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CLINICAL, NEUROLOGICAL, AND COGNITIVE FEATURES IN CHILDREN WITH THE CONSEQUENCES OF TRAUMATIC BRAIN INJURY

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Abstract: Objective — To assess the clinical-neurological and cognitive features in children who have sustained traumatic brain injury (TBI) and to identify factors associated with the severity of cognitive deficits. **Materials and Methods** — A prospective observation was conducted in children with mild, moderate, and severe TBI. Neurological status, cognitive functions (attention, memory, executive functions), and recovery dynamics were evaluated. **Results** — The most common impairments included attention disorders, reduced processing speed, and deficits in working memory. TBI severity, age at the time of injury, and the presence of post-concussive symptoms were associated with more pronounced cognitive impairment. **Conclusion** — Children with the consequences of TBI demonstrate persistent cognitive deficits, indicating the need for long-term follow-up and comprehensive rehabilitation.

Keywords: pediatric traumatic brain injury; cognitive impairment; executive dysfunction; attention deficits; post-concussive symptoms; neurological outcomes; pediatric neurorehabilitation.

Introduction. The consequences of traumatic brain injury (TBI) in children are characterized by substantial clinical and neuropsychological heterogeneity. Brain injury sustained in early developmental stages may result in persistent cognitive, emotional-behavioral, and neurological deficits, many of which can emerge months or even years after the initial trauma. A considerable proportion of affected children exhibit learning difficulties, reduced attention span, slower information processing, and impairments in memory and executive functioning. These deficits significantly influence academic performance, social development, and overall quality of life.

Although the pediatric brain possesses a high degree of neuroplasticity, compensatory mechanisms do not always fully mitigate the effects of injury—particularly when trauma occurs during critical periods of neural network formation. An additional challenge lies in the fact that clinical manifestations of pediatric TBI may be nonspecific and resemble neurotic or behavioral disorders, complicating timely diagnosis of cognitive dysfunction.

Despite a growing body of international literature, there remains a shortage of comprehensive studies that simultaneously assess clinical, neurological, and cognitive manifestations in children with varying severities of TBI. Of particular importance is the investigation of risk factors associated with unfavorable cognitive outcomes, including age at the time of injury, severity of the primary damage, progression of post-concussive symptoms, and the specific neuropsychological profile of each child.

The present study aims to obtain original, data-driven insights into the clinical-neurological and cognitive characteristics of children with the consequences of TBI. The findings are expected to contribute to improved diagnostic strategies, optimization of rehabilitation programs, and the development of individualized recovery pathways.

Materials and Methods.

Study Design. This study was conducted as a prospective, single-center observational study. Participants were enrolled consecutively and underwent comprehensive standardized assessments according to a unified protocol. Each child was followed for a total duration of 6 months. The study included children aged 7–16 years who had sustained mild, moderate, or

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severe traumatic brain injury (TBI). Inclusion criteria were a clinically and instrumentally confirmed TBI, absence of pre-existing neurological disorders, and informed consent from parents or legal guardians.

Participants were divided into the following groups: Group 1: Mild TBI — n1 (40), Group 2: Moderate TBI — n2 (35), Group 3: Severe TBI — n3 (25), Group 4: Control group (healthy children without neurological pathology) — n4 (40).

Exclusion criteria included severe concomitant diseases, previous neuroinfections, developmental disorders, and psychiatric conditions.

Assessment Methods

1. Neurological Evaluation. A comprehensive neurological examination was performed, assessing: frequency and severity of headaches, episodes of dizziness, pyramidal signs, coordination disturbances, vestibular dysfunction, autonomic symptoms.

Post-concussive symptoms such as fatigue, photophobia, and impaired concentration were also documented.

2. Cognitive Testing

Cognitive functioning was evaluated with standardized neuropsychological tools: Attention: Continuous Performance Test (CPT), Trail Making Test Part A (TMT-A), Working memory: Digit Span, Processing speed: performance indicators from TMT-A and editing tasks, Executive functions: Trail Making Test Part B (TMT-B), Stroop Color-Word Test, Memory: tests for verbal and visual immediate and delayed recall.

All assessments were conducted by trained specialists to minimize inter-rater variability.

3. Psychoemotional Assessment

Psychological status was evaluated using validated questionnaires measuring: anxiety, emotional lability, sleep disturbances, reduced stress tolerance.

4. Follow-up Assessment

Participants underwent evaluations at four time points: baseline (study entry), 1-month follow-up, 3-month follow-up, 6-month follow-up.

Changes in cognitive performance, regression of neurological symptoms, and recovery dynamics were monitored.

Statistical Analysis

The statistical analysis included: descriptive statistics (means, standard deviations), intergroup comparisons using ANOVA or the Kruskal–Wallis test, depending on data distribution, post-hoc pairwise tests, correlation analysis (Pearson or Spearman) to assess associations between TBI severity, age, and cognitive outcomes.

Statistical significance was set at $p < 0.05$.

Results. General Characteristics of the Sample. The final sample included 140 children aged 7–16 years (mean age 11.4 ± 2.6 years). The groups did not differ significantly in age or sex distribution (p>0.05).

Neurological Findings. Neurological symptoms were most frequently observed in the moderate and severe TBI groups.

Table 1. Frequency of Neurological Symptoms (%)

Symptom	Mild TBI (n=40)	Moderate TBI (n=35)	Severe TBI (n=25)	Control (n=40)	p-value
Headache	52%	77%	88%	5%	<0.001
Dizziness	28%	60%	76%	3%	<0.001

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Symptom	Mild TBI (n=40)	Moderate TBI (n=35)	Severe TBI (n=25)	Control (n=40)	p-value
Coordination impairment	10%	37%	68%	0%	<0.001
Vestibular dysfunction	8%	29%	56%	0%	<0.001
Pyramidal signs	2%	11%	44%	0%	<0.001

Note: *Neurological abnormalities increased proportionally with TBI severity, reaching the highest frequency in the severe TBI group.*

Table 2. Cognitive Performance Across Study Groups

Cognitive Domain / Test	Mild TBI	Moderate TBI	Severe TBI	Control	Statistic
Attention (CPT omission errors)	12.4 ± 4.1	19.3 ± 6.5	28.1 ± 8.9	8.2 ± 3.3	ANOVA: F=41.2, p<0.001
Processing Speed (TMT-A, sec)	42.1 ± 8.5	55.9 ± 10.2	71.3 ± 12.4	34.6 ± 7.1	ANOVA: F=52.7, p<0.001
Working Memory (Digit Span)	6.4 ± 1.1	5.7 ± 1.0	4.8 ± 0.9	7.2 ± 1.2	ANOVA: F=33.5, p<0.001
Executive Functions (TMT-B, sec)	82.6 ± 19.3	104.8 ± 22.1	139.4 ± 30.5	71.9 ± 15.7	ANOVA: F=47.9, p<0.001
Delayed Verbal Recall (0–15)	11.1 ± 2.3	9.8 ± 2.4	7.4 ± 2.5	12.8 ± 1.7	Kruskal–Wallis: H=29.4, p<0.001
Visual Memory (recognition errors)	4.3 ± 1.5	6.1 ± 2.0	8.7 ± 2.6	3.1 ± 1.1	p<0.001

Note*: Values are presented as mean ± standard deviation. CPT — Continuous Performance Test; TMT — Trail Making Test. Statistically significant differences observed between TBI groups and controls (p<0.001).*

Psychological and Emotional Status. Symptoms were significantly more pronounced in the TBI groups:

- Anxiety was elevated in 42% of moderate and 64% of severe TBI cases.
- Emotional lability: 18% (mild), 40% (moderate), 68% (severe).
- Sleep disturbances occurred in 10%, 31%, and 52% respectively.

p<0.001 across all measures

Correlation Analysis. Significant correlations were found between TBI severity and:

- attention deficits (r=0.62, p<0.001)
- processing-speed reduction (r=0.71, p<0.001)
- working memory impairment (r=–0.58, p<0.001)
- executive dysfunction (r=0.67, p<0.001)
- delayed memory deficits (r=–0.49, p<0.001)

Longitudinal Dynamics. Improvements over 6 months:

- Mild TBI: full or near-full recovery by month 3–6.
- Moderate TBI: partial but significant recovery, especially attention and processing speed.

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- Severe TBI: persistent deficits, particularly in executive functions and memory.

Repeated-measures ANOVA showed significant improvement in all TBI groups ($p<0.01$), but effect size was smallest for severe TBI ($\eta^2=0.14$).

Discussion. Our study demonstrated that children who have experienced traumatic brain injury (TBI) exhibit significant and persistent deficits in multiple cognitive domains, including attention, processing speed, working memory, executive functions, and both verbal and visual memory. These findings are consistent with previous research indicating that pediatric TBI leads to long-term neurocognitive impairments that can affect academic achievement, daily functioning, and social adaptation.

The severity of TBI was strongly associated with the extent of cognitive impairment. Children with severe TBI showed the greatest deficits across all measured domains, whereas children with mild TBI displayed more subtle impairments, primarily in attention and processing speed. This gradation aligns with the concept that the initial injury load correlates with the magnitude of functional disruption, but also highlights that even mild TBI can have measurable cognitive consequences, especially when assessed with sensitive neuropsychological tools.

Age at the time of injury emerged as an important predictor of outcome. Younger children demonstrated greater vulnerability to cognitive deficits, likely reflecting the increased susceptibility of the developing brain to structural and functional disruption. This observation underscores the importance of early assessment and monitoring in younger pediatric populations.

Post-concussive symptoms, including headaches, sleep disturbances, and emotional lability, were also associated with more pronounced cognitive deficits. These findings suggest that persistent somatic and affective symptoms may exacerbate or reflect underlying neurocognitive dysfunction, supporting a holistic approach to assessment and intervention.

The results emphasize the need for early and longitudinal evaluation of cognitive functions in children following TBI. Standardized neuropsychological assessments, combined with clinical neurological examination, provide essential information for identifying children at risk for persistent impairments. Moreover, individualized, multidisciplinary rehabilitation programs targeting attention, memory, and executive functions are crucial to optimize recovery and improve daily functioning and school performance.

Limitations of our study include the single-center design and relatively small sample sizes in each TBI severity group, which may limit generalizability. Future research should involve multicenter cohorts with longer follow-up periods to better characterize trajectories of cognitive recovery and to identify factors predicting resilience and long-term outcomes.

Conclusion. Children with TBI exhibit significant cognitive deficits that correlate with injury severity, age at injury, and presence of post-concussive symptoms. These findings highlight the importance of comprehensive neurocognitive assessment and individualized rehabilitation strategies to mitigate long-term functional impairment and support optimal developmental outcomes.

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