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Research Article

Optimal functioning after early mild traumatic brain injury: Evolution and predictors

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Abstract

Introduction and objectives: Early mild traumatic brain injury (mTBI or concussion sustained between 0 and 5 years old) can lead to post-concussive symptoms, behavioral changes, and cognitive difficulties. Although school-age children (6–17 years old) experience similar consequences, severe neuropsychological deficits are not common, and the majority have no persisting symptoms after one month. Thus, there may be value in focusing on what characterizes optimal functioning (or wellness) after mTBI, but this has not been explored in young children. This study documents the evolution and predictors of optimal functioning after early mTBI. **Method:** Participants were 190 children aged 18 – 60 months with mTBI ($n = 69$), orthopedic injury (OI; $n = 50$), or typical development (TDC; $n = 71$). Optimal functioning was defined as: (1) no clinically significant behavioral problems; (2) no cognitive difficulties; (3) no persisting post-concussive symptoms; (4) average quality of life or better. Predictors related to sociodemographic, injury, child, and caregiver characteristics included number of acute symptoms, child sex, age, temperament, maternal education, parent-child attachment and interaction quality, and parenting stress. **Results:** Fewer children with mTBI had optimal functioning over 6 and 18-months post-injury compared to those with OI and TDC. Higher parent-child interaction quality and lower child negative affectivity temperament independently predicted optimal functioning. **Conclusion:** Children who sustain early mTBI are less likely to exhibit optimal functioning than their peers in the long-term. Parent-child interaction quality could be a potential intervention target for promoting optimal function.

Keywords: Mild traumatic brain injury; early childhood; optimal functioning, wellness; parent-child interaction; temperament

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Introduction

Mild traumatic brain injury (mTBI or concussion) is especially prevalent in children aged 5 years and under (Dewan et al., 2016; Taylor et al., 2017). Compared to the substantial research in middle childhood and adolescence, few studies have focused on outcome after early childhood mTBI despite the potential for such injuries to disrupt functioning (Séguin et al., 2022), and the importance of ensuring a sound cognitive, social and behavioral basis for lifespan development.

MTBI symptoms and outcomes

Symptoms of pediatric mTBI typically manifest through affective (e.g., anxiety), cognitive (e.g., poor concentration), or physical (e.g., vomiting, headaches) signs and post-concussive symptoms (PCS) (Ewing-Cobbs et al., 2018; Todd et al., 2022; Zemek et al., 2016). While similar effects have been documented in young children (Podolak et al., 2021), loss of consciousness, vomiting, drowsiness, and headache seem to be less common (Crowe et al., 2024) and PCS appear to be characterized primarily by behavioral manifestations such as increased moodiness, irritability and comfort seeking (Dupont et al., 2021; Dupont et al., 2024; Suskauer et al., 2018). Parent report can result in both over- and under-estimations of PCS (Stevens et al., 2010), and in young children, discrepant results concerning the extent and nature of PCS are likely to be associated with challenges in identifying mTBI due to their limited cognitive and verbal abilities (Beauchamp et al., 2024). There is some evidence for elevated behavior problems (Gagner et al., 2020; Gornall et al., 2021) and social cognitive difficulties in the long-term after early mTBI (Bellerose et al., 2015, 2017; Séguin et al., 2022).

Although disruptive, PCS are usually transient and about two thirds of school-aged (5–18 years) children recover by one-month post-injury (Zemek et al., 2016). Severe neuropsychological deficits are also not common (Beauchamp et al., 2018). Given the reasonably encouraging prognosis, there is increasing focus on the large proportion of individuals who recover completely and rapidly after pediatric mTBI (e.g.; Beauchamp et al., 2019). However, no

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study has explored this topic in children with early mTBI. Determining what predicts good outcome is useful for identifying targets to promote optimal functioning and well-being.

Optimal functioning and well-being after pediatric mTBI

Optimal outcome lacks a clear definition, and its operationalization varies across studies and disciplines. Well-being (or wellness) is defined by the World Health Organization (2023) as « a positive state experienced by individuals and societies », and is associated with related constructs such as quality of life, resilience, mental health, physical health, personal satisfaction, and healthy habits (Center for Disease Control and Prevention 2018). Hawley and Joseph (2008) suggested that well-being after TBI is characterized by an individual reaching their full potential (i.e., beyond their pre-morbid state). The current study draws on these varied conceptions and uses the broader term "optimal functioning" in reference to performance in spheres typically disrupted by pediatric mTBI, namely PCS, behavior, cognition, and quality of life (Gagner et al., 2020; Moran et al., 2012; Séguin et al., 2022; Zemek et al., 2016).

Only one study has specifically focused on the concept of optimal functioning (referred to as wellness in the article) and its associated factors after pediatric mTBI. Beauchamp et al. (2019) evaluated 311 children (6–18 years) one and three months post-mTBI. Optimal functioning was defined as the presence of good quality of life, no persisting PCS, and no neuropsychological difficulties. The proportion of children with optimal functioning increased post-injury, though not significantly, from 41.5% (1-month) to 52.2% (3 months). Participants were more likely to have optimal functioning if they were younger (6 – 8 years vs. 9 years or older at injury), were injured in a sports context (versus a fall or motor vehicle accident), had no history of pre-injury problems (e.g. neurodevelopmental or mood disorders), and had better acute working memory. While innovative in its approach focusing on positive outcomes, this work was limited by the absence of a comparison group. Furthermore, studies exploring optimal outcome in older individuals are informative (Hanks et al., 2014; Vos et al., 2019), but do not represent the unique aspects of early childhood mTBI, such as differential mechanisms of injury (mainly falls rather than sports injuries), and important influences at young ages, such as parental factors (Beauchamp et al., 2021).

Child and parent factors

Family and relational factors, such as high-quality parent-child interactions and secure attachment, are associated with better cognitive and social development in typically developing children (Devine & Hughes, 2019; Madigan et al., 2013; Szpak & Białecka-Pikul, 2020). These factors also predict behavioral adjustment and social competence in young children who sustain complex to severe mTBI (Yeates et al., 2010). After early mTBI, parent-child interaction quality is reduced (Lalonde et al., 2018) and parental stress is associated with worse child quality of life (Tuerk et al., 2020), behavior problems (Yumul et al., 2024), and more PCS (Bernard et al., 2016).

Child temperament dimensions (Rothbart et al., 2001) such as negative affectivity (the propension to experience unpleasant emotions such as sadness) are associated with more externalizing behavior problems (Delgado et al., 2018). In adults, positive affectivity (the propension to experience pleasant emotions such as joy) is associated with post-TBI subjective outcomes (e.g. life satisfaction), while negative affectivity is associated with post-TBI objective outcomes (e.g. physical health; Hanks et al., 2014). No such associations have been explored after early mTBI; however, elevated internalizing and externalizing behavior problems are commonly reported after pediatric mTBI (Brooks et al., 2019; Gagner et al., 2020; Gornall et al., 2021). Given the link between temperament and behavior (Delgado et al., 2018), these factors could be associated with optimal functioning after early mTBI.

Objectives and hypotheses

No study has explored optimal functioning after early mTBI or included family factors as potential predictors, and previous work in older children is limited by the absence of a comparison group. This study aimed to (1) document the evolution of optimal functioning after early mTBI compared to orthopedic injury (OI) and typically developing (TDC) comparison groups at 6 and 18-months post-injury, and (2) identify predictors of early mTBI optimal functioning among sociodemographic (parent education, child age, sex), injury (number of acute symptoms), child (temperament), and parent (parenting stress, parent-child interaction quality, attachment) variables. It was expected that: (1) a lower proportion of children with early mTBI would have optimal functioning compared to both comparison groups over 6 and 18 months; (2) sociodemographic (higher parent education, lower child age, being a girl; Arambula et al., 2019), injury (fewer acute symptoms), child (lower negative affectivity traits), and parent (less parenting stress, better parent-child interaction quality, secure attachment) factors would be associated with optimal functioning.

Methodology

Design

Participants were recruited between 2011 and 2015 as part of a longitudinal study investigating cognitive and social outcomes of early TBI (LION project). Participants were followed at 6, 18, 30, and 60 months post-TBI. The current study includes the 6 and 18-months timepoints, was approved by the Ste-Justine Hospital research ethics committee and was conducted in accordance with Helsinki Declaration.

Participants were 190 children from three groups: mTBI ($n = 69$), OI ($n = 50$), and TDC ($n = 71$). Inclusion criteria for mTBI, assessed by research staff based on presentation and medical charts were (1) presentation to a pediatric Emergency Department (ED) within 48 hours of injury; (2) age between 18 and 60 months at injury; (3) closed head injury with a *Glasgow Coma Scale* (GCS) score between 13 and 15; (4) the presence of at least one of the following: loss of consciousness, excessive irritability, persistent vomiting (two or more times), confusion, headache, fatigue, dizziness, motor or balance problems, blurred vision, hypersensitivity to light, and/or seizures. Children with complex mTBI (GCS 13 to 15 with intracranial lesion) were included ($n = 9$). For the OI, inclusion criteria were (1) presentation to the pediatric ED; (2) aged between 18 and 60 months at injury; (3) limb injury with a final diagnosis of simple fracture, sprain, contusion, or unspecified trauma. Inclusion criterion for the TDC was to be aged between 24 and 66 months (to be comparable to the injury groups six months later).

Exclusion criteria for all groups were: (1) diagnosis of a congenital, neurological, developmental, psychiatric, or metabolic condition; (2) birth before 36 weeks gestation; (3) parent or child cannot communicate in English or French; (4) history of a previous

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TBI requiring an ED visit; (5) non-accidental injury for children with mTBI or OI.

Procedure

Children with mTBI or OI were recruited at the ED by a research nurse or assistant. Families who agreed to participate were contacted within a week of their ED visit to complete the consent form and questionnaires. A case report form was completed by research staff to document acute signs and symptoms and injury characteristics. The TDC were recruited through flyers in daycares from diverse neighborhoods. Parents expressing interest were contacted by phone by a research assistant who verified inclusion and exclusion criteria. At 6 months (T1) and 18 months (T2) post-injury, parents from all groups were asked to complete questionnaires about their child's functioning, and children participated in a direct assessment.

Measures

Sociodemographic and injury characteristics

Sociodemographic information was documented at the time of recruitment including child age, ethnicity, and sex. Maternal education was used as a proxy for socioeconomic status. Injury characteristics included: Glasgow Coma Score, mechanism, and acute symptoms: loss of consciousness, alteration of consciousness (e.g. confusion), post-traumatic amnesia, headache, excessive irritability, vomiting, hematoma, drowsiness, dizziness, convulsions, visual symptoms (e.g. blurry vision) and balance.

Definition of optimal functioning

Children were considered to have optimal functioning at T1 or T2 if they met four criteria: presence of (1) good quality of life, and absence of (2) persisting PCS, (3) clinically significant behavior problems, and (4) cognitive difficulties.

Quality of life: The *Pediatric Quality of Life Inventory 4.0* (PEDSQL; Varni et al., 2003; Varni et al., 2007) parent report was used to document child quality of life (physical, mental, social, academic) according to caregivers using 23 questions on a five-point scale (total score on 100). Higher scores indicate better quality of life. Published norms (Varni et al., 2003) were used such that a score of 65.4 or more (equal or higher than -1 SD from the population mean) was considered to represent good quality of life (as in Beauchamp et al., 2019).

Post-concussion symptoms (PCS): Due to the absence of a validated PCS measure for early TBI at the time of data collection, the *Postconcussive Symptom Interview* (PCS-I; Mittenberg et al., 1997) was used by parents to document 15 cognitive, physical, emotional, and sleep symptoms using yes/no answers. Persisting PCS were considered absent if children had fewer than three symptoms at a given timepoint (Zemek et al., 2013).

Behavior : The *Child Behavior Checklist* (CBCL 1.5–5 years or 5–18 years; Achenbach & Rescorla, 2000) consists of 100 questions completed by parents on a three-point scale. Standardized clinical cutoff thresholds were used such that T scores below 65 on both internalizing and externalizing subscales were required for behavior problems to be considered absent.

Cognition: In keeping with the goals of the broader study, cognition was measured using six tests of executive functioning and theory of mind. Since severe cognitive deficits are rare after pediatric mTBI (Ware et al., 2023), Beauchamp et al.'s (2018) rule for defining cognitive inefficiency was used. This method allows identification of subtle cognitive difficulties, rather than significant impairments. Participants scoring one standard deviation or more below average on two or more direct assessment measures were identified as having suboptimal cognitive functioning, and conversely, those not meeting this definition were considered to have no cognitive difficulties. Due to the wide age range of the sample, age was controlled by generating z scores for each task by age group (T1: 2, 3, 4 years old; T2: 3, 4, 5, 6 years old).

Conflict Scale: This flexibility task consists of four levels of six trials that represent different measures of conflicting executive functions. Younger children have to categorize items according to rules that change throughout the task (e.g. sorting by one color, then switching the rule to the shape instead of the color). Older children must sort the cards according to the presence (color game) or the absence (shape game) of a black border around the card. The rule is changed in a post-switch phase if the child succeeds on five trials (Beck et al., 2011; Zelazo, 2006). There are 12 trials per level for a maximum of 48 points.

Spin the Pots: This working memory task requires children to find 6–10 stickers placed separately in 8–12 boxes on a tray depending on their age. After each trial, the boxes are covered with a cloth, the tray is rotated 180 degrees, and the child has to find one sticker (Beck et al., 2011). The final score is the number of stickers found divided by the number of rotations required.

Delay of Gratification: This inhibition task requires children to make a series of decisions during which they must choose between a small immediate reward or a larger reward received later (e.g. one sticker now or five stickers after the task; Beck et al., 2011). One point is given for every larger reward chosen for a total of nine points.

Shape Stroop: This inhibition and flexibility task first consists of showing images of bigger and smaller fruits. Children are asked to point to the image of a fruit for six trials. Then, three cards of big fruits with a smaller fruit in the middle are shown. Children are asked to point to the little fruits (e.g. point to the little apple) and not to the bigger ones. Children receive one point for every correct answer for a total of three points (Carlson, 2005; Kochanska et al., 2000).

Desires Comprehension Tasks: Children aged from 24 to 35 months performed a desires and emotion reasoning task in which they have to choose between two snacks, one typically liked by children (e.g., cookie) and one typically disliked (e.g., brocoli; Bellerose et al., 2015; Repacholi & Gopnik, 1997). The experimenter expresses their preference for the less liked food and asks the child to give them a food item to see if they will offer the experimenter's preferred food. A total of four food combinations are presented for a total of four points, and this score was used in the analyses. For older children (> 35 months), a more advanced desires reasoning task (Desire task; Pears & Moses, 2003) was used to document understanding of how fulfilled and unfulfilled desires can affect a character's feelings through stories (Bellerose et al., 2015; Pears & Moses, 2003). The stories describe a character's search for a desired object with three possible endings, each presented twice: (1) the character finds the desired object, (2) they find nothing, or (3) they find a different object. The child is asked to determine whether the character is happy or sad. Each possible ending is presented twice, for a total of six stories with a score out of six points, which was used in the analyses.

False Belief Understanding Task: Children are presented with a picture book that incorporates a deceptive element and are asked to recall their own initial belief about what they saw (e.g., children are made to believe that they see an eye through a peep hole, but they find out that it is a spot on a snake). Then, they must predict the belief of a puppet who never saw the book: 1) "what does the puppet think it is?" and 2) "what is it really?" (Bellerose et al., 2015; Hughes et al., 2011). A control question is also included: "What is it really, an eye or a snake?" For both scenarios, children receive a point only if they can answer the corresponding control question, for a maximum of two points and this variable was used in analyses.

Candidate Predictors

Sociodemographic and acute symptoms: Child age and sex, maternal education, and acute symptoms were included.

Mutually responsive orientation scale (MRO): This measure of parent-child interaction quality is based on the dyadic nature of parent-child exchanges (Aksan et al., 2006; Kochanska et al., 2008). Two 10-minute sequences (snack and free play with toys) were videotaped. Trained research assistants coded the parent-child interactions in each video according to harmonious communication, mutual cooperation, and emotional ambiance, with a final MRO score of 15 (mean of the two interaction scores). Inter-rater reliability was satisfactory ($r = 0.74$ to 0.97, 17% of the sample).

Attachment Q-sort short version: This measure of attachment security consists of 30 cards representing child attachment behaviors towards a parental figure (Waters, 1995). After viewing the same two video sequences used to score the MRO, a research assistant places the 30 cards in five rows of six cards. Each row represents a score from 1 (does not represent the child's behavior) to 5 (represents the child's behavior perfectly) such as: "*child easily becomes angry at mother.*" The research assistant sort is then correlated with a criterion sort provided by the authors of the instrument, representing the prototypically securely attached child. The prototypically securely attached child represents a fluid balance between reliance on caregiver when support is needed and exploration of the environment, with low scores on items such as "Child rarely asks mother for help," and high scores on items such as "If mother reassures him, child will approach or play with things that initially made him cautious or afraid." The final score ranges from -1.00 (very insecure) to 1.00 (very secure). Three research assistants (different from those who scored the MRO) coded attachment security and the inter-rater reliability score was excellent ($r = 0.82$; 20% of the sample).

Parenting Stress Index - Short Form: This parent questionnaire measures the level of distress experienced with regard to their parenting role with their child (e.g., their perceived competence) (Abidin, 1995). Each item was rated on a five-point scale and the total score from two 12-item subscales (Parenting Distress and Parent-Child Dysfunctional Interaction) was used. A higher score indicates higher stress.

Early Childhood Behavior Questionnaire (ECBQ; 18 to 36 months) or *Childhood Behavior Questionnaire (CBQ; > 36 months)* (Putnam et al., 2006; Rothbart et al., 2001). The short 36-item versions based on Rothbart's model (Putnam et al., 2014; Putnam & Rothbart, 2006) were completed by parents. Each item is rated on a seven-point scale ranging from zero (extremely false) to seven (extremely true), yielding three dimensions (Reactivity, Negative Affectivity, Effortful Control). In preschool children, higher scores of negative affectivity have been linked to more behavior problems (Henderson & Wachs, 2007), therefore this dimension was used in analyses.

Statistical analyses

Missing data

Only children who completed both assessment timepoints were included ($N = 188$). Some children had missing data on some of the measures administered at either timepoint. Multiple imputation was used to handle missing data (Enders, 2010). Rates of missing data varied from 0 to 13%, far below the recommended maximum 50% for multiple imputation (Collins et al., 2001; Graham, 2008). To correct for bias and maximize the precision of imputed data, demographic information and results on the CBQ, ECBQ and PSI from T2 were included in the imputation model (Enders, 2010).The pattern of missing data was analyzed using Little's MCAR test, which indicated that data were missing completely at random ($\chi2(1) = 2238.47$, $p = 0.126$). Since Little's test has low statistical power (Enders, 2010), complete and incomplete cases (for variables with 5% or more of missing data) were also compared to investigate whether they differed on any sociodemographic variables or on the main outcomes. Children who had missing data on the Attachment Q-Sort ($n = 25$) were older at both timepoint and had higher scores on the Shape Stroop at T1 (all ts between -2.7 and -2.3, ps < 0.05). Children who had missing data on Spin the Pots at T1 ($n = 15$) were younger at both timepoint (all ts between 2.8 and 2.1, ps < 0.05). Children who had missing data on the Conflict Scale at T1 ($n = 19$) were younger at both timepoint and had higher scores on Spin the Pots at both timepoints and higher score on the Conflict Scale at T2 (all ts between 3 and -2.9, ps < 0.05). Children who had missing data on Delay of Gratification at T1 ($n = 12$) had lower Parenting Stress at T2 ($t = 2.7$, $p = 0.019$). Children who had missing data on the Desire Tasks at T1 ($n = 17$) were younger on both timepoint and had lower negative affectivity at T2 (all *t*s between 8.4 and 2.1, ps < 0.05). Children who had missing data on the Conflict Scale at T2 ($n = 12$) were younger at both timepoint and had lower scores on Spin the Pots at T2 (all *t*s between 6.0 and 2.9, ps < 0.05). Children who had missing data on the PSI at T1 ($n = 12$) had higher CBCL internalizing behaviors at T1 ($t = -3.9$, $p = 0.003$). Finally, children who had missing MRO data ($n = 24$) were older at both timepoints and had higher scores on Shape Stroop and higher Negative Affectivity at T1 (all *t*s between -2.6 and -2.1, ps < 0.05). Missing demographic information were not imputed. Maternal years of education was missing for two participants (mTBI = 1; TDC = 1).

Missing values were imputed using the Markov Chain Monte Carlo procedure in SPSS (Charles, 1992). Twenty imputations were applied according to recommendations, and missing data estimated from all other data available (cognition, temperament, behavior, quality of life, attachment, parent-child interactions, parenting stress). Sociodemographic data were also included to maximize algorithm precision (Enders, 2010; Graham, 2008). Analyses were then run on each imputed data set and results were averaged (Schafer, 1997). Descriptive statistics were calculated to examine variable distributions.

Main analyses

Participants meeting all four criteria (no clinically significant behavioral problems; no cognitive difficulties; no persisting PCS; average quality of life or above) were considered to have optimal functioning. For the first objective, a Generalized Estimating

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Table 1. Participant sociodemographic characteristics, results on markers of optimal functioning, and predictor variables

Variable/group	TBI mean (SD) ($n = 69$)	Imputed data - TBI	OI mean (SD) ($n = 50$)	Imputed data - OI	TDC mean (SD) ($n = 71$)	Imputed data - TDC
Sociodemographics						
Child age T1 (months)	43.38 (11.19)	0	40.91 (11.47)	0	42.38 (11.82)	0
Child age T2 (months)	55.35 (10.85)	0	53.51 (11.93)	0	54.65 (11.86)	0
Child sex (% boys)	54%	0	46%	0	51%	0
Ethnicity (% caucasian)	86%	0	78%	0	86%	0
Optimal functioning criteria						
Quality of life - PEDSQL T1	84.25 (10.62)	3	84.77 (8.96)	1	85.65 (9.96)	2
Quality of life – PEDSQL T2	84.64 (8.82)	2	83.71 (9.81)	0	85.86 (9.14)	3
Internalizing behavior T Score – CBCL T1	52.43 (11.29)	2	49.27 (9.56)	1	46.93 (11.11)	0
Internalizing behavior T Score – CBCL T2	53.65 (13.42)	0	50.04 (9.13)	0	48.61 (11.09)	0
Externalizing behavior T Score – CBCL T1	53.12 (9.60)	2	50.64 (9.73)	1	48.63 (10.22)	0
Externalizing behavior T Score – CBCL T2	53.17 (11.53)	0	50.62 (8.14)	0	48.49 (8.93)	0
Post-concussion symptoms –PCS-I T1	0.77 (1.38)	2	0.66 (1.14)	1	0.58 (1.25)	2
Post-concussion symptoms –PCS-I T2	0.86 (1.20)	1	0.90 (1.40)	0	0.55 (1.32)	0
Cognition – Spin the pots T1	0.71 (0.19)	7	0.71 (0.21)	4	0.71 (0.18)	4
Cognition – Spin the pots T2	0.77 (0.17)	3	0.79 (0.16)	2	0.77 (0.15)	1
Cognition – Delay of gratification T1	3.77 (3.21)	4	4.80 (3.11)	6	4.74 (2.92)	2
Cognition – Delay of gratification T2	6.09 (2.77)	2	5.75 (3.00)	2	6.13 (2.76)	1
Cognition – Conflict scale T1	31.17 (16.45)	9	29.74 (16.96)	4	30.11 (16.46)	6
Cognition – Conflict scale T2	40.94 (7.68)	5	40.82 (6.73)	5	41.06 (7.01)	3
Cognition – Shape stroop T1	2.41(0.89)	2	2.49 (0.90)	4	2.55 (0.76)	2
Cognition – Shape stroop T2	2.83 (0.58)	4	2.81 (0.50)	0	2.82 (0.55)	0
Cognition – False beliefs T1	0.56 (0.69)	2	0.73 (0.78)	1	0.92 (0.74)	0
Cognition – False beliefs T2	0.86 (0.79)	5	0.82 (0.77)	0	0.96 (0.76)	3
Cognition – Desires task T1 ($n = 121$)	5.13 (1.11)	5	5.27 (0.94)	4	5.50 (0.90)	4
Cognition – Desires task T2	5.50 (0.81)	3	5.32 (1.15)	0	5.49 (0.96)	1
Cognition – Desire task T1 discrepant ($n = 69$)	1.44 (1.46)	2	2.33 (1.49)	1	2.25 (1.41)	1
Predictors						
Attachment Q-Sort	0.45 (0.33)	10	0.50 (0.34)	7	0.52 (0.25)	8
Parenting stress – PSI	46.98 (9.37)	2	47.92 (12.51)	2	47.58 (10.11)	5
Parent-child interaction quality	9. 04 (1.55)	9	9.06 (1.68)	8	9.65 (1.62)	7
Negative affect temperament – ECBQ T1 ($n = 69$)	3.05 (0.84)	2	2.75 (0.50)	0	2.63 (0.84)	0
Negative affect temperament – CBQ T1 ($n = 121$)	4.07 (0.90)	1	4.06 (0.73)	1	4.11 (0.73)	1
Number of acute symptoms at ED	3.17 (1.65)	0	NA	NA	NA	NA

Note: Statistics presented include imputed data.
PEDSQL = Pediatric Quality of Life Inventory; *CBCL* = Child Behavior Checklist; *PCS-I* = Post-Concussive Symptoms Interview; *PSI* = Parenting Stress Index; *ECBQ* = Early Childhood Behavior Checklist; *CBQ* = Childhood Behavior Checklist; *ED* = Emergency Department.

Equation (GEE) was used to verify group and time differences between T1 and T2. For the second objective, a logistic regression with a Cox and Snell variance analysis was conducted for the mTBI group to see if predictors at T1: sociodemographic (maternal education, child sex, age); parent and child factors (parent-child interaction, attachment, parenting stress, child negative affectivity) and injury factors (number of acute symptoms), predict optimal functioning at T2. Main analyses were performed with and without participants with complex mTBI.

Results

Participant characteristics and information on imputed data are presented in Table 1.

Mechanisms of injury were mainly falls (88.40%). GCS was homogenous and high (89.90% = 15). No significant differences were found between the three groups on any sociodemographic variable, but maternal years of education (Table 2) was on the cusp (X^2 (12, $N = 188$) = 20.918, $p = 0.052$).

Correlations between the main study variables are presented in Table 3. Descriptive statistics for the percentage and number of participants meeting optimal functioning criteria are presented in Table 4.

The results of the GEE analysis (Figure 1) showed a significant group effect ($p < .001$) for the proportion of children with optimal functioning. Significantly fewer children with mTBI had optimal functioning compared to OI (mean difference = −0.158, $SE = 0.066$, $p = 0.008$, 95% Wald interval between -0.290 and −0.029) and TDC (mean difference = −0.241, $SE = 0.060$, $p <$ 0.001, 95% Wald interval between −0.358 and −0.121). There was no significant group difference between the TDC and OI groups with a mean difference of 0.082 ($SE = 0.064$, $p = 0.106$). No effect of time ($p = 0.711$) or group × time interaction ($p = 0.771$) was found. When children ($n = 9$) with complex mTBI were removed, the results were similar (Table 6; supplementary material).

The binary logistic regression model (Table 5) was significant (X^2 (7, $N = 68$) = 15.387, $p = 0.043$), explaining 20.20% of the variance. Higher quality of parent-child interactions ($B = 0.480$, $p = 0.025$) and lower child negative affectivity temperament ($B = −0.615$, $p = 0.045$) independently predicted optimal recovery at T2. The model remained significant when children with complex mTBI were removed (X^2 (7, $N = 60$) = 15.222, $p = 0.048$, $R^2 = 0.245$). Higher quality of parent-child interactions was still an

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Table 2. Maternal years of education

Education/group	TBI ($n = 68$)	OI ($n = 50$)	TDC ($n = 70$)
1- Doctoral degree university studies (Ph.D.)	6 (8.8%)	2 (4.0%)	5 (7.1%)
2- Master's degree university studies (Msc)	13 (19.1%)	17 (34.0%)	20 (28.5%)
3- Undergraduate studies (BSc)	25 (36.7%)	20 (40.0%)	39 (55.7%)
4- One to three years of college/CEGEP	13 (19.1%)	8 (16.0%)	4 (5.7%)
5- High school completed	9 (13.2%)	2 (4.0%)	2 (2.8%)
6- 10 to 11 years of education (high school not completed)	1 (1.4%)	1 (2.0%)	0 (0.0%)
7- Six to nine years of education	1 (1.4%)	0 (0.0%)	0 (0.0%)

Two mothers had missing data on years of education (TBI = 1; TDC = 1). *CEGEP* = College of General and Professional Teaching. In Quebec, Canada, students attend CEGEP after high school for 2 (preparation for university) or 3 (preparation for job market) years.

Table 3. Correlations matrix including predictors, sociodemographic variables, and optimal functioning for all groups

	Attachment	Child sex	Education	Parenting stress T1	Age T1	Parent-child interaction T1	Negative affectivity T1	Optimal functioning T1
Child sex	0.062							
Mother education	−0.073	**0.166***						
Parenting stress T1	**−0.183***	0.030	**.150***					
Age T1	0.040	0.012	−0.011	0.108				
Parent-child interaction T1	**0.221****	0.036	−0.026	**−0.234****	−0.027			
Negative affectivity T1	−0.060	−0.055	−0.006	**0.281****	0.068	−0.087		
Optimal functioning T1	0.087	−0.136	**−0.301****	**−0.211****	**0.170***	0.090	−0.144	
Optimal functioning T2	0.018	−0.114	−0.027	**−0.181***	0.131	**0.238****	**−0.195****	0.132

*$p < 0.05$; **$p < 0.01$.

Table 4. Percentage of participants meeting optimal functioning criteria

Criteria	TBI ($n = 69$)	OI ($n = 50$)	TDC ($n = 71$)
Cognition T1	51 (73.9%)	43 (86.0%)	63 (88.7%)
Quality of life T1	67 (97.1%)	49 (98.0%)	70 (98.5%)
Behavior T1	55 (79.7%)	43 (86.0%)	65 (91.5%)
Post-concussion symptoms T1	60 (86.9%)	44 (88.0%)	66 (92.9%)
Optimal functioning T1	**33 (47.8%)**	**33 (66.0%)**	**54 (76.0%)**
Cognition T2	54 (78.2%)	41 (82.0%)	57 (80.2%)
Quality of life T2	68 (98.5%)	49 (98.0%)	69 (97.1%)
Behavior T2	57 (82.6%)	47 (94.0%)	65 (91.5%)
Post-concussion symptoms T2	61 (88.4%)	45 (90.0%)	67 (94.3%)
Optimal functioning T2	**37 (53.6%)**	**34 (68.0%)**	**52 (73.2%)**

independent predictor ($B = 0.516$, $p = 0.032$), but negative affectivity temperament was no longer significant ($B = -0.601$, $p = 0.089$).

Discussion

This study aimed to document group differences and factors associated with optimal functioning after early mTBI to identify potential targets that could promote positive outcome. The findings indicate that fewer children with mTBI have optimal functioning compared to OI and TDC at 6 (mTBI = 47.8%; OI = 66.0%; TDC = 76.0%) and 18 (mTBI = 53.6%; OI = 68.0%; TDC = 73.2%) months post-injury. Beauchamp and colleagues (2019) used three similar criteria (absence of PCS and cognitive inefficiency, good quality of life) and found that 52.2% of older children (6–18 years) were classified as having optimal functioning ("being well") three months after their injury. A similar proportion was found in the present study 18-months post-injury (53.6%) and contrasted with the proportion found in typically developing children (73.2%) and children with OI (68.0%). While not directly comparable, these results suggest that younger children may have a more protracted pattern of long-term recovery. However, no data were collected between the ED visit and T1, therefore it is unclear what the rate of children meeting all four criteria of optimal functioning was during the earlier stages of recovery.

The inclusion of child behavior as a component of optimal functioning may have led to the identification of more children with poorer functioning. Previous work in the same cohort found that early mTBI was associated with more clinically significant behavior problems 6 and 18-months post-injury (Gagner et al., 2018). School-age children (5–18 years) also present more behavior problems in the first months post-injury, which lessen after 3 months (Gornall et al., 2019). Other work indicates that infants and toddlers exhibit more behavioral manifestations of PCS

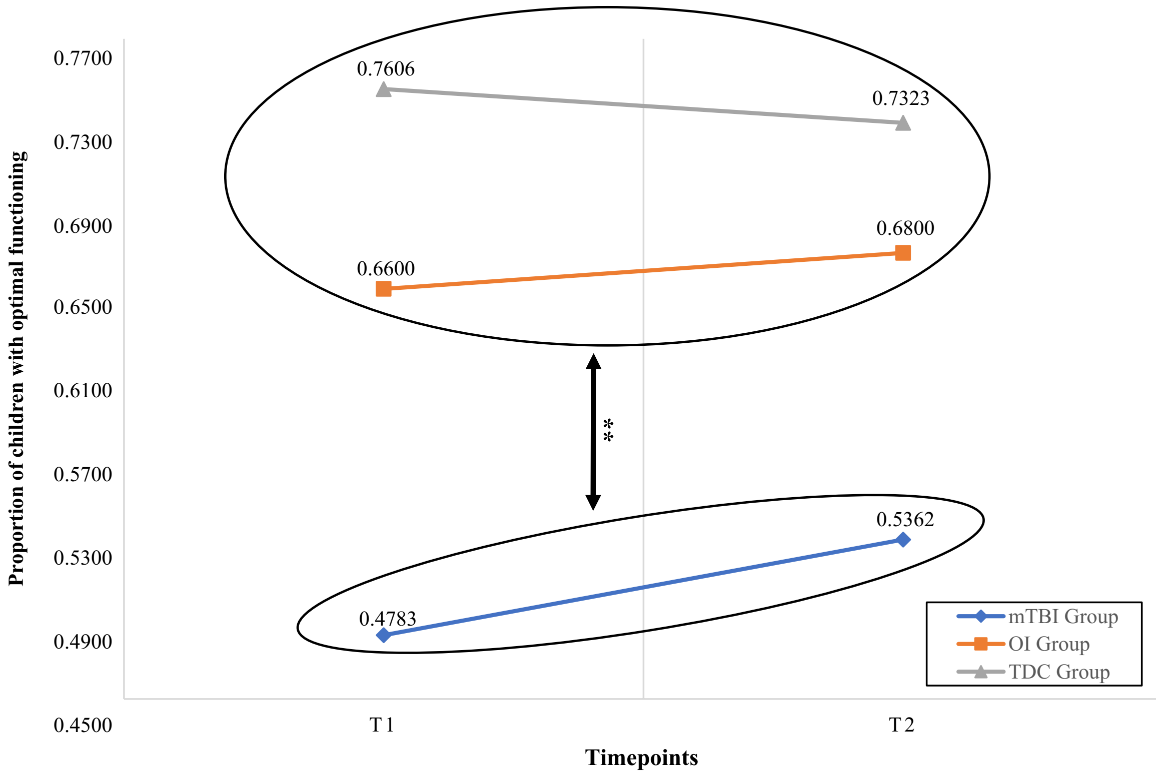

Figure 1. Evolution of the proportion of children with optimal functioning. This figure presents the percentage of children meeting all four optimal functioning criteria (*Y* axis) in each group for both timepoints (*X* axis). Each symbol represents a group: the triangle for the typically developing children, the square for children with orthopedic injury, and the diamond for children with mild traumatic brain injury. Lines within the same oval indicate no significant difference, while lines not within the same oval indicate a significant difference. **ps < 0.001.

Table 5. Regression analysis for mild traumatic brain injury group to predict optimal functioning at T2 ($n = 68$)

Variable	B	E.S	Wald	OR	Sig.
Maternal education	−0.011	0.214	0.046	0.989	0.962
Child sex	−0.573	0.621	0.939	0.564	0.356
Number of acute symptoms	−0.150	0.179	0.860	0.861	0.400
Parenting stress	−0.003	0.036	0.131	0.997	0.943
Attachment	−1.179	1.169	2.039	0.307	0.315
Parent-child interaction	**0.480**	**0.214**	**5.810**	**1.616**	**0.025**
Negative affectivity	**−0.615**	**0.307**	**4.498**	**0.541**	**0.045**

Group effect is significant ($p = 0.001$).

than children 3–8 years, likely due to their inability to verbalize what they are experiencing or due to limited cognitive abilities (Dupont et al., 2021). These behavioral manifestations may contribute to lower optimal functioning, as well as affect the quality of parent-child interactions (Beauchamp et al., 2021).

Lower child negative affectivity temperament was an independent predictor of optimal functioning. Higher negative affectivity temperament and negative beliefs and attributions are associated with internalizing behavior problems in typically developing children (Crawford et al., 2011), which can lead to a more negative view of life events (Campbell & Fehr, 1990; Witthöft et al., 2012). Children with more negative affectivity tend to react to situations with more fear, anger, discomfort, sadness or anger (Putnam & Rothbart, 2006; Rothbart, 1981). Thus, children with higher negative affectivity traits who sustain early mTBI might feel more distress in relation to the potentially traumatic experience, contributing to lowering their overall functioning. Interestingly, negative affectivity was no longer an independent predictor when participants with complex mTBI were removed from the analyses. This could be due to reduced statistical power, but evidence from the same cohort also suggests that more severe forms of early TBI (mild complex, moderate, severe) alter the trajectory of temperamental traits (Séguin et al., 2020), thus, the inclusion of a few children with more severe TBI might explain these results.

Parent-child interaction quality was also linked to optimal functioning after early mTBI. Better parent-child interaction quality is characterized by a positive emotional ambiance (e.g. displays of affection, smiles, complicity, and joy), mutual cooperation (e.g. presence of an open posture by the parent and the child), and harmonious communication (e.g. communication initiatives by the child and the parent; Kochanska et al., 2008). High parent-child interaction quality is associated with better sociocognitive skills in early childhood (Aubuchon et al., 2023; Licata et al., 2016) and low parent-child interaction quality is associated with more externalizing behaviors in middle childhood (Dubois-Comtois et al., 2013). In the context of early mTBI, children with higher negative affectivity traits might feel more distress following the injury, which in turn could elicit reactions from the parents who must respond and adjust their child's needs.

The findings did not support the idea that attachment and parenting stress predict optimal functioning after early mTBI. It may be that parent-child interaction accounts for more variance in optimal functioning because of the stimulating aspect of the interactions, which may be more salient in bolstering child recovery. While being securely attached to a parent with low stress may certainly be expected to enhance functioning, these factors do not necessarily ensure that the child has access to high-quality stimulation through verbal exchange and active play. Also, while parenting stress was not a significant independent predictor of optimal functioning, significant correlations were found with parent-child interaction quality, negative affectivity and optimal recovery, suggesting that associations are nonetheless present. Methodological factors may also be at play. Both the Parenting Stress Index and Attachment Q-Sort versions used were brief versions of the original measures. It is possible that more exhaustive, or other more extensive assessment tools, may have included elements with more predictive power.

The study findings can be interpreted in light of the Perception, Attribution, and Response after Early Non-inflicted Traumatic Brain Injury (PARENT) model (Beauchamp et al., 2021). The model posits that when a child sustains mTBI during early childhood, parents' accurate perception of the child's symptoms (present or absent), their correct attribution of the symptoms to the injury, and their own behavioral adjustment contribute to child recovery. Having a child who sustains TBI can be disruptive, especially if the injured child manifests behavioral changes that require the parent to manage and respond to the child's needs (Gagné et al., 2012; Gagner et al., 2020). Previous studies reported poorer parent-child interaction quality in this population, with interactions between mTBI dyads characterized by less communication and cooperation, and more conflicts and reprimands (Lalonde et al., 2018). Enhancing parent-child interaction may be a key intervention target to optimize functioning after early mTBI. A meta-analysis by Thomas and colleagues (2017) showed that Parent-Child Interaction Therapy, a program for parents that focuses on enhancing parent-child relationships and reducing challenging child behaviors, helps reduce externalizing problems and parent stress in typically developing children. Maggard and colleagues (2023) explored the feasibility and acceptability of online parenting-skills programs for caregivers of children with early complex mTBI and showed that the majority of participants found the program helpful. Since positive parenting contributes to child development (Knauer et al., 2019), intervention programs focusing on this aspect may be beneficial for promoting optimal functioning after early mTBI.

Strengths, limitations, and future directions

This study contributes to emerging efforts to study optimal functioning after mTBI and is the first to focus on early childhood. The inclusion of two comparison groups allowed us to tease out general injury versus brain injury effects. Nonetheless, some limitations need to be considered. First, the results are correlational and do not inform on causality. Second, participants were mainly Caucasian with educated parents, limiting generalization. Third, the PCS questionnaire was not validated for young children and may not have fully represented the reality of young, pre-verbal children. Since the study inception, developmentally appropriate methods for tracking PCS in young children have emerged (Dupont et al., 2024; Yumul et al., 2022). Fourth, parent report was used to document PCS, behavior, and temperament; as with any third party questionnaire, inherent subjective biases may have been introduced (Huynh et al., 2023). Fifth, the number of candidate predictor variables was limited to avoid overfitting the model. Given the scant literature on temperament and TBI, it is possible that other dimensions could be interesting to explore. In this study, optimal functioning was conceptualized according to four criteria (behavior, cognition, PCS, quality of life). Future studies should investigate optimal functioning using even more comprehensive approaches, and before 6 months to obtain a more complete portrait.

Conclusions

Children aged 0–5 years constitute an understudied group despite the high prevalence of mTBI during early childhood, and clinical management and treatment strategies are often not adapted to their unique characteristics (Beauchamp et al., 2024). Given the predominant role of parents during the first years of life, the potential for early mTBI to impact parent-child relationships, and the strong association between the quality of parent-child interactions and optimal functioning, interventions and strategies to enhance communication, cooperation, and emotional connections after early mTBI appear to be good targets for promoting optimal recovery and function. Potential difficulties related to behavior and the family environment or parent-child relations could be documented when children present with early mTBI in order both to reduce risk of poor outcome and to optimize recovery.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1355617724000572.

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