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Assessing Cognitive Fatigue in Pediatric Traumatic Brain Injury: Are We Capturing the Whole Picture

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ABSTRACT

Background: Cognitive fatigue is a common yet underrecognized consequence of pediatric traumatic brain injury (TBI), with significant implications for quality of life, academic performance, and long-term recovery. Despite its prevalence, there is no gold standard for assessing cognitive fatigue in children, and existing tools vary widely in scope and sensitivity.

Objective: This scoping review aims to identify and evaluate the outcome measures currently used to assess cognitive fatigue in pediatric TBI populations over the past decade (2014–2024).

Methods: Following the PRISMA-ScR guidelines, a systematic search was conducted using PubMed, Scopus, Cochrane, ScienceDirect, and Google Scholar. Studies included focused on children and adolescents with TBI and utilized at least one outcome measure assessing cognitive fatigue. Ten years of literature were reviewed to provide a comprehensive overview of available tools.

Results: A total of 10 studies met the inclusion criteria. The most commonly used instrument was the Pediatric Quality of Life Inventory (PedsQL) Multidimensional Fatigue Scale, followed by the PROMIS® Pediatric Fatigue Item Bank and related subjective self- and parent-report tools. These measures primarily captured generalized fatigue, with limited specificity for cognitive domains. Few studies incorporated performance-based or objective assessments. Methodological gaps included heterogeneity in assessment timelines, lack of standardization, and minimal inclusion of younger children or those with severe injuries.

Conclusion: Current tools for assessing cognitive fatigue in pediatric TBI populations lack developmental sensitivity, specificity, and ecological validity. There is an urgent need to develop and validate comprehensive, age-appropriate instruments that incorporate both subjective and objective components. Future tools should address fluctuations in cognitive fatigue and support individualized rehabilitation strategies aimed at improving functional outcomes and quality of life.

Keywords: *Cognitive fatigue, Outcome measures, Pediatric population, Quality of life, Traumatic brain injury*

1. INTRODUCTION

Traumatic brain injury (TBI) is a major cause of mortality and disability among children. While it involves a variety of traumatic injuries to the scalp, skull, and brain similar to those seen in adults, the underlying mechanisms and approaches to treatment differ significantly between the two populations(1). Traumatic brain injury (TBI) is a significant public health issue and the leading cause of disruptions in normal childhood development. It occurs when a sudden force causes the brain to move abruptly within the skull, resulting in neuronal damage. This injury may arise from direct head impact, nonimpact forces like blast waves or rapid acceleration and deceleration, or from objects penetrating the skull and brain tissue. While TBI can affect individuals at any age, its impact on the developing brain can be particularly severe, potentially disrupting typical brain growth and altering its developmental trajectory and function.(2)

Epidemiology –

In India, children under the age of 15 make up approximately 35% of the population and account for 20–30% of all head injuries. Head trauma during infancy and childhood is recognized as the leading cause of death in these age groups.

Additionally, the causes, injury mechanisms, and treatment approaches differ considerably between children and adults. A significant proportion of road traffic accidents (RTAs) involve pedestrians, many of whom are children. Mortality rates from head injuries range between 10% and 60%, with younger children under four years experiencing poorer outcomes compared to relatively better prognoses in those aged 5–15 years.(3)

Biomechanics of Pediatric TBI –

Pediatric traumatic brain injury (TBI) differs significantly from adult TBI due to distinct biomechanical properties of the developing brain and skull. In infants, the skull is less rigid, with open sutures allowing limited movement in response to mechanical stress, enabling external forces to be absorbed differently. However, this flexibility also makes infants more susceptible to injuries during normal delivery, such as cephalic and subglial hematomas or intracranial hemorrhages from compression or traction forces.

Children's larger head-to-body ratio and relatively heavier heads increase the likelihood of head impacts during trauma. The immature cervical spine, with weaker neck muscles and greater reliance on soft tissues for stability, makes the cranio-cervical junction particularly vulnerable to injury in severe trauma.

The pediatric brain's high water content and limited myelination further amplify its vulnerability. Unmyelinated regions absorb traumatic forces differently, leading to increased susceptibility to shear injuries. As myelination progresses, the brain becomes denser, altering how forces are distributed. Additionally, the absence of fully developed paranasal sinuses in young children reduces energy absorption, heightening direct impact risks to the skull and brain.With development, facial growth and sinus formation gradually reduce the energy transmitted to the brain, while the changing dynamics of head acceleration and improving neck strength provide increasing protection. These unique biomechanical features highlight the distinct challenges in managing pediatric TBI .(1)

Classification (1) –

Classification Criterion	Types	Description
Physical Mechanism	Blunt or Penetrating	Based on whether the injury is caused by a blunt force or a penetrating object.
	Primary or Secondary	**Primary**: Damage occurs due to direct or indirect forces (e.g. acceleration-deceleration).
		Secondary: Results from cellular and molecular damage, vasogenic edema, or cytogenic edema.
Pathoanatomy	Diffuse or Focal	**Diffuse**: Caused by acceleration-deceleration forces.
		Focal: Typically due to direct contact and includes injuries like brain contusion, hemorrhages, and hematomas.
Severity	Mild, Moderate, or Severe	**Mild**: Glasgow Coma Scale (GCS) score of 13–15, or loss of consciousness for 0–30 minutes.
		Moderate: GCS score of 9–12, or loss of consciousness for 30 minutes to 24 hours.
		Severe: GCS score below 9, or loss of consciousness for more than 24 hours.

Cognitive Fatigue –

Fatigue is a frequent and persistent issue in children following acquired brain injury (ABI), extending well beyond the acute phase. Studies indicate that up to 60% of children with traumatic brain injury (TBI) experience chronic fatigue. In pediatric populations, post-ABI fatigue is linked to reduced physical, cognitive, and emotional functioning. This fatigue can significantly affect a child's quality of life by limiting participation in school, home, and social activities. Despite its prevalence and the profound impact it can have on both short-term and long-term functioning, post-ABI fatigue in children remains an underexplored and poorly understood area. Additionally, methods for effectively assessing fatigue in this context are still limited.(4)

Hence, the aim of this study is to provide an overview of the existing outcome measures that have been used to assess cognitive fatigue of TBI patients in pediatric population.

2. MATERIAL AND METHODOLOGY

This review article encompasses substantial research conducted between 2014 and 2024 to investigate the outcome measures that have been used to assess cognitive fatigue of TBI patients in pediatric population. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMAScR) Checklist was followed.

Data sources and search engine

Data from review articles, meta-analyses, original publications, and randomized control trials were analysed for this review. Searches for the publications in this study were conducted using PubMed, Scopus, Cochrane, Science Direct, and Google Scholar. A time period of 10 years was selected to draw together studies because no scoping reviews for compiling existing outcome measures to assess cognitive fatigue exists in this time frame. Relevant full-text articles from February 2014 to December 2024 were considered. The language was restricted to English. Distinct search strategies were developed for each database to identify full-text articles. The following Keywords were used to narrow down and sort the articles: Traumatic brain injury, assessment, cognitive fatigue, outcome measures, quality of life.

Inclusion and Exclusion Criteria

The initial search yielded relevant articles. After thoroughly reviewing the references, were identified. Upon excluding publications based on inclusion criteria, lack of full-text availability, or language barriers, the study comprised research articles (Figure 1). One of the primary grounds for article exclusion was the inability to gain access to the full version of the articles.

Sr. No	Title	AAuthoror(s)	Y Year ea	Population	Outcome Measures asures	Ou Outcome Domains	Assessment Timeline	Fi Findings ndings	Significance of Findings dings	Methodological Gaps Gaps

			r			**tcome Domains**	**eline**			
1.	Fatigue Recovery and Connected Factors Following Pediatric Concussion (5)	Fabiano et al. (2024)	2024	children aged 5–18 years with concussion (mild TBI)	PedsQL MFS: General, cognitive, sleep/rest fatigue	Fatigue recovery in post-concussive symptoms	1 week, 1 month, 3 months post-injury	Significant fatigue reduction observed by 3 months. Child and parent mental health crucial predictors for persisting fatigue.	Reinforces importance of mental health screening in post-concussion care.	Exclusion of severe TBI; results generalized to mild TBI only.
2.	Neuropsychological Impairment, Brain Injury Symptoms, and Health-Related Quality of Life After Pediatric TBI in Oslo(6)	Holthe et al.	2022	52 children aged 1–15 years hospitalized for TBI (mild, moderate, severe)	PedsQL 4.0 (parent-reported & self-reported)	HRQoL: Physical, emotional, social, and school functioning	5–8 months post-injury	Lower HRQoL associated with higher symptom load but unrelated to injury severity. Moderate deficits observed in working memory	Highlights importance of symptom-driven rather than severity-driven rehabilitation.	Small sample size; lack of preinjury HRQoL data.

3.	Cognitive Fatigue in Pediatric Traumatic Brain Injury: A Meta-Analysis and Scoping Review(7)	Riccardi JS, Ciccia A	2021	Pediatric TBI patients across studies (ages 6-18)	PedsQL, MFS, other fatigue scales			Cognitive fatigue is a prevalent and persistent issue in pediatric TBI, with significant negative effects on PedsQL scores, particularly in cognitive functioning	Provides a comprehensive meta-analysis on cognitive fatigue's impact on HRQoL, supporting the need for targeted interventions.	Variability in fatigue measures and inconsistent reporting of assessment timelines; further studies needed to establish standardized protocols
4.	Sleep disturbances after pediatric traumatic brain injury: a systematic review of prevalence, risk factors, and association with recovery.(8)	Luther M, Poppert Cordts KM, Williams CN	2020	Pediatric TBI patients across studies (ages 0-18)	PedsQL, Sleep Questionnaires, Actigraphy, Polysomnography			Sleep disturbances were common post-TBI, with prevalence rates ranging from 13% to 70%. These disturbances were linked to poorer PedsQL scores and slower recovery trajectories	Highlights the need for early identification and management of sleep issues in pediatric TBI to improve recovery and quality of life outcomes	Inconsistencies in assessment methods across studies, heterogeneity in populations, and lack of longitudinal follow-up limit the generalizability of findings. Further research is needed to standardize outcome measures
5.	Self- and Parent-Reported Fatigue Seven Years After Severe Childhood Traumatic Brain	Câmara-Costa et al.	2020	38 children (7–22 years old) with severe TBI; 33	PedsQL Multidimensional Fatigue Scale (MFS), subscales for general, sleep/rest,	Fatigue and HRQoL	7 years post-injury	Fatigue significantly worse in TBI group. Fatigue strongly correlated with overall disability	Fatigue highly predictive of lower HRQoL; underlines long-term impact of fatigue post-TBI.	Limited to severe TBI; some missing self/parent reports; possible recall bias for

	Injury(9)			matched controls	and cognitive fatigue			and HRQoL.		parental reports.
6.	Fatigue Following Traumatic Brain Injury in Children and Adolescents: A Longitudinal Follow-Up 6 to 12 Months After Injury.(10)	Crichton A, Anderson V, Oakley E, Greenham M, Hearps S, Delzoppo C, Beauchamp MH, Hutchison JS, Guerguerian AM, Boutis K, Babl FE	2018	Children and adolescents with mild to severe TBI (N=80, aged 8-16)	PedsQL, Multidimensional Fatigue Scale (MFS), parent-reported fatigue scales		Baseline, 6, and 12 months post-injury	Fatigue persisted in many children up to 12 months post-injury and was associated with lower PedsQL scores, particularly in the physical and school functioning domains	Demonstrates the impact of fatigue on HRQoL in pediatric TBI, underscoring the importance of fatigue management in rehabilitation to improve overall outcomes.	Limited by reliance on self- and parent-reported data, which may introduce bias. More objective fatigue measures and studies on long-term outcomes are necessary.
7.	Predicting Fatigue 12 Months after Child Traumatic Brain Injury: Child Factors and Postinjury Symptoms.(11)	Crichton A, Oakley E, Babl FE, Greenham M, Hearps S, Delzoppo C, Beauchamp MH, Hutchison JS, Guerguerian AM, Boutis K, Anderson V	2018	Children with traumatic brain injury (TBI)	PedsQL, Functional Independence Measure for Children (WeeFIM)			Fatigue was consistently found to negatively impact functional outcomes and HRQoL across multiple domains, including physical and school functioning.	Highlights the pervasive impact of fatigue on recovery post-ABI, emphasizing its role in rehabilitation	Heterogeneity in study designs and outcome measures limits comparability. Longitudinal research with standardized tools is required.
8.	Understanding the interplay between mild traumatic	Wylie GR, Flashman LA	2017	Pediatric and adult TBI populations	PedsQL, MFS, Cognitive Behavioral Therapy (CBT)					

	brain injury and cognitive fatigue: models and treatments.(12)				outcomes					
9.	Prediction of Multidimensional Fatigue After Childhood Brain Injury.(13)	Crichton AJ, Babl F, Oakley E, Greenham M, Hearps S, Delzoppo C, Hutchison J, Beauchamp M, Anderson VA	2017	Children with moderate to severe TBI (N=110, aged 6-17	PedsQL, Multidimensional Fatigue Inventory (MFI)		6 to 12 months post-injury	Fatigue was multidimensional, impacting mental, physical, and emotional domains of PedsQL, and varied by injury severity	Provides insight into how fatigue influences HRQoL multidimensionally, aiding targeted interventions for TBI recovery.	Lack of pre-injury baseline and diverse reporting limits comprehensive conclusions
10.	Uncovering cortico-striatal correlates of cognitive fatigue in pediatric acquired brain disorder: Evidence from traumatic brain injury.(14)	Ryan NP, Beauchamp MH, Beare R, Coleman L, Ditchfield M, Kean M, Silk TJ, Genc S, Catroppa C, Anderson VA	2016	Children with moderate-to-severe TBI (N=30, aged 8-16)	Pediatric Quality of Life Inventory (PedsQL), neuroimaging (cortico-striatal connectivity)	Cognitive fatigue, health-related quality of life (HRQoL)	6-12 months post-injury	Altered cortico-striatal connectivity was associated with increased cognitive fatigue and reduced PedsQL scores. Cognitive fatigue was more pronounced in TBI patients compared to healthy controls.	Provides neurobiological evidence linking cognitive fatigue to reduced quality of life in pediatric TBI patients, emphasizing the role of cortico-striatal circuits in fatigue management.	Limited by small sample size, cross-sectional design, and reliance on self-reported PedsQL measures. Longitudinal studies with larger samples are needed to confirm causality and track recovery trajectories.

3. DISCUSSION –

The purpose of this review was to compile few outcome measures used to assess cognitive fatigue in patients of traumatic brain injury. All articles that are analyzed in this review were published from 2014 – 2024.

Fatigue encompasses both cognitive and physical aspects and is influenced by multiple factors. Despite the absence of a universally agreed-upon definition or conceptual framework, recent research differentiates between peripheral and central fatigue. Peripheral fatigue is associated with specific physiological mechanisms, including neuromuscular transmission failure, metabolic disruptions, muscle membrane dysfunction, or issues with peripheral circulation. Conversely, central or cognitive fatigue involves difficulties in maintaining attention, particularly when self-motivation is required to sustain optimal performance. Studies identified four approaches to evaluating cognitive fatigue: (1) reduced performance over an extended time due to prolonged effort; (2) diminished performance following intense mental exertion; (3) performance decline after demanding physical activity; and (4) impaired performance during periods of acute but sustained mental effort(14).

Cognitive fatigue is a frequent and debilitating consequence of pediatric traumatic brain injury (TBI), yet it remains underrecognized and poorly assessed in clinical and research contexts. Despite its prevalence, there is no gold standard for evaluating cognitive fatigue in children, and existing tools are often limited in scope, overly subjective, or not developmentally tailored. This lack of precision in measurement presents a significant barrier to timely diagnosis, targeted intervention, and long-term monitoring of children affected by brain injury.

Varni et al 2002 stated that one of the most widely used tools in pediatric fatigue research is the **Pediatric Quality of Life Inventory (PedsQL) Multidimensional Fatigue Scale**, which evaluates general fatigue, sleep/rest fatigue, and cognitive fatigue across self- and proxy-reports. While the PedsQL is validated for use in various chronic pediatric conditions, including cancer and rheumatologic diseases (15), its reliance on subjective reports and its broad structure may limit its sensitivity to subtle or task-specific cognitive fatigue—particularly in children with mild to moderate TBI.

Although the cognitive fatigue subscale of the PedsQL aims to capture difficulties with concentration, memory, and thinking, it does not offer insight into performance-based changes over time, nor does it account for situational variability (e.g., fatigue fluctuations across school days or during specific cognitive tasks). Furthermore, children—especially those under the age of 8—may lack the introspective ability to recognize or articulate their fatigue, which makes caregiver-reported tools susceptible to reporting biases (16).

Recent advancements, such as the **PROMIS® Pediatric Fatigue Item Bank**, provide an expanded pool of items measuring fatigue severity and impact in daily life(17,18). However, similar to the PedsQL, PROMIS measures primarily reflect generalized fatigue and do not isolate cognitive dimensions with sufficient precision for post-TBI assessment.

The **Behavior Rating Inventory of Executive Function (BRIEF)** has been suggested as an indirect tool for assessing executive function-related fatigue in children (19).Though not designed for fatigue assessment, its subscales (e.g., working memory, task initiation, inhibition) could reflect aspects of mental exhaustion in real-world settings. Still, it lacks specificity to fatigue and does not distinguish between acute cognitive load and chronic cognitive fatigue.

Complicating this issue further is the lack of **objective or physiological markers** for cognitive fatigue. Though studies in adults have explored neural correlates using EEG or fMRI (e.g., frontal theta activity), these methods are invasive, resource-intensive, and difficult to apply longitudinally in pediatric outpatient populations (20).Emerging research calls for the development of real-time, ecologically valid measures that can track fluctuations in cognitive fatigue during school or daily routines, possibly through **wearable technologies** or app-based assessments.

A recent systematic review by Capone et al. (2024) confirmed that across pediatric neurorehabilitation settings, there is no universally adopted measure for cognitive fatigue, and existing tools show considerable heterogeneity in content, administration mode, and psychometric quality (21).

Therefore, there is an urgent need to design and validate **pediatric-specific, objective, and multi-dimensional tools** to evaluate cognitive fatigue, especially in post-TBI populations. These tools must be developmentally appropriate, sensitive to fluctuations over time, and capable of distinguishing cognitive fatigue from overlapping symptoms such as depression or sleepiness. Incorporating both subjective and performance-based components, possibly through gamified digital tasks or teacher-reported classroom behavior scales, could enhance the clinical utility and ecological validity of future instruments.

Such efforts will not only improve diagnostic accuracy but also inform individualized intervention strategies, such as cognitive pacing, energy conservation training, and school accommodations, all of which are critical for optimizing quality of life and functional recovery in children following TBI.

4. CONCLUSION

Cognitive fatigue is a complex, under-assessed sequel of pediatric traumatic brain injury that significantly affects daily functioning, academic performance, and overall quality of life. While tools like the PedsQL Multidimensional Fatigue Scale and PROMIS Pediatric Fatigue Item Banks have contributed meaningfully to fatigue assessment in children, they fall short in capturing the nuanced and often fluctuating nature of cognitive fatigue, particularly in neurologically impaired pediatric populations. The lack of objective, developmentally appropriate, and context-sensitive measures remains a critical gap in both clinical care and research.

There is an urgent need to develop validated, pediatric-specific tools that can reliably detect and quantify cognitive fatigue across various settings. Such instruments should combine subjective reports with performance-based and potentially digital or ecological measures to enhance diagnostic precision and guide personalized rehabilitation strategies. Closing this gap will not only improve patient outcomes but also ensure that children recovering from brain injury receive the comprehensive care they need to thrive cognitively, emotionally, and socially.

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