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Unusual presentation of more common disease/injury

Sports-related mild traumatic brain injury in female youths

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SUMMARY

Sports-related concussion or mild-traumatic brain injury (mTBI) is common in children who participate in organised sports. We describe two case studies involving 14-year-old girls who each sustained a mTBI during ice hockey competition. Neurocognitive functioning post-injury is compared to baseline pre-injury assessment on the same measures. Results from Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), Conners' Continuous Performance Test II (CPT-II) and the Attention Network Test (ANT) revealed decreased performance in attention, memory functioning and reaction time. Furthermore, some measures had not returned to baseline at midseason testing sessions approximately 30–40 days post-injury. The results are discussed with respect to the difference in recovery profiles and the need for thorough and ongoing evaluation following mTBI in the paediatric population, and for girls in particular.

BACKGROUND

Traumatic brain injury (TBI) refers to damage to the brain resulting from forces exerted to the head or directly to the brain itself in the case of penetrating injuries. TBI can be classified as mild (concussion or brief loss of consciousness (LOC)), moderate (LOC that may last up to a few hours, followed by a few days or weeks of confusion) or severe (prolonged unconsciousness or coma lasting days to months). Since the neuropathological, neurological and neurobehavioural consequences of mild-traumatic brain injury (mTBI) and concussion overlap, these two terms will be used interchangeably. Children and adolescents involved in organised sports are nearly six times more likely to suffer a severe concussion than those involved in leisure physical activities.[1] Post-concussion, individuals often exhibit diverse symptomatology. Symptoms commonly reported include headache, dizziness, nausea, vomiting and fatigue among others. Abnormal neuropsychological profiles following mTBI involve learning and memory of new material, working memory, attention, information processing speed and integrative tasks that contribute to executive function (frontal-lobe function).

While the most common cognitive sequelae of concussive injuries or mTBI are similar for children and adults, the breadth of consequences to children remains largely unknown.[2] Furthermore, even less is known about the effect of gender on recovery from mTBI with inconsistencies found in the existing research. A recent review of the sports-related concussion literature suggests that female athletes have a greater risk of concussion than males.[3] In addition, females appear to experience worse outcomes compared to males following TBI. However, it is unclear whether this increased incidence, symptomology and adverse outcomes is a true difference versus a factor of reporting bias where females are more likely to report concussion and endorse more symptoms following injury and during recovery.[3] For example, the aforementioned findings are offset by research demonstrating improved predicted outcomes for females following TBI.[4] Covassin *et al*[5] found that while females showed worse outcomes on visual memory tasks post-concussion, males were significantly more likely to have post-concussion symptoms of vomiting and sadness. This study highlights the variability and lack of knowledge regarding gender influences on recovery from mTBI.

The lack of information pertaining specifically to recovery from mTBI in females is especially concerning in light of the growing popularity of participation in competitive sports, such as ice hockey for women and girls.[6] Despite the no checking rules present in women's hockey, concussion rates have been found to be comparable.[7] There is a need for more research designed to specifically explore the roles of gender and development on recovery from concussion in youths, including both girls and boys in order to better understand how these factors impact recovery and, ultimately, long-term outcome. To our knowledge, these case studies are the first to document recovery from sports-related concussion in female athletes by comparing post-injury follow-up data to pre-injury baseline functioning.

CASE PRESENTATION

The concussed youths were two 14-year-old girls who were taking part in a prospective study of mTBI in youth hockey players (to view details and updates regarding the larger prospective study please visit http://www.brainfitlab.com). Assessing any player who was concussed was part of the prospective study and the case report details two concussed girls we followed throughout the study. Concussion was defined according to the recent Consensus Statement on Concussion in Sport[8] where the definition of concussion was deemed applicable to children as young as 10 years. This definition includes memory impairment, difficulties in concentrating, dizziness, irritability, fatigue, anxiety and headache (higher than 21 on the post-concussion symptoms (PCS) scale) as well as one of the following: (1) LOC less than 30 min; (2) loss of memory of events immediately before or after the concussion <24 h; (3) alteration in mental state at the time of the accident (eg, feeling dazed, disoriented or confused). The concussed players we assessed had significantly elevated post-concussion symptoms and alteration in mental state at the time of the injury as determined via clinical interview post-injury. Informed consent was provided by the parents of the youths to participate in the study as approved by the Research Ethics Boards at Lakehead University and the University of Toronto. Assent was also obtained from the players. Case study 1 sustained her concussion as part of a regular season game. It was her first concussion and she did not report any LOC or post-traumatic amnesia (PTA) after the injury (as indicated in figure 1). Case study 2 also sustained her concussion as part of a regular season game. However, it was her second concussion as she experienced a previous injury approximately 2.5 years earlier. Neither of her injuries resulted in a LOC or PTA. PTA is defined as a loss of memory for events occurring immediately prior to or after the injury. A detailed clinical history was obtained from both the girls and their parents to conclude that no PTA was found. The girls could recall details of the game immediately prior to and following the injury. Figures 1 and 2 illustrate the injury details and post-injury sequelae for case study 1 and case study 2, respectively.

INVESTIGATIONS

Baseline testing took place October 2007. Concussions occurred 57 days after baseline testing for case study 1 and 53 days after case study 2. We assessed case study 1 for post-concussion symptoms and neurocognitive function at 1, 5, 7 and 11 days post-concussion, and case study 2 at 1, 5, 8 and 12 days post-concussion. Both subjects were also tested at 39 and 34 days post-concussion, respectively, which represents a second baseline testing session obtained with all participants at mid-season as per study protocol.

These scores were then compared to their initial baseline testing scores. The girls were assessed with the following measures: Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), the Attention Network Test (ANT) and Conners' Continuous Performance Test II (CPT-II). The measures assess neurocognitive function related to attention, memory, brain processing speed, reaction time and inhibition; functions known to be affected by mTBI. However, special emphasis was placed on evaluating attention, given research findings to date that suggest attention may be particularly affected in children and youths following TBI.[9] Neurocognitive function was assessed using standardised administration and scoring procedures, and conducted in a quiet and controlled environment to minimise distraction. All measures contained multiple versions or delivered randomised presentation of stimuli to minimise practice effects. Each full assessment period was approximately 60 min. Neither case study 1 nor case study 2 underwent neuroimaging protocol (ie, CT or MRI).

DIFFERENTIAL DIAGNOSIS

The first author is a clinical neuropsychologist with expertise in paediatric mTBI and acted as a consultant to the athletes, their family and their family physician regarding the diagnosis and prognosis of the girls' mTBI. The research team did not attend the hockey games, but received reports of concussions and need for follow-up from the athletic trainers. The differential diagnosis of concussion was determined based on both an injury report collected via clinical interview from the girls and their parents (including the presence and degree of post-concussion symptoms), as well as the results of neurocognitive testing obtained post-concussion that showed decreased performance compared to pre-injury baseline testing scores.

TREATMENT

No specific interventions or treatment were administered. The standard practice following sports-related concussion is rest from all activity until symptoms have cleared followed by a gradual return-to-play and normal activities.

OUTCOME AND FOLLOW-UP

A reliable change index[10] was applied to ImPACT and CPT-II scores in order to evaluate significant change following injury. A reliable change index could not be calculated for the ANT as there is no normative data available for this measure. Case study 1's post-concussion and neurocognitive scores are presented in table 1. As shown in table 1 case study 1's total post-concussion symptom scores showed significant change from baseline as did her verbal memory, visual motor speed and reaction time composite scores with a different recovery profile for each measure. Primary post-concussion symptoms included headache, dizziness, fatigue, nausea, drowsiness, feeling more foggy than usual and feeling more emotional than usual. All measures returned to baseline levels by mid-season testing. Neither the composite score for visual memory or impulse control indicated a significant change from baseline performance following concussion. With respect to case study 1's performance on the CPT-II, she demonstrated a significant increase in her level of inattention, hit reaction time (RT) and perseverations following injury. While hit RT returned to pre-injury baseline levels, inattention and perseverations remained elevated at mid-season testing. Levels of impulsivity did not show a significant change from baseline testing across any follow-up testing sessions or mid-season baseline testing session. On the ANT, there was a decrease in alerting and executive function post-concussion, both of which returned to baseline levels by the mid-season testing session.

The post-concussion symptom scores and neurocognitive data for case study 2 are presented in table 2. As shown in table 2, case study 2's post-concussion symptom scores were significantly increased following her injury and remained elevated at the second baseline testing session, which occurred 34 days post-injury. Her primary post-concussion symptoms included headache, nausea, dizziness, fatigue, trouble falling asleep, sleeping more than usual, feeling more foggy than usual, difficulty concentrating and remembering things. Her visual memory composite and reaction time composite scores showed decreased performance post-concussion with a return to

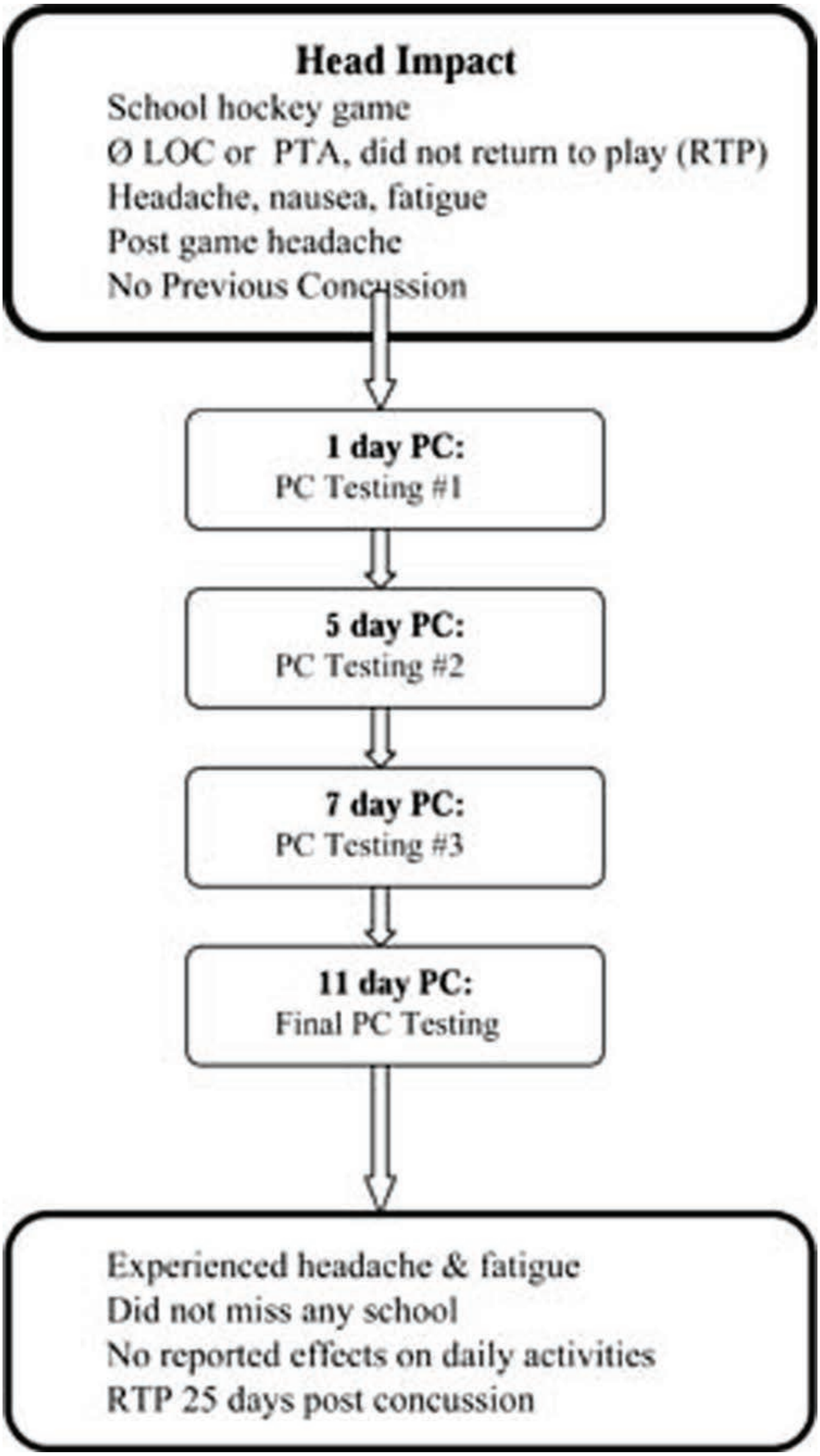

Figure 1 Post-injury sequelae and follow-up specific to case study 1. LOC, loss of consciousness; PC, post-concussion; PTA, post-traumatic amnesia; RTP, return-to-play.

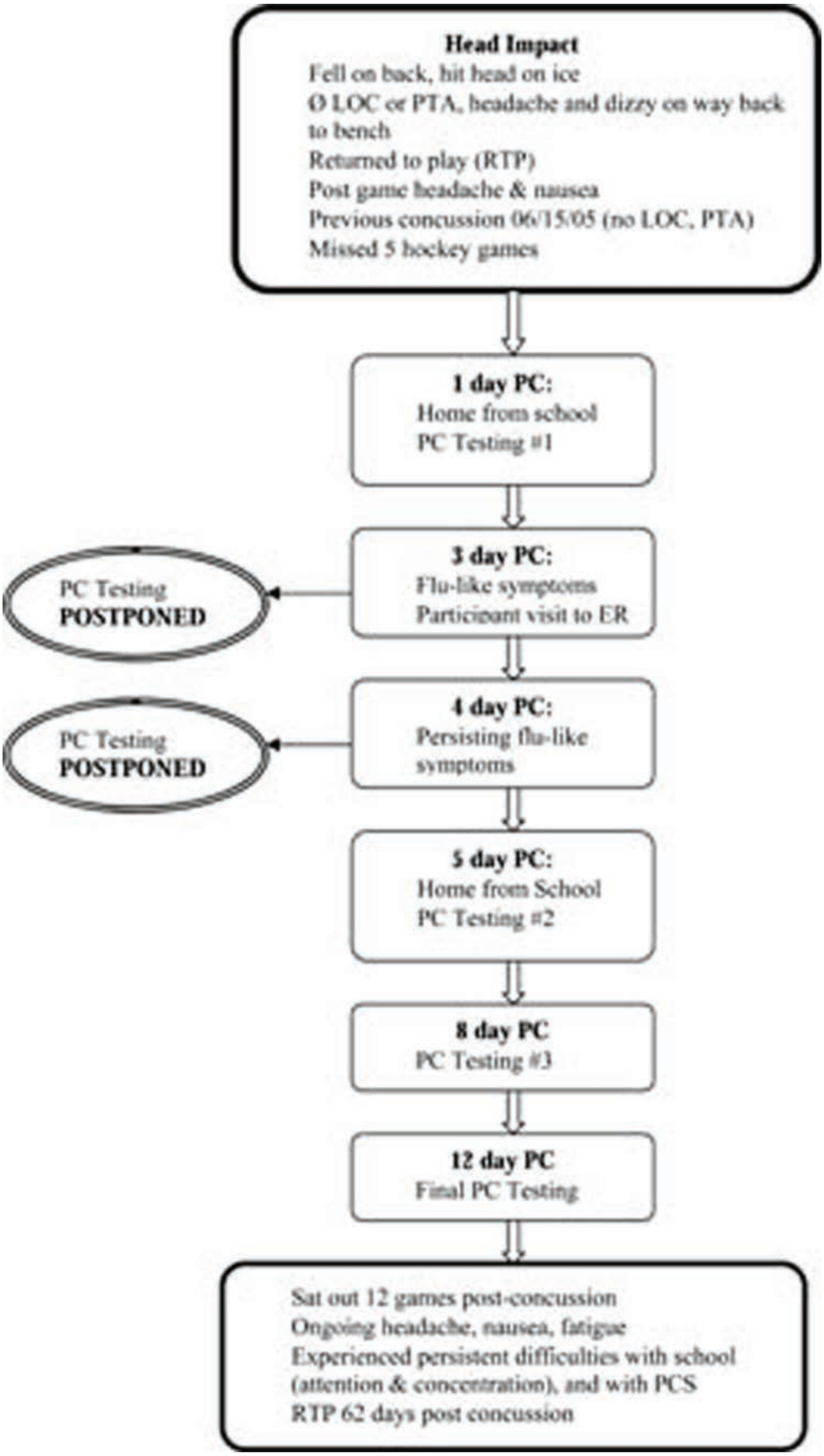

Figure 2 Post-injury sequelae and follow-up specific to case study 2. ER, emergency room; LOC, loss of consciousness; PC, post-concussion; PTA, post-traumatic amnesia; RTP, return-to-play.

Table 1 Case study 1: post-concussion symptoms and neurocognitive test scores

Test	Baseline	1 day	5 days	7 days	11 days	39 days
ImPACT (composite scores)						
Verbal memory*	0.84	0.72	0.79	0.92	0.81	1.00
Visual memory*	0.49	0.69	0.48	0.63	0.74	0.90
Reaction time†	0.52	0.92	1.01	0.71	0.63	0.51
Visual motor speed*	47.4	35.18	28.88	46.93	31.33	51.13
Impulsivity†	22	10	0	12	19	44
PCS‡	4	15	7	1	8	1
CPT II (T-score)						
Omissions	45.72	49.56	54.35	51.47	50.52	56.27
Commissions	64.80	48.99	48.99	59.05	63.36	61.92
Reaction time	29.21	61.81	69.24	37.00	33.89	36.52
Perseverations	48.29	51.74	48.29	67.22	75.82	74.10
ANT effects (time in ms)						
Alerting	43	15	68	38	68	−10
Orienting	−35	−6	−23	−28	−14	−18
Executive	115	16	11	88	79	74
Errors (total number)						
Congruent	1	0	5	6	5	6
Incongruent	20	0	2	25	25	39
Neutral	4	2	3	4	4	4
Total	25	2	10	35	34	49

*Higher score indicates better performance.
†Lower score indicates better performance.
‡Higher score indicates greater number of symptoms endorsed and/or higher intensity of symptoms; data presented in bold indicates significant change from baseline using a reliable change index calculation.
ANT, Attention Network Test; CPT-II, Conners' Continuous Performance Test II; ImPACT, Immediate Post-concussion Assessment and Cognitive Testing; PCS, post-concussion symptoms.

Table 2 Case study 2: post-concussion symptoms and neurocognitive test scores

Test	Baseline	1 day	5 days	8 days	12 days	34 days
ImPACT (composite scores)						
Verbal memory*	0.77	0.77	0.77	0.82	0.83	0.94
Visual memory*	0.83	0.67	0.59	0.68	0.67	0.91
Reaction time†	0.52	0.63	0.56	0.62	0.63	0.62
Visual motor speed*	35.00	33.35	33.63	38.33	37.70	40.68
Impulsivity†	52	43	28	41	35	29
PCS‡	5	24	31	21	19	21
CPT II (T-score)						
Omissions	48.05	48.60	49.56	44.76	58.15	48.60
Commissions	61.10	74.86	73.42	69.11	71.82	77.74
Reaction time	23.27	23.33	29.92	28.18	32.03	30.45
Perseverations	47.22	87.87	60.34	56.90	108.52	68.94
ANT effects (time in ms)						
Alerting	24	42	52	35	63	18
Orienting	10	3	−8	42	33	10
Executive	154	118	112	105	79	76
errors (total number)						
Congruent	3	1	2	2	10	1
Incongruent	42	19	23	32	38	23
Neutral	8	5	0	3	3	5
Total	53	25	25	37	51	29

*Higher score indicates better performance.
†Lower score indicates better performance.
‡Higher score indicates greater number of symptoms endorsed and/or higher intensity of symptoms; data presented in bold indicates significant change from baseline using a reliable change index calculation.
ANT, Attention Network Test; CPT-II, Conners' Continuous Performance Test II; ImPACT, Immediate Post-concussion Assessment and Cognitive Testing; PCS, post-concussion symptoms.

baseline functioning by mid-season testing. Neither the composite scores for verbal memory, visual motor speed or impulse control showed a significant change post-concussion. On the CPT-II, case study 2 demonstrated variability in attention compared to baseline with a significantly higher level of inattention and perseverations post-concussion. Both measures returned to baseline by mid-season testing. Levels of impulsivity (ie, responding to non-targets) and hit RT did not show significant change from baseline across any of the follow-up or mid-season testing sessions. On the ANT, case study 2 demonstrated an increase in alerting function post-concussion as well as a slight decline in the orienting function, both of which resolved by mid-season testing. In addition, there was a consistent decline in executive function immediately post-concussion. The decline continued through to 34 days post-concussion and did not resolve to baseline levels within that time frame.

DISCUSSION

The results of these two case studies highlight the effects of sports-related concussion in girls compared to pre-injury baseline functioning and suggest that neurocognitive changes are seen following even a single injury. Furthermore, these changes may persist following the resolution of post-concussion symptoms suggesting a need for thorough neuropsychological evaluation and follow-up in youths who have sustained a concussion or mTBI. For example, case study 1 experienced a resolution of symptoms by 5 days post-concussion, but still demonstrated significantly reduced visual motor reaction time at 11 days post-concussion. Case study 2's data also illustrates that recovery does not necessarily follow a linear model, as she experienced fluctuation in performance on attention measures across testing sessions, where she initially demonstrated an absence of symptoms, followed by fluctuating improved and decreased performance. This variability in performance may have been the result of her activity level during the day of each testing session as too much activity following mTBI can result in a delayed onset of symptoms—one reason why a gradual return to activity is recommended postconcusssion.[8] A resolution of symptoms is interpreted as a return to baseline levels. This does not necessarily reflect a complete absence of these symptoms. A rating of 4 or 5 during baseline testing may reflect endorsement of some of the symptoms, which can occur unrelated to a concussion. For example, perhaps the patient had a headache that day or was tired from a vigorous hockey practice. In addition, there may be individual differences in the extent to which people endorse and report such symptoms, which is why a baseline rating is obtained for each individual. Cut-offs for classification of concussion severity are as follows: 0–21/126 = absence of (or minimal) symptoms; 22–41 = mild; 42–84 = moderate and 105–126 = severe.[11]

The results of this case series provide support for previous research suggesting that attention may be particularly vulnerable to the effects of mTBI in youths,[8] as both girls demonstrated difficulties with attention that did not resolve by mid-season testing 39 days later for case study 1 and 34 days later for case study 2. Case study 1 demonstrated significantly higher inattention at the mid-season testing session, while case study 2's performance on the ANT revealed poorer executive function of attention. The results also highlight the variability of effects of mTBI on neurocognitive function. For example, case study 1 demonstrated difficulty with verbal memory, while case study 2 showed preserved verbal memory function but demonstrated significantly poorer visual memory ability post-injury. On the ANT, the pattern of results for alerting and orienting also varied according to the individual. While both case study 1 and case study 2 showed altered executive function post-concussion, the recovery was variable and may have been influenced by previous injury for case study 2 who still demonstrated poorer performance compared to pre-injury baseline function at the mid-season testing session. These findings further support the need for thorough neuropsychological examination following mTBI in youths in order to fully capture the effects of the injury on brain function.

We previously described a case study of a boy (14 years of age)[12] who sustained two concussions within a 24 h period. The data from the current case studies is similar to those findings with elevated post-concussion and neurocognitive symptoms in the boy following injury and a protracted recovery curve, possibly related to the occurrence of multiple injuries and a premature return-to-activity prior to full symptom resolution. Similar to the boy, both girls in the current study exhibited variability in attention that did not return to pre-injury baseline functioning even at a mid=season baseline testing session.

Neither case study 1 nor case study 2 received any neuroimaging follow-up as a result of their concussion (ie, CT scan or MRI). As indicated in the recent Consensus Statement on Concussion in Sport,[8] conventional structural neuroimaging is typically normal in concussive injury. As such, the consensus statements make the following suggestions: 'Brain CT (or, where available, MR brain scan) contributes little to concussion evaluation but should be employed whenever suspicion of an intracerebral structural lesion exists. Examples of such situations may include prolonged disturbance of conscious state, focal neurological deficit or worsening symptoms'.[8]

These case studies represent an important first step towards examining recovery from mTBI in youth. There is little data available regarding recovery from mTBI specific to children and youths with an even greater gap pertaining to gender influences during this critical stage of development. The results suggest that children and youths require greater caution when returning to play following injury, especially if there has been more than one injury, and that thorough and ongoing neurocognitive assessments may be required in order to fully uncover the effects of injury as well as determine recovery, given that some neurocognitive effects are still observed once post-concussion symptoms have resolved even after a single injury.

Learning points

- Results suggest that children and youths require greater caution when returning to play post-injury.
- Thorough and ongoing neurocognitive evaluation is required in order to fully illustrate the effects of the injury and determine recovery.
- Neurocognitive effects of the injury may be observed even once post-concussion symptoms have resolved.
- More large-scale research is needed to better understand recovery from mTBI in children and youths and to provide evidence-based guidelines for clinical management and return-to-activity.

Competing interests None.

Patient consent Obtained.

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