

Neurocognitive Deficits of Concussed Adolescent Athletes at Self-reported Symptom Resolution in the Zurich Guidelines Era

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Background: Previous studies have evaluated high school and collegiate athletes in the pre-Zurich guidelines era; whether adolescent athletes demonstrate similar neurocognitive decrements in the current concussion management era remains unclear.

Purpose: To assess for the presence of neurocognitive deficits in adolescents with a sport-related concussion at the time of self-reported symptom resolution.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: We conducted a prospective cohort study of 32 patients, aged 13 to 18 years, who sustained concussions during ice hockey and who were referred to 3 sports medicine clinics between September 1, 2012, and March 31, 2015. Demographic, anthropometric, and injury data were collected at the time of the initial postconcussion evaluation. To document symptoms, patients completed the Post-Concussion Symptom Scale (PCSS) at initial and follow-up visits. Baseline and postinjury neurocognitive function were assessed using computerized neurocognitive testing (Immediate Post-Concussion Assessment and Cognitive Test [ImPACT]), and a reliable change index was used to determine significant changes in composite scores. Statistical comparisons were conducted using the Student *t* test and Mann-Whitney *U* test.

Results: A total of 9 of 32 athletes (28.1%; 95% CI, 14.8%-46.9%) demonstrated continued neurocognitive impairment on ≥ 1 composite score when no longer reporting concussion-related symptoms, while only 2 of 32 athletes (6.3%; 95% CI, 1.4%-23.2%) demonstrated continued neurocognitive impairment on ≥ 2 composite scores.

Conclusion: Neurocognitive deficits persist in adolescent athletes who no longer report concussion-related symptoms, at rates similar to those of collegiate athletes but at longer time intervals. This finding provides further evidence that adolescent athletes with a sport-related concussion demonstrate a protracted recovery and resolution of neurocognitive deficits compared with collegiate and professional athletes. Computer-based neurocognitive testing as part of a multifaceted approach continues to play an important role in return-to-play decision making after a sport-related concussion in adolescent athletes. Test-taking strategies may erroneously identify asymptomatic athletes as exhibiting neurocognitive impairment.

Keywords: concussion; symptoms; ImPACT; adolescent; neurocognitive impairment

The cornerstone of sport-related concussion management remains a clinical evaluation and subjective reporting of the injured athlete's postconcussion symptoms. In addition, an objective evaluation with computer-based neurocognitive testing, ideally compared with a valid baseline assessment, continues to be recommended and supported by various clinical practice guidelines, consensus statements, and sports medicine organizations, although this recommendation is not universal.^{5-7,9,20} While the optimal timing

and number of postinjury neurocognitive tests continue to be debated and vary from institution to institution, there is a general consensus among those sports medicine physicians, athletic trainers, and neuropsychologists who use computer-based neurocognitive testing that an assessment should be completed once a concussed athlete no longer reports symptoms.^{5-7,9,20} Regardless of timing, the rationale for testing is that it enables clinicians to detect impairment (ie, ongoing recovery) in the absence of self-reported symptoms.

Previous studies have evaluated for the presence of neurocognitive decrements among concussed athletes after symptom resolution. Broglio and colleagues² performed a

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retrospective analysis assessing 21 National Collegiate Athletic Association (NCAA) Division I collegiate athletes (16 men, 5 women) with a mean age of 19.8 years and a mean 1.8 prior concussions, using the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) when symptomatic (within 72 hours of injury) and when asymptomatic, with a comparison of results to baseline testing. More than a third (38.1%) of concussed athletes demonstrated evidence of neurocognitive impairment on at least 1 ImPACT variable relative to their baseline evaluation when reporting to be asymptomatic, suggesting that neurocognitive deficits persisted beyond the period in which the athlete reported having symptoms.

While other studies have evaluated for neurocognitive deficits in adolescent athletes after self-reported symptom resolution,^{4,13,15,28} none of these studies observed patients beyond 14 days of injury, and all were performed before the publication of the Zurich guidelines in 2008 and 2012,^{19,20} arguably a different era of sport concussion management. Symptom reporting by athletes in recent years has possibly increased after educational efforts³ and intense media attention²⁵ directed toward sport-related concussions. While the largest proportion of at-risk athletes for sport-related concussions is at the high school level or below (based on participation levels), few studies have been conducted regarding the clinical utility of neurocognitive testing relative to player symptom reporting in high school athletes. This information is highly relevant for determining a safe return to play, particularly for high school participants who may be especially vulnerable to second-impact syndrome, which is thought to occur when a second impact occurs while recovering from a prior injury. The majority of second-impact syndrome victims have been high school athletes between the ages of 13 and 18 years.¹³ We conducted a prospective study of adolescent athletes with a sport-related concussion managed in the Zurich guidelines era to assess for the presence of neurocognitive deficits at the time of self-reported symptom resolution.

METHODS

Study Design

We included ice hockey players (male and female) aged 13 to 18 years who presented to outpatient sports concussion clinics between September 1, 2012, and March 31, 2015, at 3 regional medical centers. The players had sustained

in-season concussions during an ice hockey game or practice during the scholastic year (September-June). This is a secondary analysis of data collected for a separate study¹¹; concussion evaluations were performed by fellowship-trained sports medicine physicians.

Players were excluded from the study if they sustained a prior concussion within 6 months of presentation, had ≥ 3 prior diagnosed concussions, and, among high school ice hockey players, participated at a level other than varsity. Demographic, anthropometric, balance, and injury data were collected at the time of the initial postconcussion evaluation. The Post-Concussion Symptom Scale (PCSS),¹² a standardized 22-item concussion symptom list proposed by an international consensus on concussions in sport, was administered at initial and follow-up visits. Baseline and postinjury neurocognitive function were assessed with computerized neurocognitive testing (ImPACT) and used for making return-to-school and return-to-play decisions for injured student-athletes. To be included in the data analysis, athletes had to meet the following criteria: (1) completion of the ImPACT before injury (baseline), (2) diagnosis of a sport-related concussion, (3) reporting of the resolution of symptoms during the study period, and (4) completion of the ImPACT after injury (postinjury) once asymptomatic by a self-report (PCSS score = 0). Of 145 eligible athletes, 32 met these inclusion criteria. While all 145 eligible athletes had sustained sport-related concussions, only 32 had a self-reported PCSS score of 0 once asymptomatic with available baseline and postinjury ImPACT results. Written informed consent and assent to participate was obtained. Institutional review board approval was granted.

A concussion was defined according to the definition proposed by the International Conference on Concussion in Sport,²⁰ such that hockey players experiencing sport-related trauma followed by the signs and symptoms of a concussion included in the PCSS were diagnosed with a concussion. Symptom resolution was defined as the day that the student-athlete self-reported no longer experiencing symptoms from the concussion; as with prior studies,^{1,22,23} athletes were instructed to rate only those symptoms that started at their time of injury and were still present within 24 hours before the clinic visit. As most signs and symptoms on the PCSS are nonspecific and can result from causes other than a concussion, we were only interested in symptoms attributable to a concussion and conveyed this to study participants both verbally and in written instructions. Neurocognitive impairment was

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Ethical approval for this study was obtained from the Lifespan Research Protection Office (registration No. 0000396, 00004624).

TABLE 1
ImPACT Composite Scores at Baseline and
Self-reported Asymptomatic Time Points^a

	Baseline	Self-reported Asymptomatic Time Point
Verbal memory	85.63 ± 11.57	89.06 ± 10.35
Visual memory	73.47 ± 11.23	76.63 ± 12.21
Visual-motor speed	33.38 ± 6.28	36.66 ± 7.05
Reaction time	0.64 ± 0.09	0.61 ± 0.08
Total symptom score	4.91 ± 10.57	0.00 ± 0.00

^aData are presented as mean ± SD. ImPACT, Immediate Post-Concussion Assessment and Cognitive Test.

defined as ≥ 1 composite score diminished beyond the reliable change index (RCI) when compared with their baseline performance on computerized neurocognitive testing, consistent with the definition in prior studies.^{2,28}

Statistical Analysis

Means and SDs were calculated for composite and symptom scores on computerized neurocognitive testing for all athletes meeting inclusion criteria. Postinjury ImPACT results were compared with baseline scores to determine changes in performance. Changes in composite scores were considered significant only when they exceeded the RCI set at the 80% CI, and invalid ImPACT data were excluded according to criteria published in the ImPACT user's manual.^{8,10} Continuous variables are presented as means ± SDs and were compared using the Student *t* test if normally distributed and the Mann-Whitney *U* test if not. Simple descriptive statistics were used for dichotomous outcomes. Data analysis was performed by using SPSS version 22.0 (IBM) and Stata version 13 (StataCorp).

RESULTS

Thirty-two adolescent ice hockey players (18 male, 14 female) met inclusion criteria. The mean age, weight, and height of the athletes were 15.5 ± 1.3 years (range, 13.0-17.5 years), 63.0 ± 12.2 kg (range, 43.3-88.2 kg), and 164.3 ± 9.5 cm (range, 145.0-187.5 cm), respectively. The mean number of prior concussions was 0.7 ± 0.6 (range, 0-2). Twenty-seven of the 32 athletes completed the baseline ImPACT within 2 years of their concussion. Athletes completed the initial self-reported symptomatic assessment at a mean of 17.9 ± 22.2 days after injury. Athletes self-reported the resolution of symptoms at a mean of 23.8 ± 16.8 days after injury (95% CI, 17.7-29.8). As a group, mean scores on computerized neurocognitive testing were similar between baseline and self-reported asymptomatic time points, with no difference in mean scores exceeding the RCI (Table 1).

Overall, 9 of 32 athletes had longer reaction times on the postinjury ImPACT, 4 of whom exceeded the RCI (Table 2). At the time of symptom resolution, however, 9 athletes (28.1%; 95% CI, 14.8%-46.9%) had at least 1 composite score decreased relative to the baseline score beyond the RCI,

despite no longer reporting any concussion-related symptoms (Figure 1). Of these 9 players, 2 athletes (6.3%; 95% CI, 1.4%-23.2%) demonstrated continued neurocognitive impairment on at least 2 composite scores relative to baseline scores.

One of the 7 athletes who had a change that exceeded the RCI in only 1 category, BCH 060 had a reaction time visible that exceeded the reaction time hidden on the symbol match portion of the postinjury test. Of the 2 athletes who had >1 composite score decreased relative to the baseline score beyond the RCI, BCH 041 had a reaction time visible that exceeded the reaction time hidden on the symbol match portion of the postinjury test but not on the baseline test. For BCH 068, her reaction time visible exceeded the reaction time hidden on the symbol match portion of the postinjury test but not on the baseline test.

DISCUSSION

We found that 28.1% of adolescent athletes continued to show impaired test performance relative to their baseline evaluation, despite denying the presence of concussion-related symptoms. Our results are similar to those of Broglio et al,² who showed that 38.1% of NCAA Division I collegiate athletes demonstrated objective cognitive impairment on the ImPACT when the athlete self-reported being asymptomatic. Overall, our results are comparable with the findings of Taylor et al,²⁷ who, while utilizing a slightly different study design, published an abstract of a prospective case series indicating that 25.0% of elite male and female youth hockey players (13-17 years) had persistently impaired ImPACT performance, signified by 1 composite score below the baseline score at the time of return to play.

Athletes demonstrating persistent neurocognitive impairment after symptom resolution of a sport-related concussion have been previously described, but research delineating differences according to age or participation level (eg, high school, college, professional, etc) has been limited.^{4,13,15,16,24} Numerous sport-related concussion clinical reports and position statements^{6,19,20} have acknowledged that the recovery of full cognitive function may take longer in younger athletes compared with college-aged or professional (adult) athletes, but few studies have assessed the cognitive outcomes of athletes with a sport-related concussion beyond 7 to 14 days from the time of injury. In the Broglio et al² study, NCAA athletes self-reported being asymptomatic at an average of 9.4 ± 7.2 days after the concussion diagnosis. In our study, adolescent athletes self-reported being asymptomatic at a mean of 23.8 ± 16.8 days after the concussion diagnosis. We demonstrated that over a quarter (28.1%) of adolescent athletes with a sport-related concussion exhibited neurocognitive impairment on computer-based neurocognitive testing, defined as at least 1 composite score decreased relative to the baseline score beyond the RCI, at the time of self-reported symptom resolution, even after adjusting for practice effects (applying a strategy to learning symbol match) such as test taking. Further, we detected these differences, on average, 24 days after injury, providing further evidence that adolescent athletes with a sport-related concussion may have prolonged recovery periods compared with collegiate and professional athletes.^{3,4,13-16,24,26}

TABLE 2
Participants With Longer Reaction Times on Postinjury ImpACT^a

Participant	Composite ImpACT			Symbol Match Module of ImpACT		
	RT, s	Change	Exceeds RCI?	RT Visible, s	RT Hidden, s	RT Visible Longer Than RT Hidden
RIH 020						
Baseline	0.61	0.03	No	1.59	1.31	Yes
Postinjury	0.64			1.84	1.71	Yes
RIH 048						
Baseline	0.56	0.15	Yes	1.53	1.63	No
Postinjury	0.71			1.59	1.59	No
BCH 025						
Baseline	0.61	0.05	No	1.48	2.15	No
Postinjury	0.66			1.67	1.31	Yes
BCH 039						
Baseline	0.49	0.02	No	1.57	2.03	No
Postinjury	0.51			1.55	1.04	Yes
BCH 041						
Baseline	0.64	0.13	Yes	1.37	1.52	No
Postinjury	0.77			1.81	1.59	Yes
BCH 056						
Baseline	0.55	0.02	No	1.36	1.45	No
Postinjury	0.57			1.43	1.20	Yes
BCH 060						
Baseline	0.53	0.09	Yes	1.63	1.36	Yes
Postinjury	0.62			1.55	1.48	Yes
BCH 068						
Baseline	0.58	0.06	Yes	1.48	1.56	Yes
Postinjury	0.64			1.30	1.14	Yes
BCH 074						
Baseline	0.66	0.01	No	1.43	2.11	No
Postinjury	0.67			1.78	1.52	Yes

^aBCH, Boston Children's Hospital; ImpACT, Immediate Post-Concussion Assessment and Cognitive Test; RCI, reliable change index; RIH, Rhode Island Hospital; RT, reaction time.

One of the novel and unexpected findings of our study was the identification of a potential test-taking strategy by athletes who are familiar with computer-based neurocognitive testing. During the symbol match portion of the ImpACT, athletes are presented with one shape, above which is a row of shapes with a row of numbers beneath, the answer key (Figure 2). They are asked to look at the answer key and click on the number that corresponds to the presented shape. The time that it takes them to do this is measured (in seconds) as reaction time visible. During the hidden portion of the test, they are again presented the shapes but, this time, are not given the answer key.

Athletes, particularly those who have taken the test before and realize that for the symbol match module, the answer key will be taken away during the next section, will often spend time memorizing the answer key as opposed to simply clicking on the answer, thereby falsely elevating their reaction time visible. Thus, this would reflect a test-taking strategy as opposed to a true prolongation of reaction time. We considered this possibility for athlete BCH 060; however, even at baseline, his reaction time visible was longer than his reaction time hidden. Furthermore, his postinjury reaction time visible was faster than his baseline's. Thus, a test-taking strategy was unlikely to have

accounted for his change in reaction time, and he was left in the analysis.

Combined with recent results from Maugans et al¹⁴ demonstrating that statistically significant alterations in cerebral blood flow values frequently persisted more than 30 days out from a sport-related concussion in preadolescent and adolescent athletes, our study suggests a possible period of vulnerability in adolescents after a sport-related concussion, even after subjective symptom resolution. Furthermore, our results reiterate the importance of a multifaceted approach to return-to-play decision making, based on a clinical examination, symptom reporting, postural stability testing, and neurocognitive testing (both baseline and after injury).

Finally, underreporting of concussion symptoms among adolescent athletes remains a pervasive issue that complicates the assessment and management of sport-related concussions, despite recent strides in educating players, coaches, parents, and health care providers about concussion symptom recognition. Studies performed in the pre-Zurich guidelines era showed that less than half (47%) of high school American football players who sustain a concussion report their injury.¹⁷ Reasons for underreporting include the failure to recognize concussion symptoms, the personal desire and

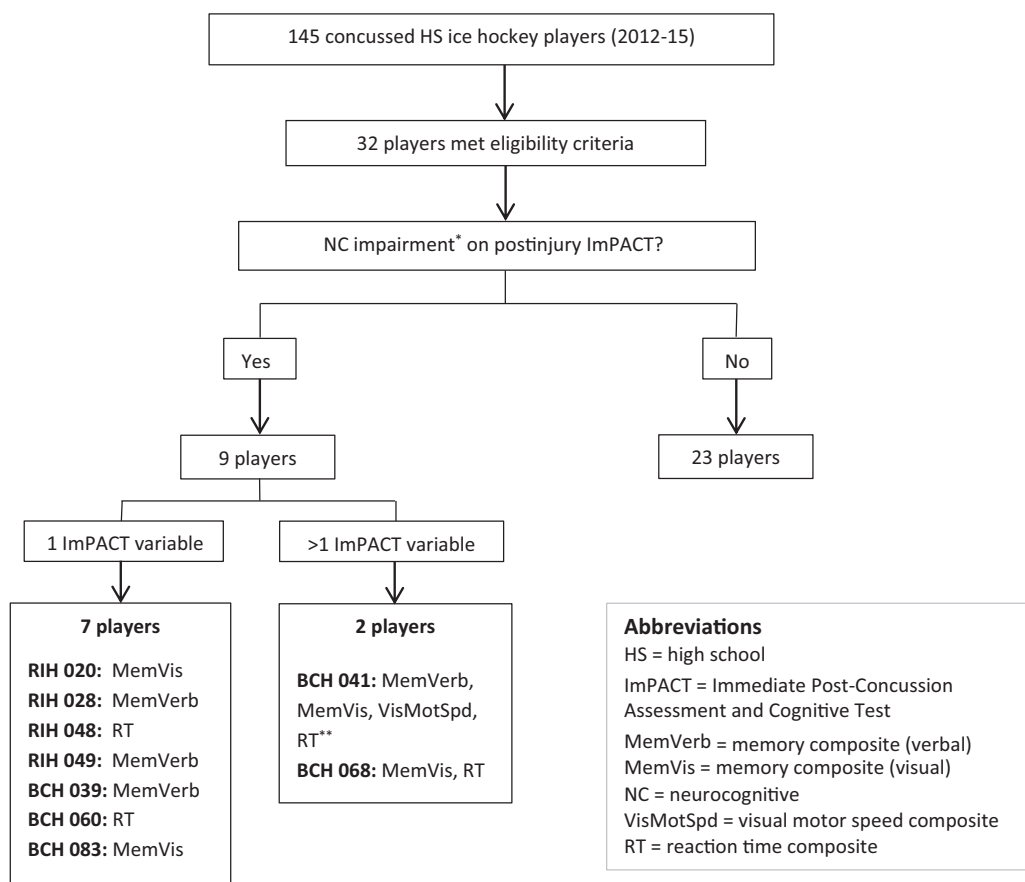


Figure 1. Flowchart of concussed high school ice hockey players. * ≥ 1 composite score diminished beyond the reliable change index when compared with baseline performance on computerized neurocognitive testing. **Reaction time diminished beyond the reliable change index but potentially because of a test-taking strategy.

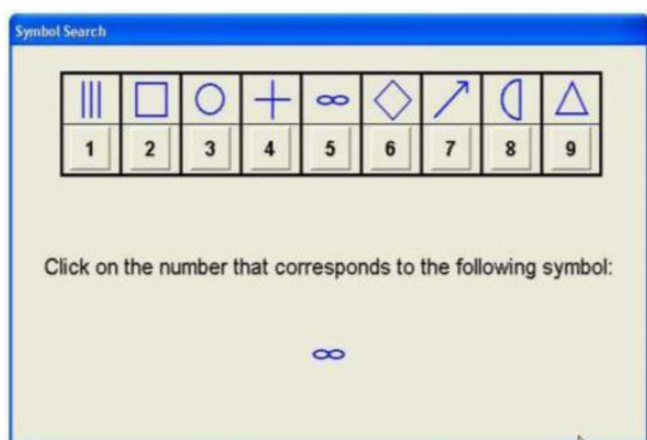


Figure 2. Symbol key from the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) symbol match module. (Reprinted with permission. Copyright 2017, ImPACT Applications Inc. All rights reserved.)

outside pressure to continue playing, and the perception that a concussion is not an injury that is serious enough to warrant reporting.²¹ Consequently, it is possible that we

may have detected, via computer-based neurocognitive testing, symptomatic athletes who claimed to be symptom free in an attempt to be cleared to initiate a gradual return to play.

Our study must be considered in light of several limitations. Our sample size of 32 is relatively small, although it is comparable with previous studies.^{2,13} Recruitment occurred from many organizations and scholastic institutions, making the acquisition of baseline ImPACT results challenging; 44.6% of the 145 adolescent athletes enrolled in our primary study did not have the baseline ImPACT performed or available, which restricted our study population because of exclusion from the data analysis. Many of our enrollees were players in youth ice hockey leagues or from public high schools, both of which inconsistently provide baseline testing to their players because of limited resources (funding, athletic trainers, computer-based neurocognitive testing licenses). Additionally, because our study population consisted exclusively of male and female adolescent ice hockey players, our results may be less generalizable than prior studies examining a broader range of athletes. Our study population also experienced significantly longer symptom durations than commonly reported, a finding that we attribute to the association between

referral patterns and specialty clinics. It is important to note that a number of factors other than a concussion affect performance on computer-based neurocognitive testing. Historical (eg, prior concussions, educational background, prior testing), psychological (eg, anxiety, depression, mood lability), genetic (eg, intelligence, visual/auditory acuity), methodological (eg, testing environment, practice effect), and other individual factors such as motivation, distractions, fatigue, and quality of sleep have been shown to affect the results of neurocognitive testing.¹⁸ Therefore, it is quite possible that some of the athletes in our study may have, in fact, been recovered but that their performance on computer-based neurocognitive testing was affected by one or more of the aforementioned factors.

Despite these limitations, we feel that the results of the present study represent real-world sport-related concussion management and clinical trajectories. What is the clinical significance of one-quarter to one-third of athletes still demonstrating objective evidence of cognitive impairment on computer-based neurocognitive testing at symptom resolution? While this finding may be attributable to the limitations of neurocognitive testing (eg, test-retest reliability), it is also possible that these athletes are truly experiencing a delay in cognitive symptom resolution in the absence of physical symptoms and that the sports medicine community is prematurely returning scholastic athletes based on an expert opinion-derived gradual return-to-play protocol, relying on feedback from the athlete regarding symptom recurrence that is solely subjective. In contact/collision sport environments such as youth and high school sports, in which the risk of recurrent injuries is not low, the true value of our small cohort study may be the following: Current concussion management overemphasizes the determination of symptom resolution, which is overwhelmingly a subjective determination based on symptoms that are neither sensitive nor specific for a concussion. Currently, there is little to no evidence supporting parameters such as symptom reporting and neurocognitive testing as determinants for a safe return to sport after a concussion. Return-to-play protocols that include neurocognitive testing as a mandatory criterion result in significant logistical challenges (eg, time, cost, personnel, need for baseline testing, etc) for youth sport organizations and academic institutions. In cases where persistent cognitive impairment remains plausible and is not clearly delineated by diagnostic (neurocognitive) testing or academic indicators (eg, exacerbation or symptoms with school work, studying, test taking), a conservative return to contact/collision sports should be advised for youth and adolescent athletes.

CONCLUSION

Our findings suggest that neurocognitive deficits may persist in some adolescent athletes who no longer report concussion-related symptoms. Although larger investigations conducted with adolescent and high school athletes participating in other contact/collision sports are required for better generalizability, our findings suggest an

important role of computer-based neurocognitive testing as part of a multifaceted approach to return-to-play decision making after a sport-related concussion in adolescent athletes. Future studies attempting to determine cutoffs for computer-based neurocognitive testing (after injury) should take into account test-taking strategies that may erroneously identify asymptomatic athletes as exhibiting neurocognitive impairment.

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