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Multimodal Evaluation and Management of Children with Concussion: Using our heads and available evidence

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Abstract

Significant attention has been focused on concussions in children but a dearth of research evidence exists supporting clinical evaluation and management. The primary objective of this review paper is to describe a multimodal, developmentally adapted, standardized concussion assessment and active rehabilitation approach for children as young as age five. We review our CDC-funded research program including the development of tools for post-concussion symptom assessment involving the child and parent, measurement of specific neurocognitive functions, and assessment of dynamic cognitive exertional effects. A clinical approach to active, individualized, moderated concussion rehabilitation management is presented, including a ten step guide to symptom management, with a specific focus on the school challenges faced by the recovering student. To better inform concussion practice across the developmental age spectrum, a significant need exists for further research evidence to refine our clinical assessment methods and develop effective treatment approaches.

Keywords

Concussion; Mild Traumatic Brain Injury; Children; Assessment; Rehabilitation

Management of concussion (or mild traumatic brain injury, mTBI) in a child presents a number of unique challenges. The recent report of the Institute of Medicine (IOM) on youth sports concussion stated that we are in significant need of research to better guide our understanding and clinical management of this injury and its risks in youth [1]. The risks and consequences of this brain injury must be defined better within the moving target of development. The ultimate goal in evaluating a concussion/ mTBI in a child is to detect and monitor adverse injury effects in meaningful ways given the age of the particular child in order to provide a workable framework for management in the child's everyday environment. We advocate for a multimodal, evidence-based evaluation and management model including structured symptom assessment from several reporters, performance-based neurocognitive and balance measures, and dynamic exertional effects. No individual tool, test or method can provide a complete understanding of a complex brain injury or the final

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answer regarding recovery[2], [3]. Instead, the skilled clinician must integrate multiple sources of data about the injury in the context of the child's developmental, medical, psychological and family/ school environment that tells the story and guides the clinical process. This paper presents an evidence-based multimodal model of evaluation and management for concussion in children with a special emphasis on management in a key environment for the injured child, the school setting.

Developmental Context of Concussion Evaluation and Management

The primary goal of the post-concussion evaluation is to define changes in a child's functioning compared with their pre-injury functioning. This information then informs the management strategy to facilitate recovery. While the fundamental domains of interest in clinical assessment of children with concussion parallel those of adults (i.e. post-concussion symptoms, specific neurocognitive functions, balance), there are important differences. Assessment with children must be framed within the context of differences in neural development, physical, cognitive, behavioural, and emotional maturation, and the influences of home, school and community supports and demands on the child. Like much of developmental neuropsychology, concussion evaluation in children is not a simple ‘downsizing’ or application of an adult assessment model to children, but instead employing a developmental approach to understanding the child in their everyday contexts.

Clinical work with children must be approached within the context of relevant and ongoing developmental processes and environmental influences and demands. For example, the developmental issues and environmental factors relevant to an injury to a 7-year-old who collides with another player in a soccer game are different from those of a 14-year-old skateboarder who falls backward onto concrete. Each of these youngsters is at a different stage of development with substantial differences in their cognitive capacities, emotional controls, capability and willingness to disclose the injury to adults, and academic, social and familial demands. Younger children may be more likely to express their injury overtly (e.g. crying), making the injury more recognizable, while at the same time their ability to self-identify and articulate an internal symptom state is more limited. Responding to the demands of school (e.g. homework that night) or social situations will be very different for these two different age groups. Understanding these developmental dynamics and environmental demands is central to evaluation and management of concussion in children and adolescents.

As the IOM report [1] and the evidence-based review of the American Academy of Neurology [2] indicate, while there is a reasonable body of research on concussion outcomes for adolescent football, there is a significant dearth of information for girls and pre-adolescent ages. Research of adolescents reports that the vast majority (80-90%) recover within two-three weeks [4],[5],[6]. There is some recent indication, however, that adolescents may take longer to recover from concussion than pre-adolescent children age 11-12. Furthermore, youth who have sustained a second concussion within one year may be at increased risk for a more prolonged recovery [7].

Research of general mTBI further helps to define the range of outcomes and factors. Post-concussion symptom outcomes in children and adolescents, age 8-15 years, with varying etiologies have been reported by [8]. Controlling for pre injury symptoms, parent ratings of somatic and cognitive symptoms were higher in children with mTBI than in children with minor orthopedic injuries. The somatic symptoms were found to resolve earlier than the cognitive symptoms, the latter of which persisted beyond 3 months, suggesting variability in patterns of symptom resolution. Child reports of symptoms were generally consistent with parent reports. The orthopedic group also reported elevated symptoms, illustrating that some of the symptom changes after concussion may reflect a more generalized response to injury than specific effects of brain insult. Also, importantly, post-concussion symptoms were found to be associated both with injury characteristics and non-injury factors. For example, higher levels of preinjury symptoms predicted higher scores on all corresponding measures of post-concussion symptoms.

This burgeoning literature begins to define the range of outcomes and underlying factors that may contribute to the variability in injury risk and recovery in children across the developmental age span. It also reinforces the need for additional research to guide evidence-based clinical practice with children and adolescents. Toward that end, this paper presents the work of the author's CDC-funded research to provide further guidance in the clinical evaluation and management of children and adolescents.

Ultimately, the practise of concussion assessment and management will benefit from an evidence-based medicine (EBM) approach [9], [10]. An EBM approach to evaluation of concussion provides clinicians with statistical bases for evaluating and describing scores relative to the standardization sample. In keeping with standards for EBM-based neuropsychology practise, the same scores are then evaluated in the context of base rates, or the frequency with which scores are seen in children with known concussions versus in non-injured children. Likelihood ratios, odds ratios and classification accuracy (‘hit’) rates aid in clinical decision making by indicating whether obtained scores are more like those seen in non-injured children or in children with known concussions. While the more traditional report of clinical assessment findings may lead to *descriptive* statements such as ‘Johnny's neurocognitive test performance reflects low average verbal memory’ or ‘Jenny's performance indicates high average processing speed,’ evaluating a child for the presence of concussion effects requires *categorical*‘yes/no’ clinical decision making. To aid in the EBM decision making process, classification statistics inform the ‘likelihood’ that score levels or patterns are statistically more likely to be found in children with known concussion effects or non-injured normative groups. For example, one would then report that ‘Johnny is a 6-year-old boy whose Post-Concussion Symptom Inventory score of 7 at 6 days post-injury indicates a high likelihood that his symptom level falls outside of normative expectations and is more like that of children with concussion effects (Odds Ratio = 4.7, Classification Accuracy = 88%).’ In arriving at a clinical decision regarding whether or not a child exhibits likely concussion effects, it is important to appreciate that no measurement tool should be used in isolation. A clinical diagnosis of concussion, or recovery, must be understood within a multidimensional context. Thus, the above statements must be contextualized to arrive at the proper diagnostic impression regarding Johnny's concussion status. Based on clinical assessment tools with appropriate evidence, the evaluation of concussion in the child substantially improves the clinician's ability to detect and quantify the presence versus absence of concussion effects.

Fundamental components of concussion evaluation in children

Concussion evaluation in a child requires the consideration of multimodal components within a developmental context, using multiple assessment methods and informants [11]. First, one must gather a solid definition of the injury characteristics (i.e. cause and mechanism of injury; presence of loss of consciousness, retrograde/ anterograde amnesia, and early signs) as well as a review of pre-morbid and post-injury risk factors. The Acute Concussion Evaluation (ACE; [12], [13]), as part of the CDC ‘Heads Up: Brain Injury in Your Practice’ toolkit [14], was developed to guide the clinician through a protocol for assessing these key elements of concussion.

Once the injury characteristics and history have been gathered, the clinician undertakes a thorough age-appropriate assessment of post-concussion symptoms, measurement of possible neurocognitive effects, and the assessment of cognitive and physical exertion effects. In the following sections, we describe these methods of clinical assessment in children, and our research evidence supporting their clinical utility (see Table 1). These methods of evaluation should consider the impact of the injury on key aspects of the child's life, i.e. school and social/recreational activity [15],[16].

Assessment of post-concussion symptoms

Thorough assessment of post-concussion symptoms is an essential, arguably foundational, component of the evaluation. While there are some widely used symptom assessment tools for adolescents and adults, few standardized tools exist to meet the needs of the pre-adolescent pediatric population [13], [17], [18]. The four symptom domains commonly described in concussion – physical, cognitive, emotional, and sleep-related – are relevant to children. They should be fully assessed and tracked from onset of injury to the time of evaluation in order to understand the severity of symptoms, rate of recovery, and impact of symptoms on the child's everyday functioning. Symptom assessment includes collecting standardized symptom ratings with the Post-Concussion Symptom Inventory (PCSI) with both child/ adolescent self-report and parent report forms [19], [11]. In addition, evaluating the severity of post-injury symptoms relative to pre-injury symptoms (e.g. fatigue, irritability) is important.

Valid evaluation of post-concussion symptoms by child or adolescent report requires developmentally-sensitive measures suited to the appropriate cognitive level, reading skill and vocabulary, and capacity to perceive their own symptoms accurately [20]. The reliability of symptom report in younger children may be lower than for older reporters due to a variety of factors, including a concrete cognitive style, limited sense of time, lack of familiarity with symptom terminology, an affirmative response style to please an inquiring adult, greater difficulties judging ‘grades’ of symptoms, and less developed social-emotional maturity [21], [22], [23]. Each of these factors must be considered when assessing symptoms in young children. Using developmentally appropriate language such as, ‘Does your head hurt?' instead of, 'Do you have a headache?'and avoiding abstract terms such as 'Do you feel foggy?' – a symptom which appears on many symptom scales developed for adults – is important. Items with complex vocabulary, that require perception of subtle internal states, and that ask about sleep behaviours may also not be appropriate.

Children have greater difficulty linking events to time, such as 'yesterday,''last week,' or 'before your injury.' They are less adept at accurately reporting the precise timing of when an event occurred. It is therefore important to focus symptom assessment on those more recently experienced by the child and not from a time point too distant from the evaluation date. Similarly, the commonly used 7-point graded scaling of symptoms is too complex for younger children [20], [24]. Instead, offering fewer choices, such as 2 or 3 point scale, is more appropriate to the younger child's developmental level. Finally, the use of a visual analog scale that makes numbered ratings more concrete such as that used in the Faces Pain Scale [25] can be very helpful in assessing younger children's symptoms [20].

Given the challenges in post-concussion symptom assessment via young children's reports, it is essential that parents serve as a complementary source of information [26]. Obtaining parent reports of a child's pre-injury and post-injury symptoms adds important information to the evaluation [11] and is now a recommended standard procedure in concussion assessment with children.

Description of Post-Concussion Symptom Inventory—To meet the need to assess symptom reports across the age range of children and adolescents, developmentally-sensitive symptom questionnaires, the Post-Concussion Symptom Inventory (PCSI), were developed. Psychometric analyses attending to children's ability to understand, and respond to, items [19] resulted in a 5-symptom PCSI for 5 to 7 year-old children (**PCSI-SR5**), a 17-item scale for 8 to 12 year-old children (**PCSI-SR8**), and a 20 item adolescent version for 13 to 18 year-olds (PCSI-SR13). A complementary 21-item PCSI parent version (PCSI-P) provides a complement to the children's symptom reports. The symptom scores on the PCSI Parent form may be compared to the child's PCSI symptom report to provide a more comprehensive understanding of the child's post-injury symptoms.

The two PCSI Child self-report scales (**PCSI-SR5, PCSI-SR8**) use a 3-point scale for 5-12 year olds, asking whether the symptom is present 'not at all,''a little,' or 'a lot.' The scales for 13-18 year-old adolescents (PCSI-SR13) and for parents (PCSI-P) use a more traditional 7-point dimensional scale. The parent report form is framed from the observers' perspective (e.g. 'Complains of headache' instead of 'Headache'), and includes four observable signs: Appears dazed or stunned, Becomes confused with directions or tasks, Appears to move in a clumsy manner, and Answers questions more slowly than usual. A *Total Symptom* score is generated for all PCSI forms while empirically-derived symptom domain scores for *Physical*, *Cognitive*, *Emotional*, and *Fatigue* symptoms are available for the PCSI-SR8 and PCSI-SR13 year-old self-report forms and for the PCSI-P parent report form.

Evidence: Sady et al. [19] examined the psychometric characteristics of the child and adolescent self-reports and the parent forms of the PCSI in a sample of 633 children with concussions and 1273 non-injured children aged 5-18 years old. The four PCSI forms demonstrated strong psychometric characteristics for use in evaluating concussion symptoms in children. Factor analyses identified physical, cognitive, emotional, and sleep factors in the parent, 8-12 and 13-18 versions. Internal consistency was strong for the total symptom score in both injured and non-injured groups (alpha range = .8 to .9). Two-week test-retest reliability for the child self-report forms was moderate to strong (ICC range = .65 to .89). Parent and self-report concordance was moderate (r = .44 to .65), underscoring the importance of both perspectives. For all ages, the parent report was an important accompaniment to symptom assessment. This was especially true for the youngest children. The PCSI-C for the 5 to 7 year-old children was less strong psychometrically than the older children and parent forms. The 5-symptom inventory for this group is provided as a guideline for what symptoms to query.

Classification analyses provided sensitivity and specificity of the PCSI, as well as Odds Ratios and classification accuracy statistics to examine clinical application of the PCSI forms. Specifically, the Odds Ratio (OR) balances the likelihood of accurately identifying children with concussion effects with the likelihood of misidentifying non-injured children (Positive likelihood ratio/ Negative likelihood ratio). For example, an OR= 4.7 indicates that it is almost 5 times more likely that a PCSI score would be seen in children with concussion effects than in children in the normative sample. Applying these statistics to the PCSI, Odds Ratios for identifying children with versus without concussions was OR=5.0 for child self-reports (8-12), OR=8.35 for adolescent self-reports, and OR=64 for parent reports of 8-12 year olds and OR=86.7 for 13-18 year olds. Combining the child and parent PCSI reports produced significant Odds Ratios for all age groups (Age 5-7 OR=43.8, 8-12 OR=63.0, 13-18 OR=134.1). The Odds Ratios indicate that elevated PCSI scores suggest a high likelihood (5-134× more likely) that a particular symptom elevation is more like that of children with concussion effects than like that of non-injured children. Specificity of the PCSI measures was generally good (range 0.79 to 1.0) and sensitivity was adequate (range 0.47 - 0.63).

Description of Retrospective Baseline PCSI. Ideally, child, adolescent and parent symptom ratings on the PCSI would be compared with 'true' pre-injury baseline symptom ratings on the same measure. More often than not, however, no 'true' baseline is available. We developed a retrospective baseline (RBL) PCSI assessment to put post-injury symptom ratings in perspective and facilitate interpretation of change in symptoms. The RBL PCSI is a parallel form to the PCSI but asks *'We would like to know if you have had any of these symptoms before your injury. Please rate the same symptoms before the injury'*. These retrospective baseline ratings provide some indication of the presence and severity of symptoms before the injury in order to place the post-injury symptom report in context. For example, if a child reports on the PCSI that they experience headache 'a lot' since their injury but also reports on the RBL PCSI that they experienced headaches 'a little' then this might modify interpretation of symptom severity. The clinical relevance of increases, or decreases, in symptoms must be evaluated in the context of the evaluation as a whole.

Evidence: To understand the psychometric characteristics of RBL PCSI ratings, reliability, validity and clinical utility of the child, adolescent and parent report forms were examined via ratings for 770 children with concussions (61% male; 51% white). Parent retrospective baseline ratings were internally consistent ($\alpha = .78$) as were ratings for 8 to 12 year-old ($\alpha = .80$) and 13 to 18 year old children ($\alpha = .82$). Internal consistency on the 5-item PCSI for younger 5 to 7 year-old child self-reports was lower ($\alpha = .64$), partly as an artifact of the limited item set. Temporal stability test-retest reliability) was high (ICC>.72) for all reporters in a subsample of children evaluated a second time within 30 days of their first visits (n=402). Parent report of pre-injury symptoms on the RBL PCSI was moderately correlated with 8 to 12 year-old child RBL reports ($r = .30$, $p < .001$) and with 13 to 18 adolescent reports ($r = .48$, $p < .001$), but not with 5 to 7 year-old child reports.

To further understand the clinical utility of the PCSI, profile analyses of the symptom subscales (Physical, Cognitive, Emotional, Sleep) revealed significant differences across raters between pre- and post-injury symptom patterns. The greatest increases from RBL reports to post-injury PCSI reports were found in the Sleep and Cognitive symptom domains, followed by smaller but significant increases in the Physical and Emotional symptom domains. The adequate psychometric properties of the RBL PCSI reports suggest evidence for their use as an alternative to ‘true’ baseline symptom reports.

The PCSI measures are included as supplementary measures in the NINDS Pediatric TBI Common Data Elements [27]. The administration and scoring details and can be downloaded from the National Institute of Neurological Disorders and Stroke (NINDS) Common Data Element (CDE) website (www.commondataelements.ninds.nih.gov).

Assessment of neurocognitive functions

There is a well-established tradition of evaluating neurocognitive functioning in adolescents and adults with concussion via both paper and pencil and computer-administered tools [28], [29], [30], [31], [32], [33]. Neurocognitive testing can provide an objective data set that is sensitive to the often subtle neurocognitive effects of concussion. Specific neurocognitive domains that have demonstrated sensitivity to concussion are: attention and concentration, working memory, processing speed, learning and memory, and executive functions [34], [35], [36]. Targeted measurement of these key neurocognitive domains is an important component of pediatric concussion evaluation [37], particularly when high risk decisions (e.g. returning to a collision sport) are pending. The student's profile of performance on neurocognitive measures can also be useful in guiding management of school demands.

Description of the Multimodal Assessment of Cognition & Symptoms (MACS) for Children—The same need for symptom questionnaires for children (i.e. the PCSI) also prompted CDC-funded development of the MACS for Children, a neurocognitive battery that can be easily administered, repeatable and sensitive to concussion effects in children [38]. We developed a series of six subtests that tap neurocognitive functions relevant for concussion assessment including episodic learning, memory, reaction time and processing speed. Each of the tasks is based on well-established neuropsychological assessment methods like those used for concussion assessment in adult-oriented measures (e.g. ImPACT, ANAM). Task instructions, stimuli, and subtest formats were designed to be appropriate for children aged 5 to 12 years. Children are given on-screen instructions with simple statements and vocabulary that may be read by an administrator as appropriate. Tasks are practised until the child demonstrates understanding of demands. Colorful pictures and simple designs rather than words or abstract designs are used as stimuli. Tasks are presented within game-like story themes to increase childrens' engagement. Five alternate forms of the battery (3 clinical, 2 research) were developed for serial assessment. Alternate forms retain task order and all parameters across forms; only equivalent stimuli are changed between forms.

The six MACS for Children neurocognitive subtests yield two Composite scores (Response Speed, Learning & Memory Accuracy) that were derived from factor analysis. Composite scores can be separated into component Subcomposite scores when there is greater-than-expected variability between specific cognitive processes. The Response Speed Composite is composed of two Subcomposites: (1) Learning/ Memory Speed, which includes response speed for the object learning subtest (Remember That Trip!) and the design learning task subtest (Beware of the Tricky Wizard!); and (2) Search/ Decision Speed, which captures response speed from non-memory subtests (Catch the Animals!, Catch the Bugs, The Pyramid's Code, Funny Fruits & Vegetables). The Learning & Memory Accuracy Composite is composed of two Subcomposite scores: (1) Learning Acquisition which captures accuracy for the learning trials of the object and design memory tasks (Remember That Trip!, Beware of the Tricky Wizard!), and; (2) Memory Storage, which summarizes accuracy for the delayed memory trials of the two memory tasks. Standard scores, percentiles, and 90% Confidence Interval (CI) values for Composite and Subcomposite scores are generated for the neurocognitive battery. Reliable change metrics using standardized regression-based (SRB) change scores are used to evaluate differences between subtest performances within a single administration and to evaluate change over time when comparing two or more administrations.

Evidence: Psychometric examination of the MACS for Children neurocognitive battery revealed substantial support for clinical use and interpretation, including high internal consistency for the Response Speed Composite (alpha = 0.96 to 0.98) and the Learning & Memory Accuracy Composite (alpha = 0.89 to 0.92) and strong temporal stability for the Response Speed Composite (ICC = 0.94 to 0.99) and moderate to strong test-retest correlations for the Learning & Memory Accuracy Composite (ICC = 0.77 to 0.84) over shorter and longer time periods, respectively. The three alternate clinical forms are statistically comparable, indicating that they may be used interchangeably without affecting reliability or validity. Reliable change score metrics using standardized regression-based (SRB) methods to control for multiple sources of error are provided within the neurocognitive battery to assist with interpretation of change within the battery (i.e. significant slowing of response speed over time, memory decay over time) and between administrations.

Multiple lines of evidence converge to facilitate valid interpretation of MACS for Children scores. The factor structures of scores on the neurocognitive tasks are stable across large samples of injured (concussed) and non-injured children and can be meaningfully interpreted, suggesting that the battery taps coherent constructs. The scores correlate in the expected direction with multiple measures of similar functions such as response speed [39], working memory, learning and memory. Strong developmental changes are seen across the age spectrum for all neurocognitive scores, indicating that the measures are sensitive to development. The findings of significant developmental change in these scores have relevance to baseline testing of children, suggesting the likely need to conduct testing on an annual basis.

Performance on the MACS for Children neurocognitive battery is best interpreted along with symptom reports on the PCSI. This reliable and valid set of measures can be used to aid clinical detection of characteristics consistent with those seen in children aged 5 to 12 years with documented concussions, and to assist in tracking recovery over time. Classification analyses suggest that the combination of PCSI symptom reports and neurocognitive battery performance in the context of history and observations can increase the diagnostic accuracy by detecting post-concussion effects in children who are referred because a concussion is suspected. Clinically, elevated symptom reports and less-than-expected performance on any of the neurocognitive tasks should alert the clinician to the likelihood that a child with a suspected concussion is experiencing concussion effects.

Assessment of cognitive exertion effects

An additional step in the multimodal post-injury evaluation involves assessing cognitive exertion effects. Cognitive exertion effects are defined as a significant increase in post-concussion symptoms in response to vigorous cognitive activity or effort. Such effects are viewed as a signal of post-injury dysfunction in handling cognitive demands. A substantial proportion of children with concussions exhibit clinically meaningful symptom exacerbation following cognitive activity compared with non-injured children [40]. Standardized assessment of cognitive exertion effects serves as an additional indicator of ongoing injury symptoms.

Description of the Exertion Effects Rating Scale (EERS)—The EERS was developed to assess cognitive exertion effects during the evaluation session. Children rate four primary symptoms (current level of headache, fatigue, concentration problems, and irritability, using a 0-10 point rating scale with associated representative faces) just prior to beginning the neurocognitive battery and then again at the end of the battery. A total cognitive exertion score, the *Exertion Effects Index (EEI)*, is generated by subtracting the total pre-test sum of ratings from the total post-test sum. A positive difference in scores (i.e. EEI > 0) reflects an increase in rated symptoms over the course of testing in response to cognitive exertion. A negative difference in scores (i.e. EEI < 0) reflects a decrease in rating of the symptoms, and a no difference (i.e. 0) reflects no reported change in symptoms.

Evidence: Base rates of cognitive exertion effects in typically developing children on the EEI were established in a non-injured sample of 382 children aged 5 to 18 years [41]. The same number of children with recent concussions (mean days since injury 14.8) served as the clinical comparison group. Reliable Change Index (RCI) and Standardized Regression Based (SRB) methods were used to develop cutoffs for unusual increases in symptoms as an index of post-concussion cognitive exertion effects. Children without concussions generally did not report any cognitive exertion effects. In contrast, almost one-third of children and adolescents who were two weeks post-injury reported an increase in exertion effects. These findings provide evidence that symptom worsening with cognitive activity is an effect of mTBI. Using the 4-symptom, 0-10 point rating scale, a total EEI increase of 4 or more points can be considered a significant increase.

Summary of concussion assessment

Evaluating concussion effects in children is the first step toward appropriate management of symptoms, cognitive impairment, and toward planning return to normal everyday activities such as school, sports and play. Thorough assessment requires a developmentally-sensitive approach suited to the needs of the child, including a developmentally-appropriate set of tools that capture key factors relevant to injury manifestation in children. Important steps include an understanding of typical child development and the developmental level of the injured child, assessment of injury characteristics, review of pre-injury and post-injury risk factors, and the use of developmentally appropriate symptom, neurocognitive, and exertional effects measures. We describe a developmentally appropriate, multi-modal, standardized concussion assessment battery including psychometric evidence for use of the multiple integrated tools with children from 5 to 12 years of age. The multimodal battery is comprised of current and retrospective symptom rating inventories for child self-report and parent report, performance-based neurocognitive tasks, and a quantifiable index of cognitive exertion that, independently and together, are sensitive to changes in children who sustain concussion.

It cannot be overstated that a comprehensive understanding of concussion diagnosis, injury manifestation, and recovery course is multi-factorial. The data gathered from the concussion evaluation as a whole must be understood within the context of the child's pre-injury history, injury characteristics, and presentation during assessment. Multiple sources of data should be integrated into the final clinical formulation including reports of symptoms and functioning from the child and parent, comparison to baseline or pre-injury symptoms and functioning, and the presence of cognitive exertion effects observed or reported during testing. With complex neurobehavioural disorders such as concussion, there is no single score or ‘signature’ profile of symptom ratings and/or performance on any given measurement instrument that is of sufficient sensitivity and specificity to enable it to be used on its own to establish a diagnosis [42], [43], [44], [45]. Instead, clinical diagnosis results from a process of integrating relevant patient history, direct observations of behaviour and performance, and test findings.

Concussion management of the child: Focus on return to school

One of the greatest challenges in managing concussion in children and adolescents is planning for return to school. The child's ‘job’ is to go to school to learn academically and engage with peers socially. The process of returning to school following concussion is gaining greater attention in clinical practice [15], as reflected in the focus of the CDC's ‘Heads Up to Schools: Know Your Concussion ABC's’ [46]. The American Academy of Pediatrics recently issued a clinical report delineating the process of returning to school following a concussion [47]. Despite this growing attention, there is scant evidence-based literature for the return to school process. Relatedly, there is equally little research on effective treatment methods to assist concussion recovery in children and adolescents [2].

The connection between concussion and effects on learning, and thus managing the student's return to school, is in the very beginning stage of development. To give some guidance, we provide a clinical-rational approach to assist clinicians in managing the return to school, recognizing that research evidence is needed to better guide treatment. Effective management entails adequately prepared school and medical systems, a clear understanding of the clinical targets for intervention, and a systematic approach to engaging the child and family in an individualized, moderated, active rehabilitation management programme. We describe such an approach below.

Systems focus

Effective concussion management in the schools starts with a prepared system. There is wide variability in preparation of both schools and medical providers to properly support students with a concussion as they return to school. Schools vary widely in their understanding of concussion including a limited awareness of how concussions present in the academic setting as well as the types and duration of academic accommodations needed to support recovery. Currently, awareness appears to be greater at the high school level relative to middle and elementary schools. There also is variability in preparation of medical providers to communicate and translate their clinical findings into meaningful, individualized recommendations for school supports and accommodations. Most schools do not have a coordinated team with defined roles for supporting the returning student from outset of the injury to recovery. Although the CDC school toolkit materials have been available for the past three years to assist with these issues, they are not yet consistently used in schools. With greater awareness, however, the trend for providing support for the student with concussion in the school continues to improve.

As indicated in Table 2, successful return to school requires five components: (1) a prepared system with trained medical providers and a defined, trained team of school personnel, (2) an initial concussion evaluation of the student by the medical provider with attention to school-relevant symptoms and communication of this symptom profile to the trained school personnel, (3) coordination and communication of the student's status and progress between the family, medical provider, school, and athletics, (4) a school team that is skilled in translating the student's needs into necessary academic adjustments and accommodations, and (5) application of an active rehabilitation approach (as described below) with ongoing monitoring of progress and modification of necessary supports.

Clinical focus

When considering the clinical needs of the student with a concussion in the academic context, there are two primary targets for management: the effect of the concussion on school learning and performance and the effect of school learning and performance on concussion recovery [15]. Both of these issues must be supported in the student's recovery. The neuropsychological effects of concussion - impaired cognition (attention/concentration, working memory, new learning and memory, speed of information processing, executive functioning,) and social-emotional functioning (increased irritability, moodiness, emotional over response) [32] – must be understood in terms how they might affect learning and performance for the student.

To gain a general perspective on the problems in school following concussion, we examined the reported academic challenges experienced by students across elementary, middle and high schools (n=216) [48]. Students in all grades reported problems paying attention in school (58%), headaches that interfered with learning (66%), difficulty understanding new material (44%), slowed performance completing homework (49%), and fatigue in class (54%) with high school students indicating the greatest effects. A higher level of academic problems and greater concern with academic performance was associated with greater symptom burden on the PCSI. The first target of an effective school management programme is to provide the supports for the areas of impaired cognitive function in the form of classroom adjustments and accommodations (e.g. providing classroom notes to the student who cannot keep pace with note-taking in a lecture), or possibly adaptations to a student's schedule following concussion. Recommendations for specific academic accommodations corresponding to the range of neuropsychological impairments that affect school learning and performance can be accessed (e.g. [15]).

The second target for intervention encompasses managing the exertional effects that the student may experience in response to the cognitive, emotional and physical demands of the school setting. Recall that periods of prolonged concentration, class work, homework or lengthy classes can produce an increase in post-concussion symptoms such as headaches, fatigue or decreased concentration. These exertional effects can vary from person to person, task to task and across recovery, necessitating an individualized assessment of the student's cognitive exertional response. A chart review conducted in our concussion clinic revealed that 62.5% of high school students (n= 206) reported a worsening of their post-concussion symptoms with cognitive demands in school [49], [40]. Management of cognitive exertional effects becomes a critical issue in supporting students with concussions in the academically demanding school setting to, at a minimum, reduce symptom burden, if not promote recovery.

Activity-exertion symptom management

Active treatment of concussion is in an early stage of understanding and research. The recent AAN evidence-based review found only four treatment-related studies that qualified at any level for inclusion [2]. Nevertheless, there has been increasing discussion within the field about an ‘active rehabilitation’ model of concussion treatment beyond the simple, general ‘rest’ recommendations [50], [51], [52], especially for those who are slow to recover but also possibly for all children. The current view is that the child who is slow to recover may be at risk for developing secondary problems if their normal activities are restricted for extended periods of time while waiting for complete symptom resolution. Such problems might include physical deconditioning and secondary fatigue as well as behavioural/ emotional issues (e.g. irritability, anxiety, depression, and acting out behaviour). While there has been little clinical research with children with concussion, indirect evidence exists to support an active rehabilitation approach [53, 54].

We propose a clinical-rational approach to the management of symptom exertion, based on therapeutic principles used in behavioural medicine with various medical disorders such as pain and acute and chronic illnesses. The foundation of this approach is to teach the patient and family an active, constructive approach to the management of medical conditions. Applied to the child with concussion, the focus becomes the management of cognitive and physical activity in the context of associated symptom expression (exacerbation and reduction). This strategy involves optimal re-engagement of the student in their school and social milieu while avoiding worsening symptoms. This approach aims to help the student return progressively to normal school and social activities while, in the short-term, reducing the adverse effects of increased symptom levels (i.e. exertional effects), which can further impair learning and performance. Whether this moderated approach results in shorter time to recovery is yet to be determined and requires further research.

In applying an active rehabilitation model of treatment, it is important to recognize that each injury has its own manifestations, including the type and severity of the biomechanical injury, symptom pattern, and patient pre-injury history that potentially modifies the injury and symptoms. A thorough evaluation, as described in the first part of this article, is essential to guiding an effective, individualized rehabilitation programme.

The proposed management approach has several underlying assumptions— Concussion is generally viewed as an injury to the neurometabolic/ neurotransmission mechanisms of the brain with a significant crisis in terms of available energy to perform one's typical everyday cognitive and physical activities [55]. Recovery is hypothesized to be the gradual re-establishing of the brain's equilibrium with respect to these neurometabolic/ neurotransmission functions. A general treatment recommendation is to avoid engaging in activities that significantly worsen one's symptoms, especially in the early stages of recovery (i.e. first days to week). Symptom exacerbation following physical or cognitive activity is hypothesized as a signal that the brain's dysfunctional neurometabolism is being pushed beyond its tolerable limits. In guiding recovery, management of neurometabolic demands on the brain is central, not allowing the neurophysiologic threshold to be exceeded and keeping symptoms in check. The flip side of this relatively ‘restrictive’ management strategy (i.e. not doing too much) – and arguably the challenge - is not to reinforce the recovering child for becoming too underactive (i.e. not doing too little). Thus, one wants to encourage the child to engage in cognitive and physical activities to the extent that they are tolerable and do not significantly worsen symptoms. This ‘moderate activity’ strategy gains support from Majerske et al. [56] who found better concussion outcomes in recovering patients that were neither too underactive or too overactive.

Factors to consider when applying this approach include a clinical understanding of the cognitive and emotional status of the child and family. The emotional history of the child is particularly important to take into account in designing a treatment strategy, especially if there is a history of anxiety or mood disorder. Children with these histories may require special supports to encourage their active participation in the rehabilitation programme and may be particularly sensitive to symptoms. The anxious child or family may tend to engage in a less optimally active programme for fear of symptoms increasing to any slight degree. In this case, the clinician will need to actively encourage an appropriate activity level, providing clinical supports for perceived symptom exacerbation (e.g. reassurance, distraction techniques). At the same time, a youngster with a history of Attention-Deficit/ Hyperactivity Disorder, for example, may also require a different type of support to successfully manage their rehabilitation programme. These children may need greater constraints or structure than usual to ensure that they are not overactive in their daily activities. Other motivations must also be considered in guiding the student's recovery plan. For example, a highly motivated or anxious student with many impending academic deadlines may push themselves to exceed their capabilities (e.g. staying up late multiple nights to finish homework or projects to the detriment of their sleep). The management plan must, therefore, take the child and family's unique clinical strengths and challenges into account to promote optimal recovery.

Progressive Activities of Controlled Exertion (PACE): Ten Elements of Activity-Exertion Management

To guide the active, though moderated, rehabilitation process systematically, we offer the PACE model and its ten elements to guide activity-exertion management (see Table 3). As previously noted, the clinician must have a reasonable understanding– as per one's clinical assessment – of the child's unique injury, developmental, medical, emotional, and family situation as well as school environment and programme to tailor the management plan appropriately. The PACE model is offered for two reasons: to provide clinicians with a script to use in an active, progressive management approach, as well as a possible structure for future research. When applying this positive, active rehabilitation approach specifically to the school setting, it is essential that the school team be skilled in dynamically monitoring the student's activity-symptom exertion status and translating the needs into necessary academic adjustments and accommodations. Also, critical to the process is the capability of ongoing monitoring of progress and the associated modification of necessary supports. The ten-element PACE model can be conceptualized in four stages: (1) setting the positive foundation for recovery, (2) defining the parameters of activity-exertion management across the day and week, (3) teaching activity-exertion monitoring skills, and (4) reinforcing positive progress toward recovery.

Set the Positive Foundation (Steps 1-3)

1. Provide the student, family, and school with a psychologically positive, active problem-solving context for rehabilitation. Use frequent statements such as “You will improve and recover.” “Your efforts to manage your activity and time will pay off.” “Recovery is the light at the end of the tunnel, and you will reach it.” “You have control of your activity.” Highlight for the child and family symptoms that may have already resolved or are improving as evidence of progress toward recovery. Framing the injury and its recovery in a positive, constructive, reassuring manner is critical.

2. 2. Explore and manage the emotional response of the child and family to the injury. Assess how it has disrupted their lives. Ask what stresses or demands they are facing (school, peer, athletics). How do they typically manage stress? What do they know about mTBI and its effects? What have they heard about mTBI, and how is this affecting a positive, constructive, active approach to recovery? What fears or anxieties do they have about the injury and its effects? Correcting non-productive or incorrect thoughts/ knowledge about mTBI (e.g., one injury will result in long-term brain damage) is critical. (See the developmentally appropriate education in #3.) Realigning the emotions associated with these errant thoughts in a positive, constructive direction is essential to an active approach to recovery.

3. Provide developmentally appropriate education regarding mTBI and its dynamics (i.e., software injury, energy deficit), including the typical timeframes for recovery (i.e., typically days to several weeks) and the relationship between the student's level of activity and the potential for symptom exacerbation (exertional effects). Types of exertion are reviewed: physical, cognitive, emotional – and the need to manage their energy demands. This knowledge serves as the basis for teaching the concepts of moderated "optimal" activity, managing the activity-exertion relationship, and sub-exertion effects threshold. [57]

Define Parameters of Activity-Exertion Schedule (Steps 4-5)

4. Define the student's typical daily schedule (before, during, after school, weekends), including the times of the day when activities might present the greatest exertional challenges ("hot spots") and lesser challenges ("cool spots"). Define the specific type, intensity and duration of cognitive and physical activities within the schedule and their exertional effects on symptoms (e.g., "first period is a 60 minute Algebra class, which is very hard for me because there is a long lecture and my headaches increase a lot." vs. "second period is a 60 minute Art class where we work at our own pace on our sculpture project, and I feel fine."). This definition allows the medical provider to target the most troublesome or symptom-eliciting activities, and can be used to teach the student the specific activity-exertion connection. Define symptom triggers- e.g., sensitizing/ exacerbating environmental stimulation (sound, light).

5. Define the limits of tolerability for activity intensity/duration - i.e., where symptoms do not increase substantially/ meaningfully. Ideally, this should be done for each key class. A sample question might be "How long can you typically go in your classes before you notice your symptoms become much worse and affect your learning?" Use these time / intensity limits as the frame within which to schedule the "work-rest" breaks.

Teach Activity/ Monitoring/ Management Skills (Steps 6-8)

6. Teach the concept of engaging in "Not too little, not too much" activity. The student's goal is to find the activity "sweet spot" where activity time and effort are maximized without symptoms worsening. In other words, teach the related concepts of moderated activity and symptom management. It is important to emphasized to the student, parents and teachers that small increases in symptoms (e.g., where exertion ratings change by 1) are not counterproductive to recovery but large increases may be.

7. Teach "reasonable" symptom monitoring and recording. Be aware of the child or parent that is either an overly anxious over-reporter or an oblivious under-reporter, and coach them accordingly to monitor symptoms reasonably. For example, counsel the over-reporter to tolerate a bit more of the symptoms, and the under-reporter to attend a bit more closely to their symptom exacerbation.

8. Instruct the student to work up to their symptom limits, but to not exceed them, by being aware of (i.e., reasonable monitoring) their symptoms. When the symptoms increase several points on their exertion monitoring scale, take a defined rest break. Emphasize that tolerating a mild increase in symptoms is OK, but too much increase is not. When symptoms return to “typical” levels, they should return to the activity.

Reinforce Progress to Recovery (Steps 9-10)

9. Help the student to understand that the recovery process is dynamic, and with good activity-exertion management under their control, they will feel better, and the symptoms will decrease. Highlight symptoms that may already be resolving as evidence of progress toward recovery.

10. As the student improves (i.e., reduced symptoms and greater tolerance for activity), it is important to work constructively with the child and family (and school) to gradually increase the time/ intensity of activity, while continuing to monitor the exertional symptom response. The “sweet spot” of activity-exertion management will be moving closer to their normal schedule and toward the recovery state.

Conclusion

Evidence-based clinical evaluation and management of concussion in children is an evolving field. A developmentally-appropriate and rational clinical model, emphasizing key factors relevant to the injury manifestation and needs of the child, is fundamental to effective evaluation and management. Key considerations include an understanding of normal development and the developmental level of the injured child; the child's capacity to fully engage in the evaluation and treatment; the central involvement of others such as parents in the process; the use of developmentally appropriate measures to assess symptoms and neurocognitive functions, and understanding of the life demands of the child at home and school to develop an age-appropriate active rehabilitation management plan. The fundamental elements of a pediatric concussion evaluation are described including definition of the injury characteristics; pre-injury history; assessment of the child's post-concussion symptoms and select neurocognitive functions as well as exertional effects utilizing standardized quantitative methods. We describe evidence for a developmentally adapted standardized concussion assessment approach for children as young as age five, including a post-concussion symptom inventory completed by the child and parent, measurement of specific neurocognitive functions, and the assessment of dynamic cognitive exertional effects. A clinical-rational approach to active, individualized, moderated concussion management is offered via the ten elements of the PACE model with a specific focus on the school challenges faced by the recovering student. Consideration of all these clinical factors within a developmental framework will result in appropriate evaluation and management of the concussion in the developing child and adolescent. As indicated in the IOM report, however, there is a significant need to develop a solid evidence base to better understand the **short-and long-term** effects of concussion in the developing child upon which to develop clinical guidelines, further refine and validate our clinical assessment tools, and to inform the development of effective evidence-based treatment approaches for children and adolescents who experience typical and prolonged courses of recovery.

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Table 1

Multidimensional Post-Concussion Assessment Tools for Children

Assessment Domain	Name	Age	Scores	Available Psychometric Evidence
Post-Concussion Symptoms – Parent Report	Post-Concussion Symptom Inventory – Parent scale (PCSI-P)	5-18	Total Symptoms Physical, Cognitive, Fatigue, Emotional	Reliability: Internal consistency, test-retest, inter-rater Validity: Factor analysis, clinical groups, classification analyses, parent-child concordance Clinical utility: Reliable change (SRB), Symptom validity
Post-Concussion Symptoms – Self Report (SR)	PCSI-SR5	5-7	Total Symptoms	
	PCSI-SR8	8-12	Total Symptoms Physical, Cognitive, Fatigue, Emotional	
	PCSI-SR13	13-18	Total Symptoms Physical, Cognitive, Fatigue, Emotional	
Retrospective Baseline (RBL) Symptoms- Parent	RBL PCSI-P		Total Symptoms Physical, Cognitive, Fatigue, Emotional	Reliability: Internal consistency, test-retest, inter-rater Validity: Factor analysis, clinical groups, parent-child concordance
RBL Symptoms –Self Report (SR)	PCSI-SR5	5-7	Total Symptoms	
	PCSI-SR8	8-12	Total Symptoms Physical, Cognitive, Fatigue, Emotional	
	PCSI-SR13	13-18	Total Symptoms Physical, Cognitive, Fatigue, Emotional	
Neurocognitive Performance	Multimodal Assessment of Cognition & Symptoms (MACS)	5-12	Neurocognitive Test Composites: Learning & Memory Accuracy Response Speed Speed Consistency Learning to Memory Retention	Reliability: Internal consistency, test-retest, alternate forms Validity: Factor analysis, developmental change, clinical groups, classification analyses, other performance measures Clinical utility: Reliable change (SRB), performance validity
Exertional Effects	Exertional Effects Rating Scale (EERS)	5-18	Exertional Effects Index (EEI)	

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Table 2

Five system components for successful return to school following a concussion

Component	Detail
Trained medical providers, school personnel	Medical providers trained in concussion evaluation and management with specific understanding of school environment and learning demands. School concussion team identified, educated about concussion effects, and trained in the range of appropriate academic supports. General inservicing on post-concussion academic effects and supports is provided to all school staff.
Initial concussion evaluation	Initial definition of post-concussion symptom profile, including school-relevant symptoms, and suggested adjustments and accommodations to the school program; communication of symptom profile to the school liaison.
Coordination and communication of student status between family, medical provider, school, athletics	Lines of communication between all key parties are opened; key symptoms and recommended academic program supports are communicated; input and questions regarding the student's needs are addressed.
Translation of student needs into necessary academic supports	School team receives the concussion evaluation and translates the symptom issues into the necessary academic adjustments and accommodations across the student's entire program and schedule. Teacher consultation is provided.
Application of a progressive, active rehabilitation approach	Stepwise, gradual return to normal school schedule and program is mapped out with ongoing symptom monitoring, and modification of supports instituted as appropriate.

Table 3

Concussion Activity-Exertion Management: Progressive Activities of Controlled Exertion (PACE)

Stage	Treatment Component	Description
Set the Positive Foundation	1. Establish a positive, active problem-solving context	Provide the student, family, and school with a psychologically positive, active problem-solving context for rehabilitation. Framing the injury and its recovery in a positive, constructive, reassuring manner is critical.
	2. Assess and manage emotional response to injury	Explore the emotional response of the child and family to the injury. Assess how it has disrupted their lives. Ask what stresses or demands they are facing (school, peer, athletics).
	3. Developmentally appropriate education about mTBI and its effects	Provide developmentally appropriate education regarding the dynamics of mTBI (i.e., software injury, energy deficit), and the relationship between the student's level of activity and symptom exacerbation (exertional effects). Review the sources of exertion: physical, cognitive, emotional – and the need to manage these energy demands.
Define the Parameters of Activity-Exertion	4a. Define daily schedule 4b. Define type, intensity & duration of cognitive & physical activities and their exertional effects	a. Define the student's typical daily schedule (before, during, after school, weekends), b. Define times of the day when activities present the greatest exertional challenges (“hot spots”) and lesser challenges (“cool spots”). Identify the type, intensity and duration of cognitive and physical activities within the daily schedule.
	5. Define tolerability for activity intensity and duration	Define limits of tolerability for activity intensity/duration. Identify when symptoms do not increase substantially. This should be done for each key class. Sample question: “How long can you typically go in your classes before you notice your symptoms worsening and affecting your learning?” Use time / intensity limits to schedule “work-rest” breaks.
Teach Activity-Exertion Monitoring Skills	6. Teach “Not too little, not too much” concept	Teach the concept of moderated activity - engaging in “Not too little, but not too much” activity. The student's goal is to find the activity “sweet spot” where activity time and effort are maximized without symptoms worsening.
	7. Teach “reasonable” symptom monitoring	Teach “reasonable” symptom monitoring and recording. Be aware of child or parent that is overly anxious or oblivious. Coach them to monitor symptoms reasonably.
	8. Teach working to tolerable limits – using a work-rest-work-rest approach	Instruct the student to work up to their symptom limits, but to not exceed them, by being aware of (i.e., reasonable monitoring) their symptoms. Emphasize tolerance of a mild increase in symptoms, but not excessive increase.
Reinforce Progress	9. Recovery is dynamic; activity-exertion management will reduce symptoms	Instruct the student to work up to their symptom limits, but to not exceed them, by being aware of (i.e., reasonable monitoring) their symptoms. Emphasize tolerance of a mild increase in symptoms, but not excessive increase.
	10. Gradual increase activity time/ intensity.	As symptoms reduced with greater tolerance for activity, gradually increase the time/ intensity of activity. The “sweet spot” of activity-exertion will move closer to their norm.