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Cognitive and physical symptoms of concussive injury in children: a detailed longitudinal recovery study

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ABSTRACT

Background Recovery from concussion sustained in childhood and adolescence is poorly understood. We explored patterns of recovery for neurocognition and postconcussive symptoms following concussion in children and adolescents.

Methods Using a prospective, longitudinal design, we collected baseline data on 728 children and adolescents aged 10–17 years. 10 participants sustained a concussive injury (n=10) in the 12 months following baseline testing and they were reviewed at day 5, 10 and 30 postconcussion. Assessments included the CogSport for Kids computerised test battery to evaluate neurocognitive function and self-report, and parent measures of postconcussive symptoms. At day 30, parents also completed measures rating their child's quality of life and executive functions.

Results Children and adolescents displayed a gradual reduction in postconcussive symptoms over the 30 days following injury. At day 5, 87% of participants were reporting physical and cognitive symptoms, with a generalised reduction in all symptoms by day 10 (40% of participants). On the computerised measure, reaction time was slower after concussion, but returned to baseline levels by day 30. At day 30, 10% of participants demonstrated ongoing postconcussive symptoms. Number of previous concussions was related to speed of symptom resolution.

Conclusions At 5 days postconcussion, the majority of children and adolescents experienced debilitating postconcussive symptoms. However, by 30 days postinjury, 90% demonstrated recovery to normal for both neurocognition and postconcussive symptoms.

INTRODUCTION

Mild traumatic brain injuries (TBIs), including *concussive injuries*, comprise approximately 90% of all child and adolescent TBI.[1 2] Immediately following a concussive injury, transient postconcussive symptoms, including headache, dizziness, nausea, excessive fatigue and impairment in attention and processing speed, are common.[3 4] In adults, these symptoms generally resolve within 7–10 days.[4–7] In children and adolescents, postconcussive symptoms are likely to impede skills critical for performing common day-to-day activities, with some young people developing deficits resulting in an inability to participate effectively in academic and social activities.[8] In children and adolescents, postconcussive symptoms affect between 6% and 35% of young people until 3 months postconcussion,[3 9 10] reducing to 1% by 1 year.[9] Children and adolescents with concussion may have a protracted recovery.[9–14] In concussed children and adolescents (0–18 years) at 3 months postinjury, 11% of participants were symptomatic compared with 0.5% of controls.[9]

It appears that cognitive symptoms resolve at a slower rate than physical symptoms with problems in attention, processing speed and executive skills present up to 3 months postinjury.[15–18] These data fit with the immature status of the young brain, and differences in its physiological response to mechanical stress.[19] Many studies have used pen and paper neurobehavioural measures,[20 21] which are not designed for serial use or to detect reliable changes in performance.[22] Behavioural and somatic symptoms (eg, headache) have also been examined, via rating scales, with recovery overall similar to that reported on direct cognitive assessment.[9 17 21] While recent studies have attempted to identify clinical predictors of persisting postconcussive symptoms,[15 17 18 21 23–27] findings are inconsistent, likely reflecting the differences in definitions of concussion, and what constitutes persisting symptoms, heterogeneous and insensitive outcome measures, and variations in time points used for follow-up.

To date, research has emphasised group-level findings with little focus on early stages of recovery postinjury, and no study has explored postconcussion function in relation to preinjury levels. As a result, we have little information regarding acute recovery trajectories, or when management decisions must be made (eg, return to school). The aim of this study was to explore recovery from postconcussion symptoms and neurocognition from preinjury baseline assessment to 30 days postinjury using computerised testing and rating scales at three time points.

METHOD

Design

In this prospective, longitudinal study conducted across the state of Victoria, Australia, we initially recruited and assessed a large sample of healthy children and adolescents.[28] Participants sustaining a concussion within 12 months of their baseline assessment were followed at 5, 10 and 30 days postinjury.

Participants

Baseline assessments

Participants were recruited and evaluated between 2008 and 2012 to participate in a statewide study.

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The total sample comprised 728 children and adolescents (64% male, 10–17 years), attending mainstream school. Participants were identified via local schools or sporting groups, and provided with study details. For consenting participants, the parent/caregiver completed an eligibility screen. Exclusion criteria were: history of concussion within the previous 12 months, pre-existing medical, neurological or psychiatric condition. Eligible participants were assessed in their school or sports club. Subsequent to baseline assessment, schools and families were asked to contact the research coordinator in the event that their child had a concussive injury within 12 months of their baseline evaluation.

Postconcussion follow-up

In total, 10 young people (7 males, mean age 14.6 years) sustained a concussion within 12 months of their baseline assessment. Concussion was defined as a blunt injury to the head associated with an altered mental state or any of the following symptoms: headache, dizziness, fatigue, drowsiness, nausea/vomiting, and balance, memory or concentration problems.[29] The inclusion criteria for the concussion follow-up study were: (1) concussion diagnosed by a medical practitioner within 24 h of injury; and (2) contact with the research team prior to day 5 postconcussion. None of the 10 participants who sustained a concussion had returned to school or play by day 5 postinjury.

Measures

Outcome measures

For all 728 children participating in the prospective study, the primary outcome measure was *CogSport for Kids* (*CogSport*).[30] *CogSport* was administered twice at baseline (to eliminate practice effects). For participants sustaining a concussion, *CogSport* was also completed at 5, 10 and 30 days postinjury. *CogSport* comprises a postconcussion symptom checklist (PCSC) and six computerised tasks, assessing speed of processing, attention and working memory.[18 25] See table 1 for details. Test–retest reliability (1 h and 1 week: 0.69 and 0.90, respectively) and construct validity (0.50 –0.86) have been documented.[30]

The *CogSport PCSC* comprises 24 items describing common symptoms following concussion and divided into five symptom clusters. Participants rated presence and severity of postconcussive symptoms at each time point (day 5, 10 and 30), using a six-point scale: 0=not a problem to 6=severe problems.

1. *Arousal symptoms (n=4)*: dinged/dazed, confused, slowed down, not feeling right.
2. *Somatic symptoms (n=9)*: headache, balance/dizziness problems, nausea/vomiting, light or sound sensitivity, vision or hearing problems (ringing in ears), neck pressure or pain.
3. *Cognitive symptoms (n=4)*: in a fog, difficulty concentrating or remembering, cognitive fatigue.
4. *Emotional symptoms (n=4)*: emotional, irritable, sad, nervous/anxious.
5. *Sleep dysregulation (n=3)*: drowsiness, insomnia, hypersomnia.

In keeping with previous research,[3] a total score ≥8 on the PCSC was considered to represent significant ongoing postconcussive symptoms.

Table 1 Description of CogSport for Kids (CogSport)[34] assessment tasks used in the present study

Task name (abbreviation)	Cognition assessed
Detection	Processing speed
Identification	Decision-making
Matching	Simple attention
Monitoring	Divided attention
One card back	Working memory
One card learning	Learning/memory

CogSport was presented on a laptop computer fitted with headphones. All tasks were in the form of card games and participants were required to respond by pressing predetermined keys representing 'Yes' or 'No' on the laptop (figure 1). Written instructions were presented to the left of the screen to indicate the rule for each task. To start each task, the participant pressed the 'Yes' key. Once the participant had successfully completed a practice trial and demonstrated their awareness of the task rules, the task began. For each task, 30 correct responses were required before proceeding to the next task. Brief descriptions of each task are provided below.

Detection: simple reaction time/processing speed

A card is presented face down at the centre of the computer screen. The participant is instructed to 'Press YES' as soon as a card turns face up. After a randomised delay, the next card flips face up, and the participant must press the 'Yes' key as quickly as possible. This task provides simple reaction time baseline data for the remaining four tasks.

Identification: simple decision-making

A card is presented face down at the centre of the computer screen. When the card turns face up, the participant is asked: 'Is the face up card red?' and responds by pressing 'Yes'. After a randomised delay, the next card flips face up, and the participant must respond 'Yes' (red card) or 'No' (black card) (see figure 1A).

Matching: simple attention

Two cards are presented face up on the screen. The participant is asked: 'Are the two face up cards the same color?' and responds 'Yes' or 'No'. The two cards go to the back of the pack and after a random delay, the next two cards are revealed. If both cards are the same colour (both black or both red), the participant presses 'Yes' (figure 1B).

One back: working memory

A card is presented face up at the centre of the computer screen. The participant is asked: 'Does the face up card exactly match the one before?' The card then goes to the back of the pack and after a random delay, the next card is revealed. If the card is identical to the card before it, the participant presses 'Yes' key, if not, 'No'.

One card learning: learning/memory

A card is presented face down at the centre of the computer screen. The participant is asked 'Have you seen this card before in this task?' After a randomised delay, the card flips face up. For each card, participants must decide whether they have seen that card before in the task and respond 'Yes' or 'No'.

Descriptive measures (day 30)

The *Behavioral Rating Inventory of Executive Function (BRIEF)*[31]*—parent and self-report (children ≥12 years):* assesses executive function in day-to-day environments. It consists of 86 items and provides an overall score, the Global Executive Composite (M=50, SD=10). Higher scores reflect greater

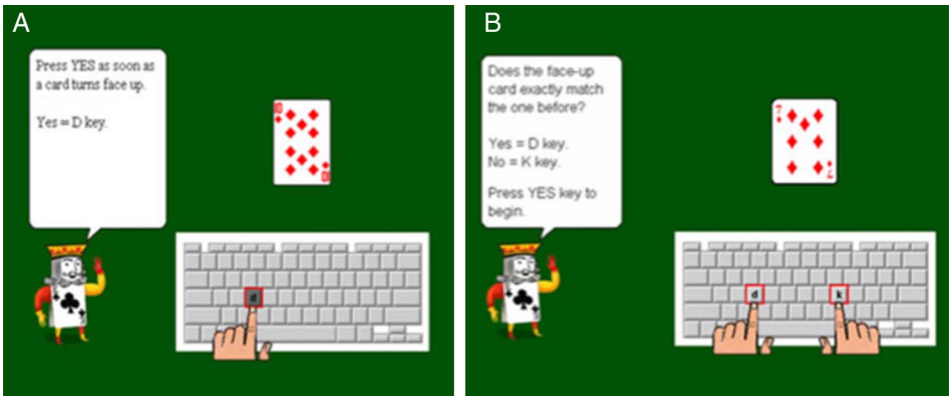

Figure 1 CogSport for Kids (CogSport)[34] screenshots for (A) Detection and (B) Matching subtests.

executive dysfunction, and scores >60 reflect significant executive dysfunction. Internal consistency is high, ranging from 0.80 to 0.98. Clinical validity has been supported with a variety of diagnostic groups.[25]

The *Child Health Questionnaire (CHQ)*[32] is a measure of functional health status and well-being. It has been validated with Australian children aged 5–18 years.[33] The CHQ was administered to determine any persisting health or psychosocial problems at 30 days postconcussion. Scores range from 0 to 100, with higher scores reflecting better quality of life. Behaviour Problems (M=81.70), Mental Health (M=80.13), Family Activities (M=76.35) and Family Cohesion (M=85.44) subscales are reported, with a five-point discrepancy from mean scores considered clinically significant, based on the data published by Waters *et al*[33] and Landgraf *et al*.[32]

Procedure

The study was approved by the Research Ethics Committees of the University of Melbourne and Victorian Government prior to participant recruitment. Participants were initially ascertained from their school, sporting club or organisation via a mail sent out to parents and caregivers. Families provided informed consent for the young person's enrolment in the study. Participants over 10 years of age provided verbal assent and written consent.

For children and adolescents meeting inclusion criteria, baseline assessments were conducted at the child's school or sports organisation. *CogSport* was administered twice at baseline, to control for practice effects,[22] with each administration taking between 15 and 20 min. Rest breaks of approximately 10 min were provided between assessments. Results from the second administration were employed as baseline data.

Families of participants sustaining a concussion contacted the research team, who recorded details of injury and arranged for postconcussion follow-up assessment, with the first on day 5 postinjury. Two further assessments were conducted on day 10 and 30.

Data analysis

Given the small sample size (n=10) results were treated descriptively.

The outcome variable for each computer task was speed of response, defined as mean response time (RT) in milliseconds. Responses faster than 100 ms (ie, anticipatory responses) were defined as anticipatory and were excluded from the analysis. Data from practice trials were discarded prior to formal statistical analyses.

In keeping with recommendations for analysis of *CogSport* data,[28 34] raw RT data were normalised using $\log_{10}$ transformation to eliminate positive skew. Individual reliable change indices were calculated for each score at day 5, 10 and 30. The reliable change index was calculated based on individual participant's score at each time point after concussion minus their score at baseline and this score was then divided by the SE of the test.

Repeated measures Student t tests were conducted to explore mean group differences between baseline and day 30 on

Table 2 Demographics and injury characteristics

	Injury age (years)	Gender	Injury cause	LOC	Previous concussion	Outcomes at day 30 postinjury					
						BRIEF:P	BRIEF:SR	CHQ:BEH	CHQ:MH	CHQ:FA	CHQ:FC
1	15	F	Basketball	N	N	38	32	95.8	100	91.7	85
2	15	M	Blow	N	N	*63*	57	75	*70*	75	*60*
3	15	M	Fall from chair	N	1	57	46	91.7	*70*	95.8	85
4	13	M	Football	Y	N	37	–	91.7	85	100	100
5	14	M	Cricket	N	N	39	52	91.7	95	100	85
6	17	M	Hockey	N	N	*71*	50	*68.3*	80	75	*60*
7	16	M	Football	N	N	50	57	85	90	91.7	85
8	16	F	Blow	Y	N	42	46	90	*75*	91.7	*60*
9	11*	M	Football	N	1	60	–	–	–	–	–
10	14**	F	Fall from bike	N	2	58	*65*	–	–	–	–

*No self-report data available for case 9 who was less than 12 years of age. Italics show clinically significant scores.
**, did not return to normal function on BRIEF SR at 30 days post-injury.
BEH: behavior; BRIEF,[31] Behavior Rating Inventory of Executive Function (lower scores=better function, scores >60 reflect clinically significant impairment); BRIEF P, behaviour rating inventory of executive function parent; BRIEF SR: behaviour rating inventory of executive function self report; CHQ[32], Child Health Questionnaire; F, female; FA, Family Activities; FC, Family Cohesion (higher scores=better function, scores greater than 5 points below subscale imply clinically significant impairment); LOC: loss of consciousness; M, male; MH, Mental Health; N, no; Y, yes.

CogSport subtests, with the ability to detect an effect size of Cohen's d=1, with 80% power and $\alpha<0.05$.

RESULTS

Demographics and injury details

Table 2 lists the demographic and injury details of the 10 participants who sustained a concussion (7 males, mean age 14.6 years). Six participants sustained injury while participating in contact sports, while four injuries were due to falls or blows. Two participants (cases 4 and 8) experienced a brief loss of consciousness, and none demonstrated abnormal neurological signs. Two participants (cases 3 and 9) had sustained one previous concussion and case 10 had sustained two prior concussions, all at least 12 months prior to baseline assessment.

Results from standardised questionnaires completed on day 30 postinjury are present in table 2. For the BRIEF self-report, (n=8), with the exception of case 10, participants rated their everyday executive function as normal 30 days postinjury.

For parent ratings (n=9), cases 2 and 6 were reported to exhibit clinically significant levels of executive dysfunction (ie, BRIEF >60), with case 9's borderline score indicating a risk of executive deficits. The remaining participants (676.7%) were reported by their parents to have normal everyday executive function by day 30.

Parents (n=8) also completed the CHQ at day 30 postconcussion, with 50% of parents reporting no abnormalities across any of the four CHQ domains. Ratings of Family Activities were uniformly normal; two parents rated their child as demonstrating postinjury Behaviour Problems (cases 2 and 6). Significant concerns were reported for three participants (37.5% of cases) for both Mental Health (cases 2, 3 and 8) and Family Cohesion (cases 2, 6 and 8).

In summary, for the majority of participants normal executive function (self-report=87.5%, parent report=66.7%) was reported at day 30. Intact quality of life at day 30 was documented for 50% of participants. Three participants (cases 2, 6 and 8), representing 30% of our sample, were rated as scoring within the clinical range on multiple executive function or quality of life indices. Of note, this percentage is significantly higher than expected from population data.[31 32]

Postconcussion symptoms

As illustrated in figure 2, the number of participants reporting postconcussion symptoms decreased with time postinjury, for all symptom clusters. The majority of participants (70–90%) reported experiencing postconcussion symptoms across symptom clusters on day 5 postinjury. By day 10, fewer young people identified ongoing symptoms (40–50%), and once again all symptom clusters were equally represented in participant ratings. At day 30 postinjury, somatic and/or arousal symptoms were maintained in seven participants from day 10, with less participants (10–20%) recording emotional-related, cognitive-related or mood-related symptoms. In all but one case, these symptoms were rated as mild in severity.

Combined ratings for number and severity of postconcussion symptoms indicated a reduction in symptom intensity with time postconcussion for cognitive, somatic and emotional symptoms. In particular, fewer concentration problems, headaches and balance problems were endorsed over time. In contrast, sleep problems were more intense at day 30 and arousal symptoms increased from day 5 to 10, but decreased by day 30 (figure 3).

CogSport

Repeated measures Student t tests explored mean differences in $\log_{10}$ reaction times from baseline to 30 days postinsult for the *Cogsport* subtests, with means and SDs displayed in table 3. Analyses of reaction time change shows a significant decrease in RT in the Matching subtest, with a $\log_{10}$ millisecond reaction time difference of 0.034 (95% CI 0.005 to 0.064, p=0.025). The remaining subtests showed no significant differences.

Figure 4 illustrates individual trajectories for concussed participants from baseline to day 30, using $\log_{10}$ transformed reaction time data. While the group mean trajectories are either flat or show gradual decreases in RT postinjury within 30 days, individual data highlight the heterogeneity of recovery profiles across participants, particularly up to day 10 postinjury, consistent with clinical experience. Individual differences appear greatest from baseline to day 10, with the majority of participants showing decreasing reaction times from day 5 to 10. Unexpectedly, some participants (20–30% across all tasks) record increases in RT (ie, poorer performances) from day 5 to 10.

DISCUSSION

In this study of recovery from postconcussion symptoms and of neurocognitive function over the 30 days following concussion in children and adolescents, we found that postconcussion, symptoms and performances on cognitive tasks were generally

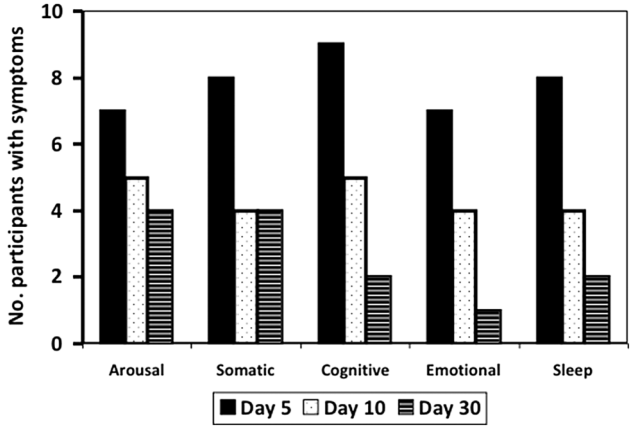

Figure 2 Number of children recording transient postconcussive symptoms.

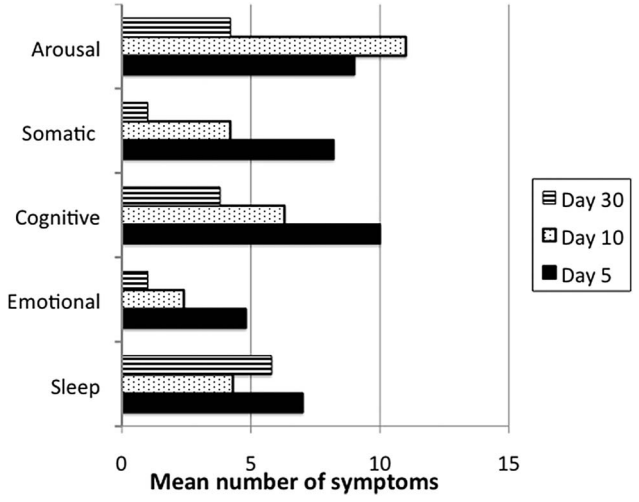

Figure 3 Mean number of transient postconcussive symptoms per participant at day 5, 10 and 30.

Table 3 CogSport[34] results: mean log_{10} RT (and SDs) from baseline to day 30 (n=10)

	Baseline M (SD)	Day 30 M (SD)	p Value
Detection	2.41 (0.07)	2.40 (0.06)	0.605
Identification	2.66 (0.09)	2.66 (0.06)	0.658
Matching	2.79 (0.09)	2.75 (0.07)	0.025
One card back	2.77 (0.08)	2.75 (0.07)	0.144
One card learning	2.88 (0.13)	2.86 (0.12)	0.671

CogSport, CogSport for Kids; RT, response time.

severely impaired postconcussion, with recovery over a 30-day period. Importantly, there was less clear recovery identified on cognitive measures.

Pattern of recovery of postconcussion symptoms

With respect to postconcussive symptoms, these gradually reduced over time. At day 5, the majority of participants reported persisting and generalised postconcussive symptoms, impacting all domains—arousal, cognitive, somatic, emotional and sleep. By day 10, when adult data suggest that most symptoms have resolved,[4–7] half of our participants continued to experience this pattern of generalised symptoms. Further, at day 30, 70% of our sample continued to endorse mild symptoms, particularly headache and fatigue, with only one participant (case 3) reporting global symptoms. On average, participants endorsed between 5 and 10 symptoms as moderate-to-severe across all postconcussion symptoms domains at day 5, suggesting significant functional impairment. As expected, by day 30, symptom intensity had reduced in all domains for all participants, again with the exception of case 3.

Recovery on cognitive measures

Recovery trajectories on cognitive measures provided a less clear picture, possibly reflecting inadequate sensitivity or reliability.[35] Group-based exploration provided little evidence of persisting cognitive problems at day 30 relative to preinjury baseline, with few significant differences across *CogSport* subtests from baseline to day 30. However, in keeping with clinical experience of variations in recovery, exploration of individual recovery trajectories highlighted variability, with a small proportion of our sample demonstrating deteriorations in performance from day 10 to 30, across both basic (eg, Identify) and more complex (eg, Matching and Card learning) tasks.

Questionnaires providing ratings of everyday function, including executive skills and quality of life, completed at 30 days—when recovery should have been largely complete based on adult models—generally failed to identify persisting impairments in our participants, with most results falling within the normal range. Of note, these measures did not specifically address domains recently identified as at risk following concussion (eg, anxiety, depression); these should be included in future research.

In our small sample, we found only a 10% rate (case 3 only) of clearly 'delayed recovery' 30 days postconcussion, which is less than that reported elsewhere in the literature.[18] Case 3, with a history of concussive injury, functioned within age expectations at baseline,[28] but demonstrated persisting and functionally significant postconcussive symptoms at all time points postinjury, with no signs of resolution even at day 30. While ratings of executive function and quality of life were unremarkable, examination of his *CogSport* performances indicated deteriorating processing speed from day 5 to 30, and significant mental health difficulties. Further exploration of the impact of previous concussion on outcomes (cases 9 and 10), indicated one child (case 9) showed full recovery of cognitive function,

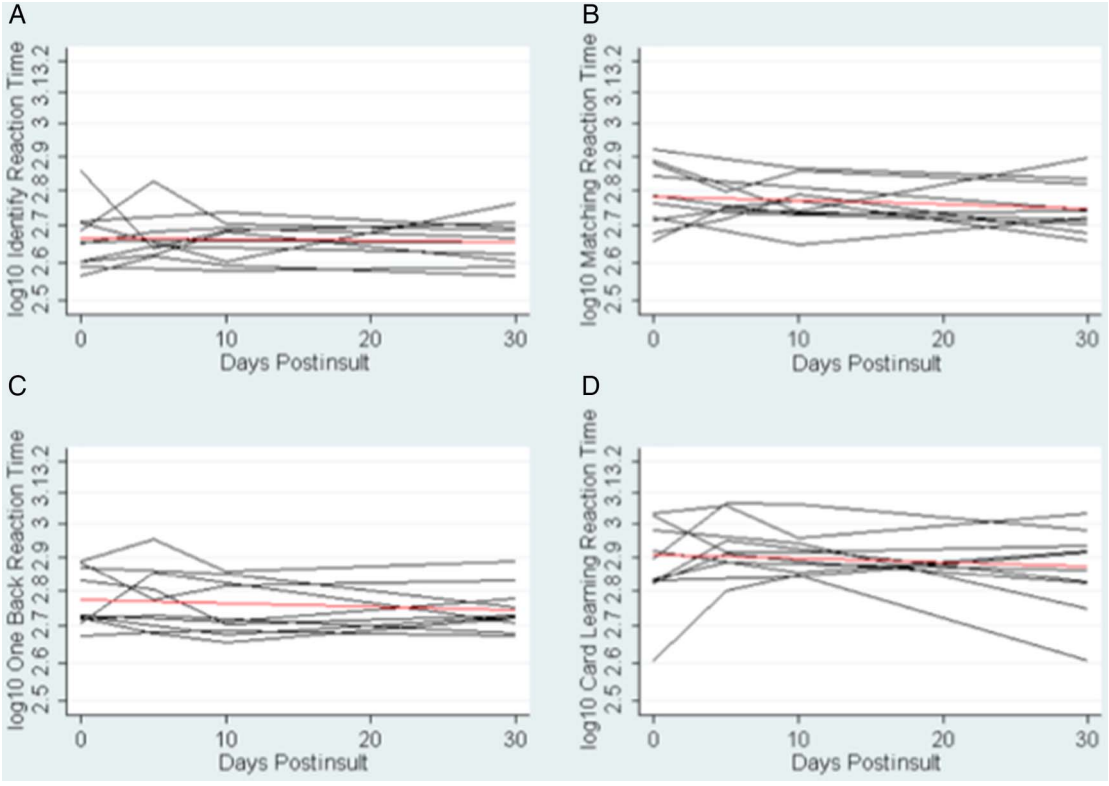

Figure 4 Raw log_{10} reaction times for (A) Detection; (B) Identification; (C) Matching; (D) One back and (E) One card learning.

and complete resolution of postconcussion symptoms by day 30. In contrast, case 10 showed slower overall recovery than the other participants; she demonstrated ongoing deficits on *CogSport* on day 30, relative to baseline, particularly on subtests tapping new learning and working memory. She also reported clinically significant executive deficits and slow resolution of postconcussion symptoms, with ongoing headaches reported up to day 30. Whether these symptoms are solely due to concussion history, or reflect preinjury status is unclear.

Clinical implication, limitations, strengths

When considering these results, the small sample size must be taken into account. Further, our age range was restricted to children 11 years and older, and thus we cannot comment on recovery duration for younger children. Future research, including assessment at presentation—particularly focusing on functional status and biomarkers—is important to further understand child outcomes.

Taken together, these results have important implications. While children and adolescents may experience protracted recovery, the majority of those followed in this case series showed resolution by 30 days postinjury. Findings also caution reliance on group-based cognitive data to inform clinical management. Even with access to preinjury baseline data, considerable variation in recovery trajectories is evident, and future research is needed to determine whether there are acute clinical factors that may assist in identifying the nature of postconcussion recovery at the individual level. Our results show the need to consider multiple dimensions, including both neurocognitive status and functional symptoms when managing young people postconcussion.

What are the findings?

- Our unselected cases indicated that by day 30 postconcussion, children and adolescents had recovered to preinjury levels of function.
- Postconcussive symptoms are global and functionally significant up to day 10, postinjury.
- Commonly used computer-based measures of neurocognitive outcome may not be sensitive to neurocognitive recovery.

How might it impact on clinical practice in the future?

- Identification of persisting symptoms till at least day 10 postconcussion will inform clinicians regarding timing of return to school and play.
- The management of children postconcussion should assess cognition and physical symptoms.

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Competing interests AC was employed by CogSport until 2006.

Patient consent Obtained.

Ethics approval Research Ethics Committees of the University of Melbourne and Victorian Government.

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REFERENCES

1 Crowe L, Babl F, Anderson V, *et al*. The epidemiology of paediatric head injuries: data from a referral centre in Victoria, Australia. *J Paediatr Child Health* 2009;45:346–50.
2 Langlois J, Rutland-Brown W, Thamas KE. *TBI in the US: emergency dept visits, hospitalizations, and deaths*. Atlanta GA: Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, 2006.
3 Zemek R, Farion K, Sampson M, *et al*. Prognosticators of persistent symptoms following pediatric concussion. *JAMA Pediatr* 2013;167:259–65.
4 Carney N, Ghajar J, Jagoda A, *et al*. Concussion guidelines Step 1: systematic review of prevalent indicators. *Neurosurg* 2014;75:S3–15.
5 Broglio SP, Puetz TW. The effect of sports concussion on neurocognitive function, self-report symptoms and postural control—a meta-analysis. *Sports Med* 2008;38:53–67.
6 Guskiewicz KK, Ross SE, Marshall SW. Postural stability and neuropsychological deficits after concussion in collegiate athletes. *J Athletic Train* 2001;36:263–73.
7 Iverson GL, Brooks BL, Collins MW, *et al*. Tracking neuropsychological recovery following concussion in sport. *Brain Inj* 2006;20:245–52.
8 Davis G, Purcell P. The evaluation and management of acute concussion differs in young children. *Br J Sports Med* 2014;48:98–101.
9 Barlow K, Crawford S, Stevenson A, *et al*. Epidemiology of postconcussional syndrome in pediatric mild traumatic brain injury. *Pediatrics* 2010;126:e374–81.
10 Babcock L, Byczowski T, Wade S, *et al*. Predicting postconcussional syndrome after mild traumatic brain injury in children and adolescents who present to the emergency department. *JAMA Pediatr* 2013;167:156–61.
11 Blume H, Hawash K. Subacute concussion related symptoms and postconcussive syndrome in paediatrics. *Curr Opin Pediatr* 2012;24:724–30.
12 Field M, Collins MW, Lovell MR, *et al*. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *J Pediatr* 2003;142:546–53.
13 McCrory P, Collie A, Anderson V. Can we manage sport-related concussion in children the same as in adults? *Br J Sports Med* 2004;38:516–19.
14 Purcell L. What are the most appropriate return-to-play guidelines for concussed child athletes? *Br J Sports Med* 2009;43:i51–5.
15 Taylor HG, Wright M, Bangert B, *et al*. Post-concussive symptoms in children with mild traumatic brain injury. *Neuropsychol* 2010;24:148–59.
16 Yeates KO, Taylor HG, Rusin J, *et al*. Premorbid child and family functioning as predictors of post-concussive symptoms in children with mild traumatic brain injuries. *Int J Dev Neurosci* 2012;30:231–7.
17 Lovell M, Solomon G. Neurocognitive test performance and symptom reporting in cheerleaders with concussions. *J Pediatr* 2013;163:1192–5.
18 McCrea M, Guskiewicz K, Randolf C, *et al*. Incidence, clinical course, and predictors of prolonged recovery time following sports-related concussion in high school and college athletes. *J Int Neuropsychol Soc* 2013;19:22–33.
19 Mayer AR Ling JM, Yang Z. Diffusion abnormalities in pediatric mild traumatic brain injury. *J Neurosci* 2012;32:1761–9.
20 Gioia G, Schneider J, Vaughn C, *et al*. Which symptom assessments and approaches are uniquely appropriate for paediatric concussion? *Br J Sports Med* 2009;43:i13–22.
21 Yeates KO, Taylor HG, Rusin J, *et al*. Longitudinal trajectories of postconcussive symptoms in children with mild traumatic brain injuries and their relationship to acute clinical status. *Pediatrics* 2009;123:735–43.
22 Falleti M, Maruff P, Collie A, *et al*. Practice effects with repeated assessment of cognitive function using the CogState battery at 10 minutes, one week, and one month test-retest intervals. *J Clin Exp Neuropsychol* 2006;28:1095–112.
23 Castille L, Collins CL, McIlvain NM, *et al*. The epidemiology of new versus recurrent sports concussions among high school athletes, 2005–2010. *Br J Sports Med* 2012;46:603–10.
24 McKinlay A, Grace R, Horwood L, *et al*. Long-term behavioural outcomes of pre-school mild traumatic brain injury. *Child Care Health Dev* 2010;36:22–30.
25 Babikan T, Satz P, Zaucha K, *et al*. The UCLA longitudinal study of neurocognitive outcomes following mild pediatric traumatic brain injury. *J Int Neuropsychol Soc* 2011;17:886–95.
26 Ponsford J, Willmott C, Rothwell A, *et al*. Cognitive and behavioural outcome following mild traumatic brain injury in children. *J Head Trauma Rehabil* 1999;14:360–72.
27 McNally K, Bangert B, Dietrich A. Injury versus noninjury factors as predictors of postconcussive symptoms in children with mild traumatic brain injuries. *Neuropsychol* 2013;27:1–12.
28 Williams J, Crowe LM, Dooley J, *et al*. Developmental trajectory of information processing skills in children: computer-based assessment. *App Neuropsychol Child* 2014:1–9.

29 McCrory P, Meeuwisse WH, Aubry M, *et al*. Consensus statement on concussion in sport: the 4th international conference on concussion in sport held in Zurich, November 2012. *J Am Coll Surg* 2013;216:e55–71.
30 Collie A, Maruff P, Makdissi M, *et al*. CogSport: reliability and correlation with conventional cognitive tests used in postconcussion medical evaluations. *Clin J Sport Med* 2003;13:28–32.
31 Gioia GA, Isquith PK, Guy SC, *et al*. *Behavior rating inventory of executive function*. Odessa, FL: Psychological Assessment Resources, 2000.
32 Landgraf JM, Abetz L, Ware JE. *Child Health Questionnaire (CHQ): a user's manual*. Boston, MA: The Health Institute, New England Medical Centre, 1996.
33 Waters E, Salmon L, Wake M, *et al*. *Australian authorised adaptation of the child health questionnaire*. Melbourne, VIC: Centre for Community Child Health, 1999.
34 Anastasi A, Urbina S. *Psychological testing*. Upper Saddle River, NJ: Prentice Hall, 1997.
35 De Marco AP, Broshek DK. Computerized cognitive testing in the management of youth sport-related concussion. *J Child Neurol* 2014. Published online first Dec 4.

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