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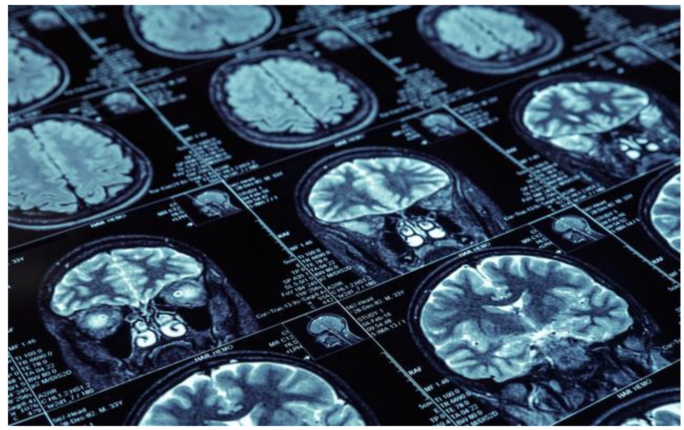
Concussion in youth: What's to know about higher order cognitive deficits across time.

ORIGINAL RESEARCH: REVIEW



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Mild traumatic brain injury (mTBI), also known as concussion, is the least understood of any subgroup of TBI, despite the finding that 70-80% of all TBIs are considered mild in severity (1). The incidence of mTBI is highest in youth populations, and in Ontario, injury incidence has risen from 467 to 754/100,000 in males and 208 to 440/100,000 in females from 2003 to 2010 (2). Concussion is defined as a "pathophysiological injury, induced by traumatic biomechanical forces to the head, neck or body, generating force to the head"(3). Herein referred to as mTBI, this injury results in a host of physical (e.g. headache, dizziness), cognitive (e.g. mental fog, slower information processing, difficulty concentrating), emotional (e.g. sadness, irritability) and sleep symptoms (e.g. difficulty falling asleep). However, regardless of the constellation of symptoms, those in the cognitive domain are unstudied, despite being of great concern in youth following mTBI (4).

High-level cognitive abilities, subserved by frontal lobe structures, are essential to daily functional performance in school and sport (5). In school environments, the ability to create goals and monitor the success of those goals is key to learning and application tasks such assignments and tests. In a sporting context, the use of rapid set-shifting (i.e. the ability to shift attention from one task to another) and speed of information processing of various types of environmental stimuli is critical to athletic performance (6). These frontal lobe functions (FLF) include attention, executive function and information processing, which are often compromised following mTBI. Regardless of age, mTBI can result in decreased attention and concentration (7–10), slowed information-processing speed (10–15), and executive dysfunction (7,16–18). Understanding how these FLF are affected along the recovery trajectory in youth can increase the knowledge of mTBI in rehabilitation science research while guiding age-specific clinical management decisions. For the purposes of this review, recovery will be defined as the ability to return to pre-injury performance on measures of FLF. Youth should be treated differently than adults as FLF is in a critical period of substantial and rapid neurodevelopment (7). Additionally, youth have an increased vulnerability to mTBI (19) and experience protracted recovery compared to adults (20). In youth post-mTBI, neuroimaging research has shown that FLF impairments in attention or executive function can be due to disruptions in frontal lobe activation (21). Despite evidence of frontal lobe disruptions following mTBI in youth, few investigations have sought to understand how FLF are affected by head trauma. From a rehabilitation sciences perspective, FLF impairments following mTBI may prevent youth from participating in desired daily activities, ultimately impacting their function and well-being (6). The aim of this scoping review is to address what is known about FLF impairments following mTBI in youth.

Methods

A scoping review was conducted on the FLF of youth with mTBI using the Arksey and O'Malley's (22) six-stage methodological framework. This framework was suitable for this review as the goal was to address a broad research question on what is currently known about a topic, while also highlighting potential gaps to investigate in the future (22). Thematic analysis was used to summarize the findings.

Study Selection

Four electronic databases were used to identify relevant studies, including the following: CINAHL, EMBASE, PsycINFO, and Medline (January 2000 to present). An outline of MeSH terms and keywords can be viewed in Table 1. Inclusion criteria: youth 12-17 years of age; diagnosis of mTBI; and, examination of FLF at any stage of recovery following mTBI, although authors also accepted articles in which FLF was a secondary outcome. Exclusion criteria: diagnosed developmental delay; learning disabilities and/or psychiatric disorders; and, participants under 8 years of age and over 25 years of age. A framework for FLF provided by Gillen (23) was chosen to examine higher-order cognitive abilities subserved by the frontal lobes. This FLF includes: attention, executive functions (planning, inhibition, set-shifting, working memory), and speed of information processing. The acute stage of recovery was operationally defined as < 10 days post-injury (3), whereas the chronic stage was defined as ≥ 1 month (24) post injury. The sub-acute phase of mTBI is a phase less well understood and defined in the literature; as such, the authors focused their comparisons of FLF deficits to the comparison between acute and chronic phase of mTBI.

Results

Two hundred and fifty articles were obtained from the initial search. A bibliographic data manager, Zotero (25) was used to identify and remove duplicates. Titles and abstracts were filtered by two occupational therapy graduate students (co-authors SS and HM). When a discrepancy for study inclusion occurred, the two reviewers collaborated until a unanimous decision was made. This process yielded 12 articles for final review. See Figure 1 for a breakdown of the article filtering process. A data extraction spreadsheet was created to document various study characteristics and main findings (Table 2).

Main Findings

FLF Across the Recovery Trajectory

Attention

In the acute stage of mTBI, one study found no group differences in a sustained attention task between youth with mTBI and healthy controls (26). Whereas studies evaluating youth with mTBI in the chronic stage of recovery demonstrated worse performance on attentional ability (in addition to other attentional skills) (27–29). These youth with mTBI demonstrated worse performance during sustained, shifting, divided and attentional control tasks in comparison to healthy controls (28,29). For instance, Scherwath et al. (29) found that youth with mTBI had decreased attention performance 29-108 days post-injury. Similarly, Anderson et al. (27) found that complex (e.g. shifting attention) and simple attention skills (e.g. sustained attention) in youth with mTBI were significantly below test norms at 3 months post-injury (Table 3).

Executive Function

In two of the three studies that examined the acute phase of mTBI, no significant decreases in executive function were found (30,31). There was no difference between the mTBI and orthopedic injury group (OI) in accuracy on a cognitive flexibility task within 72 hours post-injury (30). Similarly, a spatial planning task did not reveal significant differences in performance between the mTBI and OI group 10 days post-injury (31). In contrast, one study found that youth with mTBI had poorer performance on a working memory task, an aspect of executive function, in comparison with healthy controls at 13 hours post-injury (26).

In the chronic stages of recovery, the literature on executive function was mixed. Some of the studies indicated that mTBI in the chronic phase did not result in executive dysfunction in youth. For example, youth with mTBI and healthy controls did not differ in their executive function performance (26,28,31–33). Hammeke et al. (26) also noted no significant group differences between youth with mTBI and healthy controls on a working memory task at 7 weeks post-injury. Additionally, parent reports of executive function found more difficulties were reported in youth with an OI than in youth with mTBI at 3 months post injury (34). This finding was supported by Maillard-Wermelinger et al. (31) in which youth with an OI had decreased executive function performance compared to the mTBI group at 3 months post-injury. Two studies revealed contrasting effects in which executive dysfunction was found in the chronic phase of mTBI. Scherwath et al. (29) found that youth with mTBI performed more poorly on a verbal working memory subtest in comparison to controls between 29-108 days post-injury. Lax et al. (5) also found persisting executive function impairments following mTBI in youth despite self-reported resolution of post-injury symptoms (Table 3).

Speed of Information Processing

One study revealed decreased speed of information processing, as measured by reaction time on a working memory task in the acute phases following mTBI (26). In contrast, Brooks et al. (30) found no group differences between mTBI and OI groups in psychomotor speed and reaction time within 72 hours post-injury. In the chronic stage, speed of information processing appeared to be vulnerable following mTBI (21,34,35). In one study 96% of youth participants with mTBI were below average on at least one composite score on a computerized neurocognitive assessment (i.e. verbal memory, reaction time, and speed of information processing) at 3 months post-injury (35). Youth with mTBI were found to have unaffected accuracy scores during a working memory dual task, despite having a significantly lower speed of responding at 3 to 6 months post-injury (21). As such, while youth with mTBI scored similarly to controls, they took longer to achieve the correct response. (30,34).

Discussion

This scoping review found that subsets of FLF (i.e. attention, executive function and speed of information processing) were affected differently in the acute and chronic phases; clear impairments were identified in the chronic phase of recovery, despite mixed findings identified in the acute recovery phase. However, speed of information processing revealed impairments in both acute and chronic phases of mTBI in youth. Attention was unaffected acutely, with disruptions evident in the chronic stage. Finally, there were mixed results for executive function in the chronic phase of mTBI, in which some studies demonstrated no difference in executive function, while others demonstrated impairments after controlling for symptoms.

This review is the first of its kind to examine the recovery trajectory of FLF in youth with mTBI. Our results are consistent with other studies that have examined the general recovery trajectory of symptoms in youth. Yeates et al. (4) found that the acute recovery stage is dominated by physical symptoms. Conversely, cognitive symptoms predominate in the chronic stages. This may be due to psychosocial/emotional regulation issues that occur secondary to mTBI symptoms, which may limit optimal FLF. Thus, there is a need for further research on rehabilitation paradigms that consider the multitude of factors (e.g. mental health issues, interventions received, time it took to return to school) that influence higher order cognitive performance.

The use of neuropsychological outcomes was pervasive in these studies, and they may not be sensitive enough to detect FLF impairment in a sample of developing youth. A rehabilitation sciences perspective prompts the investigation and use of activity-based assessments that focuses on function in daily activities. These top-down assessments may enhance ecological applications in the form of age-specific activity recommendations in school, family and community domains. Finally, a limitation to this review is the focus on FLF, where expanding the search to include functional outcome measures such as academic performance may have provided a more holistic account of how mTBI affects youth. In conclusion, examining FLF in youth with mTBI is key to unpacking this complex injury. Continued investigation is crucial to enhancing the function and wellbeing of youth re-integrating to meaningful activities following head injury.

** All tables and figures can be viewed in following pages **

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Table 1. MeSH Terms and Keywords

<table>
<tr><th>MeSH Terms</th><th colspan="2">Keywords</th></tr>
<tr><td rowspan="2">Adolescence
Brain injuries
Brain concussion
Cognition
Cognitive ability
Concussion
Neurocognitive
Post Concussive Syndrome</td><td>Population</td><td>youth*
adolescen*
teen*
mild traumatic brain injur*
traumatic brain injur*
mild adj3 injur*
concussion*</td></tr>
<tr><td>Outcome focus</td><td>acute
sub-acute
chronic
long-term
short-term
cogniti*
neurocogniti*
neuropsycholog*</td></tr>
</table>

Table 2. Inclusion article study characteristics

Study Characteristic	Description	N
Study Design	Longitudinal	11
	Cross-sectional	5
	Prospective	1
Definition of mTBI	Glasgow Coma Scale	9
	Criteria for post-traumatic amnesia	5
	Physician diagnosis only	3
	Other screening tools (e.g. Acute Concussion Evaluation [ACE])	3
Sample	Emergency room	10
	Secondary analysis	2
	Sports team	2
	Counselling centre	1
	Did not report	2
Mechanism of mTBI	Multiple mechanisms of injury	8
	Sports-related	6
	Did not report	3
Outcome Measures	Neuropsychological pen-and-paper assessment	12
	Computerized neurocognitive assessment	4
	Self-report measures	3
	Dual task measures	2

Note: In cases where total N per study characteristic do not add up to 12 (total amount of inclusion articles), articles were classified multiple times to illustrate the various factors that were taken into consideration.

Table 3. Study findings for inclusion articles (N=12)

Author & Year	**Method**	**Age (years)** *Mean (SD)*	**Stage of Recovery**	**Frontal Lobe Function Domain**	**Main Findings**
Anderson et al. (2012)	Longitudinal; no control group	10.43 (2.47)	Chronic; 3-6 months post injury	Attention *Simple:* selective and sustained attention *Complex:* Divided attention	Attention skills were vulnerable to the impact of mTBI. More severe injury was associated with decreased complex and simple attention performance. Attention skills improved from 3 to 6 months post injury.
Babikian et al. (2011)	Longitudinal repeated measures study; with control group	11.9 (2.9)	Chronic; 1,6, 12 months post injury	Speed of information processing Attention *Simple:* sustained	Significant difference between mTBI and control group on speed of information processing and attention.
Brooks et al. (2014)	Cohort study; with orthopaedic injury control (OI) group	13.6 (2.6)	Acute; emergency department visits between 24 and 72 hours post injury	Speed of information processing Executive function (i.e. cognitive flexibility, set-shifting)	No differences in cognitive flexibility between mTBI and control. mTBI had significantly reduced speed of information processing compared to (OI). Cognitive flexibility better at 24 hours post injury compared to 72 hours post injury in mTBI group.
Hammeke et al. (2013)	Repeated measures study; with control group	16.5 (0.52)	Acute and Chronic; 13 hours to 7 weeks post injury	Speed of information processing Executive Function (working memory task)	At 13 hours post injury, mTBI group less accurate than controls on executive function assessment At 7 weeks post injury, no significant differences observed between the mTBI and controls

Table 1 continued

Krivitzky et al. (2011)	Pilot cohort study; with control group	13.3 (3.1)	Acute; majority (70%) tested within 30 days post injury	Executive function (working memory and inhibition task)	Children with mTBI did not show significant deficits on traditional neuropsychological assessment of executive function Significant differences in the parent reporting of executive function, with the mTBI group reported to have greater difficulties in behaviour regulation.
Keightley et al. (2014)	Cohort study; with control group	14.47 (2.29)	Acute and Chronic; 9 to 90 days post injury	Executive function (working memory task)	No significant differences in executive function
Lax et al. (2015)	Prospective, longitudinal study	11.8 (1.44)	Acute and Chronic; measures taken weekly, 1, 3 and 6 months following injury	Executive function (cognitive flexibility task) Speed of information processing	mTBI group attained higher scores on a symbol digit task (speed of information processing) with increased days post injury compared to controls who did not show an effect of time on performance. Psychomotor speed score between low and medium severity mTBI participants lower than between medium and high severity mTBI. In acute stage (<30 days), females had decreased performance on measure of cognitive flexibility compared to males. Following 30 days, females and males had similar cognitive flexibility performance, but still decreased compared to baseline.
Maillard-Wermelinger et al. (2009)	Prospective and longitudinal design; with OI control	11.96 (2.22)	Acute and Chronic; administered assessments at 10 days, 3 months, and 12 months post-injury	Executive function (working memory)	Significant differences in working memory between mTBI and orthopaedic control group; difference decreased along time points in mTBI recovery trajectory More metacognitive difficulties were reported in the mTBI group, specifically an organization of materials subscale on an executive function measure In mTBI group deficits in above frontal lobe function domains improved across time points in recovery trajectory

Table 1 continued

Mayer et al. (2012)	Cohort study; with control group	13.47 (2.22)	Acute; 7-21 days post injury	Executive function (working memory task) Attention Speed of information processing	No significant differences in executive function Significant but minimal decreases in attention and speed of information processing
Scherwath et al. (2011)	Longitudinal study; with control group	11.59 (2.37)	Acute and Chronic	Speed of information processing	mTBI group performed poorer on digit span and digit symbol tasks than healthy controls when measurement was between 29-108 days post injury. At 3 months and 12 months post injury, no significant differences on performance between mTBI and control group, indicating resolution of impairments.
Sinopoli et al. (2014)	Cohort study; with control group	12.61(1.55)	Chronic; youth with history of mTBI 3-6 months prior	Speed of information processing	mTBI group had significantly decreased speed of information processing compared to control on dual task, with no differences in accuracy.
Rieger et al. (2013)	Cohort study; with control group	13.67 (2.94)	Chronic, 3 month follow-up	Speed of information processing Executive function	No significant difference in measure of speed of information processing. The OC group had higher levels of parent-reported executive dysfunction at initial and 3-month assessments.

Figure 1. Article Inclusion Selection Process