Greater than 90% of concussed athletes will improve by 2–4 weeks [1, 4], while those with persistent symptoms greater than 4 weeks are diagnosed with post-concussion syndrome (PCS). PCS includes varying degrees of somatic, cognitive, sleep, and emotional symptoms [5]. Several premorbid and sport-specific risk factors have been outlined, including age [6], gender [7, 8], early/initial symptom burden [9, 16], and various acute and sub-acute symptoms [10, 11]. Herein, we aim to succinctly and practically summarize the care of the pediatric athlete with SRC, from injury, to return to play/school, and risk factors for PCS.

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Definitions

Sport-Related Concussion The most widely used definition of a SRC comes from the 2016 Concussion In Sport Group (CISG) held in Berlin, Germany [12••]. This was the 5th international conference of experts, and while the definition has been slightly modified over the years [13], the core features have remained the same. The expert panel defines a SRC as, "a traumatic brain injury induced by biomechanical forces" [12••], with four noteworthy features, paraphrased below:

1. Caused by a blow to the head or anywhere else on the body with a force transmitted directly or indirectly to the head.
2. Results in the rapid onset of short-lived neurologic impairment that resolves spontaneously; symptoms can evolve over minutes to hours in some cases.
3. Acute clinical signs and symptoms reflect a disturbance in function, rather than a structural injury, with negative standard brain imaging.
4. A range of clinical signs and symptoms, with or without loss of consciousness, is seen with resolution in a sequential course, yet symptoms may be prolonged in some cases.

Post-Concussion Syndrome PCS is an often-used term that describes a distinct population, yet the formal definition remains debated. PCS is defined in the *Diagnostic and Statistical Manual of Mental Disorders*, 4th edition (DSM-IV) [14] as three or more symptoms for greater than 3 months, while the *International Statistical Classification of Diseases and Related Health Problems, 10th Revision* (ICD-10) [15] defines PCS as three or more symptoms, without specifying a symptom duration length. Oddly enough, the PCS diagnosis has been omitted from the DSM-5 [14]. However, the most practical definition, used in both the research and clinical realms, is any symptom lasting more than 1 month after a SRC. Rose et al. [16] surveyed 597 sports medicine physicians and the most common time course to diagnose PCS clinically was 1–3 months (33%) with a minimum of at least one symptom (56%). Notably, though the time course of 1–3 months was most common, a true majority opinion did not exist [16]. Though we believe this is the simplest and most practical definition for PCS, the lack of consensus must be acknowledged.

Recovery In the majority of studies of SRC in pediatric patients, the end point is either return to play (RTP) or return to neurologic baseline, and less commonly, though arguably most important, return to learn (RTL). RTP can be defined as a return to team activities, such as practice, or to game play competition. At the pediatric and youth level, these are usually one in the same; however, healthcare professionals, parents, and coaches should have a keen eye to which endpoint is used. Return to neurologic baseline is a more complex entity, which can mean many things, listed below:

- *Asymptomatic*—symptoms resolve entirely.
- *Prior symptom level*—symptoms return to preinjury level of symptom endorsement prior to the SRC, usually derived from baseline symptom assessment.
- *Prior neurocognitive baseline*—through many of the commonly used paper and pencil and/or computerized neurocognitive tests, when scores on neurocognitive indices such as memory, speed of information processing, and reaction time return to their previous ranges, the athlete is said to have returned to prior functioning. These ranges are often measured via reliable change indices (RCI), which is a standardized difference from pre- to post-concussion considered large enough, compared to the error variance of the test, to be a clinically significant change [17].
- *Balance testing*—scores on balance testing return to level prior to the injury, most commonly through the modified Balance Error Scoring System (mBESS) [18].

Prognosis vs. Incidence Many studies of pediatric SRC focus on "risk factors" or "prognostic factors," and it is important to qualify what is being prognosticated. The current review focuses on risk factors for recovery and/or injury severity, most often predicting the risk for PCS. Though PCS is defined somewhat differently in each study, these investigations aim to predict which biopsychosocial factor may lead to a routine versus protracted recovery. Though important and necessary, SRC incidence and risk factors for incurring a SRC in the pediatric population will not be the focus of the current paper.

Immediate Management and Initial Recovery

After an athlete suffers a SRC, an appropriate treatment plan must ensue. First and foremost, no athlete returns to play the same day. Once an athlete is diagnosed with a SRC, at any level, they are removed for at least the remainder of that day. In the ensuing days and weeks, the overarching theme is *an individualized approach* to recovery. Several clinical domains and corresponding tests exist that objectively document neurologic deficits at the time of injury and throughout recovery (Table 1). No athlete is the same, and factors such as prior concussion, learning disabilities, family history, and other host factors must be considered in determining recovery.

Table 1 Recommended assessment and suggests test(s)

Domain	Suggested test(s)
Postural stability	Modified BESS
Oculomotor functions	VOMS
Neurocognitive functions	ImPACT, SCAT5
Symptoms	PCSS, SCAT5

BESS Balance Error Scoring System, *VOMS* Vestibular/Ocular Motor Screening, *ImPACT* Immediate Post-Concussion Assessment and Cognitive Testing, *SCAT5* Sport Concussion Assessment Tool—5th edition, *PCSS* Post Concussion Symptom Scale

Treatment

Summary and position statements [12••, 19••] have advocated for rest, which has been interpreted by some clinicians as ranging from restriction of physical exertion at one level, to "cocoon therapy" at another, after a SRC. The latter refers to rest in a dark room with little to no physical stimuli. This isolative therapy is no recommended, but rather a more active recovery approach is taken. Succinctly summarized in a meeting of experts held in Pittsburgh in 2015, the Targeted Evaluation and Active Management (TEAM) document recommended initial and circumscribed physical and cognitive rest with faster progression to active rehabilitation, accommodations at work/school as required, and progressive aerobic exertion based on symptoms [19••]. The TEAM group also determined that active rehabilitation may improve symptom recovery more than rest alone, and that these active strategies should be initiated early. Several exploratory studies have shown early benefit to active rehabilitation, including vestibular rehabilitation [20, 21], and earlier aerobic exercise [22].

Several studies have addressed pharmacological treatments of SRC [23, 24]. To date, medical prescriptions have been driven by targeting symptomatology. Preliminary analyses of novel agents are in their infancy, and no evidence-based, formal endorsements of medical therapies to treat SRC have been made.

Return to Play and School

Once symptoms have resolved, a graduated RTP protocol can be undertaken. Recommended by the CISG panel, this includes no activity, progressing to light aerobic exercise, sport-specific exercise, non-contact drills, full contact practice, and full RTP. The athlete must be asymptomatic at each stage for at least 24 h, and if symptoms recur, the athlete returns to the prior level in the stepwise progression [12••].

Return to school or RTL should be a part of every pediatric SRC recovery plan. In addition to no same day RTP, a second zero tolerance policy adopted by many clinicians is that RTL always precedes RTP. Education and scholastic involvement supersedes sport, especially at the pediatric level. Simply put, RTP is not considered until the athlete attends full days of school and demonstrates asymptomatic status with cognitive exertion.

Modifying Factors

The CISG introduced the term concussion modifiers in 3rd CISG consensus statement in 2008. The group defined these factors broadly as "factors that may influence the investigation and management of concussion and in some cases, may predict potential for prolonged symptoms." These factors are important to note during an initial evaluation and are often open areas for further research [25].

Initial Symptom Burden

Evidence for the relationship between slower recovery and greater acute/subacute symptom severity among youth and adolescent athletes has been consistently reported [7, 8, 26–30, 31••, 32, 33], with fewer studies failing to demonstrate the association [10, 34, 35]. Many of the supporting studies demonstrate that greater symptom severity yields the largest statistical effect sizes, as compared to other significant factors. For example, Miller et al. [7] revealed that a SCAT2 symptom severity score of > 20 was 8.7 times more likely to result in PCS among 294 pediatric patients, whereas five other significant factors were 2.1 to 6.9 times more likely to be associated with the diagnosis. This strong association between acute symptom severity and time to recovery has been demonstrated across a number of clinical settings, such as multidisciplinary concussion clinics [7, 8, 28, 33], emergency departments [26, 31••], and a general sports medicine clinic [32].

The influence of greater symptom severity on recovery has been observed in samples including combined youth, middle, and high school (5–18 years) [31••], high school only [27, 29, 30], and middle and high school schools [26, 28, 32, 33]. Additionally, the relationship between acute symptom severity and PCS has been observed when using different definitions of PCS or prolonged recovery, including > 28 days [7, 31••], > 30 days [28], and at 60 days [33]. When looking deeper into specific symptom endorsement, there is currently not enough evidence to suggest that greater severity in one symptom or another can affect length of recovery. Moreover, while it is clear that greater aggregate symptom severity predicts recovery, the precise definition of "greater severity" has not yet been determined. As highlighted above, Miller et al. [7] utilized a score of 20 on the SCAT2 as a cutoff for severity; however, it is unclear whether other score thresholds have greater sensitivity or specify. While this may be unique to each individual athlete, future studies should aim to identify the optimal cutoff for predicting protracted recovery in athletes across the wide array of symptom inventories used in SRC assessment.

Prior Concussion

The relationship between prior concussion and recovery following SRC in pediatric athletes has been inconsistent, with some studies demonstrating a relationship between the two [7, 10, 26, 27, 31••, 36, 37] and others failing to find an association [11, 28, 34, 38–41]. Inconsistent findings regarding length to recovery have been observed not only in symptom duration but also in timing of return to school [37, 41]. Variable findings are likely due to the heterogeneity across studies, some of which is highlighted below. Ultimately, the evidence for an association between prior concussion and length of recovery is currently inconclusive and warrants further study.

Three large-scale studies have demonstrated that prior concussion was significantly associated with slower recovery (> 28 days) [7, 37], one of which was a prospective design [31••]. In contrast, a large, ambispective study including 1334 high school athletes failed to find an association between prior SRC history and delayed recovery (> 28 days) [11]. A second large-scale study of 1953 youth athletes also failed to demonstrate a significant effect of prior concussion on time to recovery, defined as resolution of symptoms and/or return to play [8]. Setting of referral may be a relevant factor in discerning the inconsistencies, as the large-scale studies demonstrating a significant association included initial presentation to the ED or a specialty concussion clinic. Conversely, one study that did not demonstrate a relationship between prior concussion and symptom duration involved data collection at various high schools as part of a national injury surveillance program [11].

Contradictory findings regarding prior concussion and length of recovery may also be due to heterogeneity in the operational definition of prior SRC. Previous SRC has been examined as binary variable in multiple ways, with some studies classifying a positive history as > 0 SRCs [31••], whereas others regard positive history as > 2 [37], and others have examined concussion history as a continuous [8] or categorical variable (0, 1, > 1) [26, 40]. Moreover, wide heterogeneity in the definition of delayed recovery and PCS also exists, with some studies involving cutoffs of > 28 days or symptom resolution/ return to play as a continuous outcome variable.

Although the relationship between prior concussion and length of recovery is currently inconclusive, findings from select studies have demonstrated preliminary evidence that a second head impact closer in time to the initial head impact may increase time to recovery [38, 42]. For example, Terwillger et al. [38] found that athletes who sustain an additional significant head impact within 24 h of the initial concussion were significantly more likely to have a longer recovery than those who did not, with moderate effect sizes. However, further research is needed to validate this potential relationship, as well as determine at which point in recovery this relationship weakens and dissipates.

Gender

Considerable attention has been given to the role of gender in recovery after pediatric SRC, and findings have thus far been divided [13]. Numerous studies point to a disparity in the incidence of SRC in youth populations, with females being affected more frequently [43, 44••]. Though not our focus, a brief mention of incidence is helpful to understand the role of gender. Female athletes at the high school level have been shown to experience a greater number of concussions in sports that are played by both male and female athletes (ice hockey, soccer, and baseball/softball) [43, 45, 46]. For example, O'Connor et al. found that in high school athletes playing sex-comparable sports, the SRC rate was 56% higher in females than males (RR = 1.56, 95% CI = 1.34–1.81) [47]. The question remains as to whether this disparity is also represented with regard to patterns of recovery from SRC.

A number of papers have identified females as experiencing a greater time loss from concussions than males. Miller et al. [7] found that female gender was associated with a higher rate of delayed recovery after SRC (OR 3.2, 95% CI 1.84–5.41, $p = 0.001$) [7]. In a study of 37 athletes (aged 15.0 ± 1.9 years) with a SRC, Berz et al. [48] reported that females endorsed more symptoms on initial assessment post injury, and took longer to become symptom free [48]. In a study of youth athletes, Bock et al. [49] found that the males had a median RTP of 22 days, while the females had a median of 35 days ($p < 0.001$). Other studies corroborate findings that female gender is predictive of prolonged recovery from SRC [7, 8, 28, 31••, 50].

A considerable number of studies have not found this relationship to be statistically significant [10, 26, 35, 36, 38, 51–53]. Moor et al. [35] found no association between gender and recovery time ($p = 0.21$), though one collegiate athlete was included. When looking at risk factors for experiencing concussive symptoms lasting ≥ 1 week, Chrisman et al. [36] did not find gender to be statistically significant in non-football sports (RR 1.1, 95% CI 0.7–1.6, $p = 0.81$). Ono et al. [53] reported that compared to males, female athletes did endorse more symptoms at baseline ($p < 0.001$) and in the acute phase after SRC ($p = 0.05$), but that symptom resolution patterns were the same. Findings like these suggest that sex differences in concussion recovery may be better explained by increased symptom frequency/ acknowledgment in female athletes, rather than in patterns of symptom resolution time. Others point to the possibility of females feeling more comfortable endorsing symptoms than males, thus creating a bias [54].

Migraine Headache

Studies that examine a correlation between a personal and/or family history of migraine and prolonged recovery from SRC in pediatric populations have been limited. In a population involved in a mix of SRC and non-SRC athletes, Zemek et al. [31••] identified a personal preinjury history of physician-diagnosed migraine as associated with the development of PCS (OR 1.9, 95% CI 1.4–2.6). More commonly though, studies have been unable demonstrate this relationship with statistical significance [7, 28, 39, 55]. With regard to a family history of migraine, Morgan et al. [10] found that in their sample of youth athletes (mean age = 14.9), a self-reported family history of migraine was positively correlated with the development of PCS ($p = 0.003$), but that a personal history of migraine was not ($p = 0.088$). Sufrinko et al. [56] found that individuals with a family history of migraine were 2.6 times more likely (95% CI 1.35–5.02, $p = 0.003$) to experience post-concussion migraine compared to peers who did not share that history. This is relevant, as it has been demonstrated that those with post-traumatic migraine were 7.3 times more likely to experience a protracted recovery than those with no headache or migraine (95% CI 1.80–29.91), and 2.6 times more likely than peers with only post-traumatic headache (95% CI 1.10–6.54) [57]. While Zemek and colleagues [31••] found that a personal history of migraine was predictive of developing PCS, they did not find this for a family history of migraine. It is notable that many of these studies utilized smaller sample sizes and self-report of symptoms. A correlation between personal history of migraine and prolonged recovery from SRC remains controversial and further research is warranted.

Learning Disability and ADHD

In general, studies on the relationship between learning disability and prolonged recovery from SRC in pediatric populations have failed to demonstrate a strong correlation. However, Zemek et al. [31••] reported that in their population of SRC and non-SRC youths, those with a prior history of learning disability were more likely to experience prolonged symptoms (OR 1.5, 95% CI 1.0–2.1, $p = 0.03$) [31••]. Others have not found any support for this relationship [10, 26, 39]. While there is additional data on adult and collegiate populations [58, 59•], there is limited research on the pediatric populations.

In a single-center case control study of pediatric SRC, Miller et al. [7] identified a prior history of ADHD as predictive of a prolonged recovery (> 28 days) (OR 2.45, 95% CI 1.1–5.5) [7]. Mautner et al. [40] examined HS students with SRC and found that those with a preinjury history of ADHD did have a longer, though not statistically significant, time to recovery. In that study, the athletes with a preinjury history of ADHD ($n = 70$) took on average 16.5 days to recover, compared with the control ($n = 70$) who took an average of 13.5 days to recover ($p = 0.12$, 95% CI − 1.70–2.21). Morgan et al. [10] did not find any relationship between ADHD and the development of PCS ($p = 0.750$), and a number of other studies have been unable demonstrate a significant relationship between the two conditions [7, 26, 31••, 39].

Psychiatric History and Family Psychiatric History

Several studies have shown that a positive past medical or family history for psychiatric illness is an important modifying factor for concussion in young athletes. The literature is sparse in regard to evaluating the effect of premorbid psychiatric illness on recovery in children. However, recently, Guerriero et al. [60] published a prospective cohort study of 569 school-aged children seen in a neurology clinic for concussion, 171 of which were sport related. The authors reported that specifically in children under 12 years old, a premorbid psychiatric diagnosis (anxiety, depression, suicide attempt, bipolar, or post-traumatic stress disorder) was associated with a significantly longer recovery time (235 days vs. 143 days, $p = 0.03$) [60]. Ellis et al. [28] found that pediatric patients with preconcussion history of a diagnosed psychiatric condition were more likely to develop a novel psychiatric condition and complicated post-concussion course. Further, Morgan et al. found in a matched case-control study of 40 concussed young athletes that a preinjury mood disorder substantially increased the risk of developing PCS (OR, 17.9, 95% CI 2.9–113.0, $p = 0.002$) [10].

Family psychiatric history also appears to confer additional risk of prolonged recovery in this population. In the same study as mentioned above, Morgan et al. [10] found that family history of mood disorders increased odds of developing PCS roughly threefold (OR 3.1, 95% CI 1.1–8.5, $p = 0.026$). More recently, this work was further substantiated by Legarreta et al. who demonstrated that simply being positive for a family psychiatric history more than doubled the chance of developing PCS (OR 2.52, 95% CI 1.2–5.30, $p = 0.03$). Interestingly, Legarreta and colleagues found that while having both personal and family history of psychiatric illness increased the risk of PCS substantially (OR 5.06, 95% CI 1.71–14.99, $p = 0.018$) compared to those without either history, having both personal and family psychiatric history did not confer any more risk when compared to children with only a family history (OR 2.01, 95% CI 0.68–5.94, $p = 0.247$) [61].

Psychotropic Medications and Neurocognitive Test Results

The treatment of psychiatric conditions in the pediatric population and the possible effect on baseline and post-concussion neurocognitive test results deserves brief mention. Yengo-Kahn et al. [62] performed a retrospective matched case-control study to evaluate the effect of various classes of psychotropic medications on baseline ImPACT test scores. Young athletes prescribed psychostimulants demonstrated significantly lower visual motor speed scores (32.8 vs. 37.1, $p = 0.030$) and slower reaction times (0.65 vs. 0.60, $p = 0.044$) while those athletes prescribed antidepressant medications demonstrated faster reaction times (0.58 vs. 0.61, $p = 0.029$). These findings led the authors to conclude that baseline testing would be an important consideration in this subgroup and that the effect of psychotropic medications and post-concussion testing would likely be most valid if athletes were tested in the same medicated or unmedicated state in which the baseline was obtained [62]. Gardner et al. performed a similar study evaluating psychotropic medications' effects on post-concussion neurocognitive test scores. Similarly, differences existed depending on the class of medication prescribed and the results concluded that ADHD diagnosis and treatment status in particular are important considerations when interpreting neuropsychological test scores in this population during recovery from SRC [63].

Sport Factors

Amidst a variety of factors, a minority of studies has assessed sport-specific risk factors for pediatric athletes, including contact level, mechanism, position, and others. In a study solely devoted to mechanisms, Zuckerman et al. [64•] assessed three mechanisms in mostly high school athletes playing football ($n = 92$), soccer ($n = 47$), and basketball ($n = 42$). These mechanisms were contact mechanism (with what the player collided), sports mechanism (player action during time of injury), and awareness mechanism (whether the athlete was aware of oncoming collision) [64•]. Though the study had a small sample size, no specific contact or sport mechanism was associated with PCS; however, soccer players unaware of an oncoming collision had a longer duration of symptoms. A study of high school football players found that concussion suffered later in the season presented with increased symptomatology, which suggests a hypothesis of compounding severity as the season progresses [65]. However, the study did not asses risk for PCS, only acute symptom burden.

Several studies have reported negative results related to sport factors. In a larger, national database study of 1334 high school athletes, Kerr and colleagues [11] found a host of symptoms were associated with PCS, but sport contact mechanism (collision vs. high contact vs. low contact) was not associated with PCS. In a pilot study of 136 high school athletes, the variable of team versus individual sport was not associated with an increased risk of PCS. An earlier study compared 69 helmeted athletes to 69 unhelmeted athletes and found no different in acute neurocognitive and symptom scores, suggesting that helmet status was not a factor in acute outcomes in pediatric athletes [66].

Socioeconomic

Environment and socioeconomic factors may also play a role in the development of long-term symptoms and PCS. This area has been more heavily investigated in general mTBI, where some authors have shown that higher parent stress and higher socioeconomic status were associated with PCS, though this was not in a sports population [6, 67, 68]. In one of the few studies to assess socioeconomic factors in an exclusive sports population, Zuckerman et al. [69] assessed 282 mostly middle and high school athletes and assessed the effect of cost of living, median income percentile, college graduate status, homeowners, and insurance status (all viewed as surrogate markers for SES) on risk of PCS, and found that private insurance status was associated with delayed return to school. No other factors were associated with PCS. This finding suggested that those with private insurance may receive treatment from more conservative practitioners. More research into practice patterns depending on practitioner specialty and qualifications is warranted.

Conclusions

The assessment of SRC in pediatric athletes is crucial to improving the care of pediatric athletes with mTBI. In the current review, we have highlighted key definitions, guidelines for returning to play and school, and risk factors for prolonged recovery. While much improvement has been made in the care of concussed pediatric athletes, additional knowledge is still needed. Future study of pediatric SRC should include additional scrutiny of controversial risk factors, in conjunction with studies specifically targeting the difficult to study youth population from ages 8 to 12 years. Moreover, exploratory analyses can begin to combine the novel areas of advanced imaging, helmet engineering, and genetic predictors into the current assessment and treatment of SRC in pediatric athletes.

Compliance with Ethical Standards

Conflict of Interest Gary *S. Solomon* reports personal fees from the National Football League, personal fees from NHL Nashville Predators, other from Tennessee Titans, other from University of Tennessee Athletics, other from Tennessee Tech Athletics, other from Department of Defense, outside the submitted work. Benjamin L. Brett, Aaron M. Yengo-Kahn, Scott L. Zuckerman, and Aaron Jeckell each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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