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Early developmental, behavioral, and quality of life outcomes following abusive head trauma in infants

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ABSTRACT

Background: Developmental delays following pediatric abusive head trauma are common.
Objective: To assess early developmental, behavioral, and quality of life outcomes following infant abusive head trauma and evaluate injury severity and early therapeutic intervention as potential predictors.
Participants and setting: Infants under 12 months old who were admitted to a large pediatric hospital with abusive head trauma between October 2010 and October 2017 and followed at a multidisciplinary post-injury clinic were included.
Methods: Injury severity groups were classified based on days in the Pediatric Intensive Care Unit. Participation in early intervention services and/or physical or occupational therapy by the first clinic visit was documented. Development was assessed using the Mullen Scales of Early Learning, which 47 patients completed at approximately 6 month intervals up to 3 years of age (an average of 19 months post-injury). Behavior and quality of life were assessed around age 2 using the Child Behavior Checklist ($n = 24$) and PedsQL™ ($n = 27$), respectively.
Results: Overall cognitive development, fine motor function, and expressive language significantly declined with age up to 3 years ($p < 0.05$). The changes in these developmental scales with age differed significantly between injury severity groups ($p < 0.05$). Internalizing behaviors were also greater in patients with moderate than mild injuries ($t = 2.37$, $p = 0.037$). Quality of life was comparable to healthy populations. Early therapeutic intervention was not significantly associated with developmental, behavioral, or quality of life outcomes ($p > 0.05$).
Conclusions: Long-term comprehensive follow-up is recommended for children following abusive head trauma, as developmental delays and behavioral problems may present at later ages.

1. Introduction

Pediatric abusive head trauma is an injury to the head of a young child that results from inflicted blunt impact and/or violent shaking (Christian, Block, & the Committee on Child Abuse and Neglect, 2009). Abusive head trauma has an incidence rate of 14–40

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per 100,000 infants (Barlow & Minns, 2000; Fanconi & Lips, 2010; Keenan et al., 2003; Talvik et al., 2006) and is the leading cause of traumatic death in infants (Ortega, Vander Velden, Kreykes, & Reid, 2013). The mortality rate has been estimated to be 13–36 % (Barlow, Thompson, Johnson, & Minns, 2004).

Evidence from across studies has found that the majority of children who survive (45–96 %) suffer significant morbidity and neurological impairment (Lind et al., 2016; Nuño et al., 2018), with developmental delays in 47 %, learning disorders in 42 %, epilepsy in 36 %, motor deficits in 34 %, visual impairment in 30 %, behavioral disorders in 30 %, and communication deficits in 11 % (Nuño et al., 2018). Head trauma resulting from abuse is associated with worse functional outcomes than non-inflicted head trauma (Adamo, Drazin, Smith, & Waldman, 2009; Keenan, Runyan, & Nocera, 2006).

Since abusive head trauma occurs most often to infants under one year of age, peaking between 1–3 months of age (Parks, Sugerman, Xu, & Coronado, 2012; Parks, Kegler, Annest, & Mercy, 2012), its full impact on development may not become apparent for years (Bonnier, Nassogne, & Evrard, 1995). Studies have found a delayed presentation of sequelae among children thought to have recovered in infancy, with deficits emerging years later and impacting daily functioning, learning, and behavior (Barlow, Thomson, Johnson, & Minns, 2005; Bonnier et al., 1995; Duhaime, Christian, Moss, & Seidl, 1996; Karandikar, Coles, Jayawant, & Kemp, 2004). Primary medical providers and families often inquire about an infant's prognosis following injury. Many indicators of severity at the time of injury have been correlated with worse global functional outcomes with age (Barlow et al., 2005; Bonnier et al., 2003; Duhaime et al., 1996; Greiner, Lawrence, Horn, Newmeyer, & Makoroff, 2012; Rhine, Wade, Makoroff, Cassedy, & Michaud, 2012). These prior studies, however, had mostly small sample sizes (under 50 patients), and many evaluated function at inconsistent lengths of follow-up using categorical assessments of disability/recovery (Barlow et al., 2004; Chevignard & Lind, 2014; Lind et al., 2016; McMillan et al., 2016). Children who survive abusive head trauma often utilize long-term rehabilitative services, including physical, occupational, and speech therapies and special education. Little is known about the impact of these services on outcomes.

The purpose of this study was to evaluate developmental trajectories up to 3 years of age among children who suffered abusive head trauma prior to 1 year of age and to characterize behavioral and health-related quality of life outcomes using validated, multidimensional, quantitative assessments. Injury severity was assessed as a potential predictor of these developmental, behavioral, and health-related quality of life outcome measures, given its identified association with functional outcomes following abusive head trauma. Participation in early intervention or physical or occupational therapy shortly after injury and its influence on these outcomes was also investigated. It was hypothesized that children with moderate and severe injuries would show greater loss of developmental function with age than children with mild injuries and that early participation in therapy would preserve developmental function with age.

2. Methods

2.1. Participants

This retrospective longitudinal study included patients under 12.0 months of age who were admitted to a large Midwestern tertiary-care children's hospital with a diagnosis of abusive head trauma between October 1, 2010 and October 31, 2017 and followed up in a post-injury clinic within a hospital-based child advocacy center. This multidisciplinary clinic evaluates and routinely monitors the physical health and development of children with a history of abusive head trauma from injury to school age with the goal of identifying needs early and connecting families with supports. Patients are followed in post injury clinic first at 3–6 months following injury and then at approximately 6 month intervals. A child abuse pediatrician performs medical examinations; a trained nurse

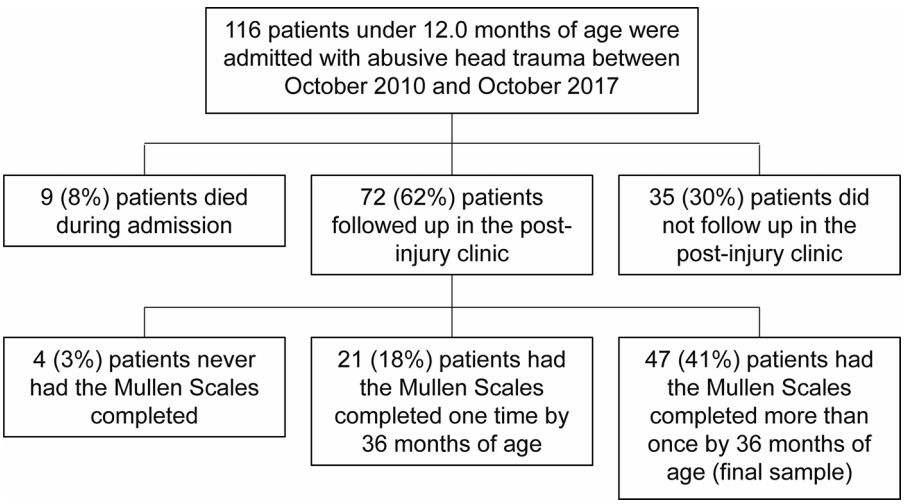

Fig. 1. Consort Flow Diagram of Infants Admitted with Abusive Head Trauma Who Followed up in Post-Injury Clinic and Completed the Mullen Scales of Early Learning More Than Once.

practitioner performs developmental testing, and a social worker performs psychosocial assessment and referrals. A consort flow diagram of the patient population included in analyses can be found in Fig. 1. This study was approved by the hospital Institutional Review Board, which granted a waiver of informed consent.

2.2. Data source

The electronic medical records of identified patients were manually reviewed for patient demographics (e.g. age, gender, race, ethnicity, insurance), injury severity at the time of hospital presentation (e.g. Glasgow Coma Scale [GCS] score, number of days hospitalized, number of days in the Pediatric Intensive Care Unit [PICU]), dates of post-injury clinic visits, types of therapies received following injury (e.g. early intervention, physical therapy [PT], occupational therapy [OT]) and outcome measures.

2.3. Outcome variables

The Mullen Scales of Early Learning is a standardized developmental assessment that measures cognitive and motor function in children 0–68 months of age. The assessment is based on the concept that early cognitive development is best measured by a group of distinct cognitive abilities since a global score alone may mask variability in a child's skills. The Mullen Scales consist of a Gross Motor Scale administered from birth through 33 months and four cognitive scales administered from birth through 68 months: Visual Reception, Fine Motor, Receptive Language, and Expressive Language. Raw scores for each Mullen scale are converted to a normative score (T-score), and T-scores for the four cognitive scales are used to derive a composite score called the Early Learning Composite (Mullen, 1995). The Mullen Scales of Early Learning demonstrate good construct, convergent, and divergent validity (Swineford, Guthrie, & Thurm, 2015). The assessment utilizes responses from both caregiver and child and demonstration of skills by the child. It was completed at post-injury clinic visits by a trained clinician. T-scores were quantified for each scale (mean [M] = 50, standard deviation [SD] = 10) and used in all analyses. An early learning composite was also quantified with a standardized score (M = 100, SD = 15) and used in all analyses. Higher scores indicate better function. Patients were considered to have a delay in a domain if their score was over one SD below the mean for age-based norms. Patients were excluded from this study if they did not complete the Mullen Scales of Early Learning more than once by 36 months of age. For patients who completed the Mullen Scales more than once, up to four assessments were included per patient.

The Child Behavior Checklist (CBCL) for Ages 1½ -5 is a 99-item caregiver-report questionnaire that assesses child behavioral and emotional problems (Achenbach & Rescorla, 2001). The CBCL exhibits good construct validity, test-retest and inter-rater reliabilities, and internal consistency (Ha, Kim, Song, Kwak, & Eom, 2011; Pandolfi, Magyar, & Dill, 2009). The CBCL was given to caregivers to complete about their child at an appointment between 18–36 months of age. T-scores for the internalizing behaviors (includes the emotionally reactive, anxious/depressed, somatic complaints, and withdrawn syndrome scales), externalizing behaviors (includes the attention problems and aggressive behaviors syndrome scales), and total problems scales were used in all analyses. Scores range from 28 to 100, with higher scores indicating more behavioral problems. Scores from 60 to 63 are in the borderline clinical range, and scores above 63 are in the clinical range.

The PedsQL™ assesses health-related quality of life in children and exhibits excellent internal consistency and construct validity (Varni, Seid, & Rode, 1999). The PedsQL™ Infant Scale or Generic Core Scale for Toddlers was given to caregivers to complete about their child at an appointment between 12–36 months of age. The Infant Scale (ages 13–24 months) is a 45-item questionnaire that assesses child physical symptoms and physical, emotional, social, and cognitive functioning. The Parent Report for Toddlers (ages 2–4 years) is a 21-item questionnaire that assesses child physical, emotional, social, and school functioning. The psychosocial health, physical health, and total summary scores were used in all analyses. Scores range from 0 to 100, with higher scores indicating better health-related quality of life. Patients were considered at-risk for impaired health-related quality of life if they had scores below 83.3 for physical health, 80.2 for psychosocial health, and 81.3 for the total scale, which is over one SD below the healthy population mean (Varni, Burwinkle, Seid, & Skarr, 2003).

2.4. Predictor variables

Injury severity at the time of injury was classified based on the length of stay in the Pediatric Intensive Care Unit (PICU). The Glasgow Coma Scale (GCS), a more typical measure of severity of acute brain injuries, was not used because it was not available in 10 patients in this sample. Previous research has shown that the GCS score strongly correlates with length of stay in the PICU among children admitted to the PICU after a traumatic brain injury (Natale, Joseph, Helfaer, & Shaffner, 2000; Ongun & Dursun, 2018; White et al., 2001). Using Pearson correlations, the present study found the GCS score at hospital admission to be more highly correlated with days in the PICU (r=-0.62, $p < 0.001$) than days admitted to the hospital (r=-0.47, $p = 0.003$). Children with a GCS score $\leq$8 have previously been found to have 44.8 (9.4–200) times greater odds of having a PICU stay of 4 or more days ($p < 0.01$, Natale et al., 2000). Therefore, the current study classified severe injuries as 4 or more days in the PICU (value of 2), moderate injuries as 2–3 days in the PICU (value of 1), and mild injuries as 0–1 days in the PICU (value of 0).

Early therapy participation was defined as the patient participating in either home-based early intervention, outpatient physical therapy, or outpatient occupational therapy at the time of their first Mullen Scales assessment and dichotomized as "yes" (value of 1) or "no" (value of 0).

2.5. Data analysis

Descriptive statistics were used to characterize the sample. Demographic characteristics, injury severity, Mullen Scales at first assessment, and therapy participation at first assessment were compared between patients who did and did not follow-up in post-injury clinic as well as between patients who did and did not complete the Mullen Scales more than once by 36 months of age using independent sample t-tests (for age at injury, days admitted to the hospital, days in the PICU, age at first assessment, and each Mullen Scale score at first assessment), Fisher exact tests (for gender, race, ethnicity, and therapy participation at first assessment), and chi-square tests (for insurance type and injury severity). The prevalence of patients participating in early therapy was compared between injury severity groups using a chi-square test. General Estimating Equations (GEE) were run with age (in months) at Mullen Scale assessment predicting each Mullen Scale score and were fit using an exchangeable correlation matrix structure and an identity link function (normal distribution). Linear regressions were then run for each patient to derive their individual slope of change with age (using the unstandardized beta coefficient) for each Mullen Scale. One-way ANOVAs were run comparing the three injury severity groups on their initial function at the first assessment for each Mullen Scale. For scales where their initial function differed by injury severity, independent sample t-tests were run comparing each of the injury severity groups (mild vs. moderate, mild vs. severe, moderate vs. severe) to determine specifically which groups differed in initial function. Multivariable linear regressions were then run with injury severity and their initial function on each Mullen Scale predicting the slope of change with age for each Mullen Scale to determine whether injury severity influenced their change in function with age. Subsequent regressions were run comparing each of the injury severity groups to determine specifically which groups differed in their change in function with age. Next, early therapy participation was added as a predictor variable to the multivariable linear regression models with injury severity and initial function to determine the influence of early participation in therapy on their slope of change in function with age. After that, an interaction term (therapy participation by injury severity) was added to these models in stepwise fashion to determine if therapy had a differential effect depending on the degree of injury severity for any of the Mullen Scales. For each of the CBCL and PedsQL™ scales, scores were compared between genders, races, ethnicities, insurance types, and whether or not the patient was living in their home of origin at the time of assessment using independent sample t-tests, between the types of caregivers who completed the surveys (biological parents, kinship caregivers, or foster/adoptive caregivers) using one-way ANOVAs, and by age at the time of injury using linear regression. For each scale, linear regressions were run with the following predictors in three steps: 1) age at assessment, 2) age at assessment and injury severity, then 3) age at assessment, injury severity, and early therapy participation.

3. Results

3.1. Sample characteristics

A total of 116 patients under 12.0 months of age were admitted with abusive head trauma during the study period, nine (8%) of whom died during their hospital admission. The diagnosis of abusive head trauma was made at initial hospitalization by a child abuse pediatrician with a multidisciplinary team review. The demographic characteristics and injury severity of the remaining 107 patients can be found in Table 1. Seventy-two patients (67 %) attended a follow-up appointment at the post-injury clinic. These patients did not significantly differ from those who did not follow-up in terms of demographics and injury severity (Table 1). Forty-seven patients completed the Mullen Scales of Early Learning more than once by 3 years of age and were followed an average of 19 months (SD = 7) after their injury. The Mullen Scales were completed approximately every six months in 25 (53 %) patients, with 13 (28 %) patients missing one assessment and 9 (19 %) patients missing two assessments. The patients who completed the Mullen Scales more than once did not significantly differ from those who did not (Table 1). The final sample size included in analyses was 47 patients.

3.2. Development with age

The Mullen Scales were assessed for the first time an average of 5.3 (SD = 2.6) months after injury at an average age of 9.5 (SD = 3.4) months. At this first assessment, none of the Mullen Scales differed significantly based on patient gender, race, ethnicity, age at the time of injury, or insurance type ($p > 0.05$), except publicly insured patients had worse visual reception initially ($M = 42.5$, $SD = 9.8$) than privately insured ($M = 54.5$, $SD = 11.3$, $t = -2.97$, $p = 0.005$) or self-pay ($M = 52.6$, $SD = 15.7$, $t = 2.32$, $p = 0.026$) patients. Greater time between injury and first assessment was associated with significantly lower initial early learning composite ($t = -2.30$, $p = 0.027$) and receptive language scores ($t = -3.27$, $p = 0.002$), but not with the slope of change with age of any of the Mullen Scales ($p > 0.05$).

As patients aged, their early learning composite, fine motor, and expressive language scores significantly decreased (Table 2). Estimates indicate that average function on these three scales declined from *within* one standard deviation (SD) below age-based norms at the first assessment to *over* one SD below age-based norms by 3 years of age (Table 2). At first assessment, the percentage of patients with scores *over* one SD below age-based norms was 23 % ($n = 11$) for the early learning composite, 26 % ($n = 12$) for gross motor function, 19 % ($n = 9$) for fine motor function, 30 % ($n = 14$) for receptive language, 28 % ($n = 13$) for expressive language, and 30 % ($n = 14$) for visual reception. At last assessment, the percentage of patients with scores *over* one SD below age-based norms was 32 % ($n = 15$) for the early learning composite, 28 % ($n = 13$) for gross motor function, 30 % ($n = 14$) for fine motor function, 30 % ($n = 14$) for receptive language, 40 % ($n = 19$) for expressive language, and 28 % ($n = 13$) for visual reception.

Table 1
Demographic Characteristics and Injury Severity during Hospital Admission among Infants with Abusive Head Trauma and Based on Attendance at Post-Injury Clinic and Completion of Mullen Scales of Early Learning.

Variables	Attended Post-Injury Clinic		Difference	Completed Mullen Scales More than Once		Difference
	No (n = 35)	Yes (n = 72)	t or χ^2 (p-value)	No (n = 25)	Yes (n = 47)	t or χ^2 (p-value)
Demographic Characteristics						
Age at Injury (months), mean (SD)	4.4 (2.1)	4.0 (2.4)	0.91 (0.37)	3.6 (2.2)	4.2 (2.5)	−0.97 (0.34)
Gender			(0.52)			(0.077)
Male, n (%)	24 (69 %)	44 (61 %)		19 (76 %)	25 (53 %)	
Female, n (%)	11 (31 %)	28 (39 %)		6 (24 %)	22 (47 %)	
Race			(1.00)[a]			(0.55)[a]
White/Caucasian, n (%)	24 (77 %)	49 (74 %)		19 (83 %)	30 (70 %)	
Black/African American, n (%)	7 (23 %)	14 (21 %)		4 (17 %)	10 (23 %)	
More than One Race, n (%)	0 (0%)	3 (5%)		0 (0%)	3 (7%)	
Ethnicity			(0.22)			(0.68)
Non-Hispanic/Latino, n (%)	28 (80 %)	63 (90 %)		20 (87 %)	43 (91 %)	
Hispanic/Latino, n (%)	7 (20 %)	7 (10 %)		3 (13 %)	4 (9%)	
Insurance Type at First Assessment			–			0.52 (0.77)
Public, n (%)	–	48 (67 %)		18 (72 %)	30 (64 %)	
Private, n (%)	–	11 (15 %)		3 (12 %)	8 (17 %)	
Self-pay, n (%)	–	13 (18 %)		4 (16 %)	9 (19 %)	
Injury Severity						
Days Admitted to Hospital, mean (SD)	8 (10)	10 (9)	−1.01 (0.32)	10 (9)	10 (9)	−0.15 (0.88)
PICU Days, mean (SD)	3 (4)	4 (4)	−0.87 (0.39)	4 (4)	4 (4)	0.62 (0.54)
Injury Severity			1.31 (0.52)			0.51 (0.77)
Mild, n (%)	15 (43 %)	23 (32 %)		7 (28 %)	16 (34 %)	
Moderate, n (%)	9 (26 %)	24 (33 %)		8 (32 %)	16 (34 %)	
Severe, n (%)	11 (31 %)	25 (35 %)		10 (40 %)	15 (32 %)	
Mullen Scales at First Assessment						
Age at Initial Mullen Scale, mean (SD)	–	10.2 (4.7)	–	11.6 (6.4)	9.5 (3.4)	1.50 (0.14)
Early Learning Composite Score, mean (SD)	–	94.7 (16.9)	–	93.9 (18.3)	95.0 (16.5)	−0.22 (0.83)
Gross Motor Score, mean (SD)	–	45.5 (13.5)	–	45.6 (15.3)	45.5 (12.7)	0.04 (0.97)
Fine Motor Score, mean (SD)	–	46.9 (13.4)	–	44.4 (15.1)	48.0 (12.7)	−1.01 (0.32)
Receptive Language Score, mean (SD)	–	46.6 (12.2)	–	47.7 (13.9)	46.1 (11.5)	0.48 (0.63)
Expressive Language Score, mean (SD)	–	45.3 (10.2)	–	42.3 (10.2)	46.6 (10.0)	−1.61 (0.11)
Visual Reception Score, mean (SD)	–	46.6 (12.2)	–	46.8 (12.0)	46.5 (12.4)	0.09 (0.93)
Therapy Participation at First Assessment						
Any Therapy, n (%)	–	37 (51 %)	–	13 (52 %)	24 (51 %)	(1.00)
Early Intervention, n (%)	–	28 (39 %)	–	8 (32 %)	20 (43 %)	(0.45)
Physical or Occupational Therapy, n (%)	–	22 (31 %)	–	8 (32 %)	14 (30 %)	(1.00)

Notes: n (%) or means and standard deviations (SD) are reported.
[a] "More than one race" category was not included in statistical analysis.

Table 2
General Estimating Equations with Age Predicting the Mullen Scales of Early Learning Scores Up to 3 Years of Age among Children Following Abusive Head Trauma (n = 47).

Variables	Age					Change with Age	
	12 Months *M (SE)*	18 Months *M (SE)*	24 Months *M (SE)*	30 Months *M (SE)*	36 Months *M (SE)*	*B* (95 % *CI*)	*t* (*p*-value)
Early Learning Composite	93.3 (5.2)	90.9 (6.1)	88.5 (7.1)	86.1 (8.0)	83.7 (9.0)	−0.40 (-0.72, -0.07)	−2.41 (0.016)*
Gross Motor	45.5 (4.0)	44.7 (4.7)	44.0 (5.5)	43.2 (6.2)	42.4 (6.9)	−0.13 (-0.37, 0.11)	−1.07 (0.28)
Fine Motor	47.9 (3.7)	45.8 (4.4)	43.8 (5.0)	41.8 (5.7)	39.7 (6.3)	−0.34 (-0.56, -0.12)	−3.05 (0.002)*
Receptive Language	44.9 (3.7)	44.4 (4.3)	43.9 (5.0)	43.4 (5.6)	43.0 (6.3)	−0.08 (-0.29, 0.14)	−0.71 (0.48)
Expressive Language	45.0 (4.2)	43.1 (5.0)	41.1 (5.8)	39.1 (6.7)	37.1 (7.5)	−0.33 (-0.61, -0.05)	−2.31 (0.021)*
Visual Reception	46.9 (3.3)	46.0 (3.9)	45.2 (4.5)	44.3 (5.1)	43.5 (5.7)	−0.14 (-0.34, 0.06)	−1.39 (0.16)

Notes: Means (M) and standard errors (SE) are reported.
* $p < 0.05$ indicates statistical significance.

Table 3
Differences in Initial Function and Slope of Change with Age in Mullen Scales of Early Learning Scores Based on Injury Severity among Children Following Abusive Head Trauma Up to 3 Years of Age (n = 47).

Variables	Injury Severity			Difference between Injury Severity Groups		
	Mild (n = 16)	Moderate (n = 16)	Severe (n = 15)			
	M (SD)	*M (SD)*	*M (SD)*		η^2	*F (p-value)*
Initial scores						
Early Learning Composite	99.8 (13.4)	102.6 (12.6)	81.4 (15.8)		0.32	9.80 (< 0.001)*,†,‡
Gross Motor	52.0 (7.7)	45.8 (14.3)	38.3 (12.1)		0.19	5.39 (0.008)*,†
Fine Motor	51.0 (7.9)	49.6 (13.2)	43.2 (15.4)		0.07	1.69 (0.20)
Receptive Language	51.4 (12.9)	47.7 (9.8)	38.8 (7.9)		0.21	5.93 (0.005)*,†,‡
Expressive Language	46.9 (7.8)	51.1 (10.3)	41.6 (10.1)		0.15	3.91 (0.027)*,‡
Visual Reception	50.1 (11.3)	51.4 (11.5)	37.9 (10.1)		0.25	6.99 (0.002)*,†,‡
	M (SE)	*M (SE)*	*M (SE)*	*B (95 % CI)*	*β*	*t (p-value)*
Slope of change with age[a]						
Early Learning Composite	−0.16 (2.47)	−1.14 (2.78)	−0.67 (2.84)	−0.80 (-1.36, -0.24)	−0.42	−2.90 (0.006)*,†
Gross Motor	−0.28 (1.28)	−0.30 (1.43)	−0.25 (1.56)	−0.33 (-0.76, 0.10)	−0.23	−1.54 (0.13)‡
Fine Motor	0.22 (1.20)	−0.18 (1.38)	−0.33 (1.50)	−0.47 (-0.86, -0.08)	−0.31	−2.41 (0.020)*,†
Receptive Language	0.18 (1.29)	−0.06 (1.28)	−0.09 (1.21)	−0.39 (-0.80, 0.01)	−0.30	−1.95 (0.057)†
Expressive Language	−0.07 (1.15)	−0.79 (1.35)	−0.70 (1.42)	−0.47 (-0.80, -0.15)	−0.37	−2.92 (0.005)*,†
Visual Reception	0.13 (1.90)	−0.44 (2.17)	0.03 (2.14)	−0.48 (-0.97, 0.01)	−0.27	−1.99 (0.053)

Notes: Means (M) and either standard deviations (SD) or standard errors (SE) are reported.
[a] Estimates are provided of the average slope of change with age for each injury severity group based on the average initial function for that injury severity group for each scale.
* Indicates a significant difference between all three injury severity groups ($p < 0.05$).
† Indicates a significant difference between mild and severe injury groups ($p < 0.05$).
‡ Indicates a significant difference between moderate and severe injury groups ($p < 0.05$).

3.3. Developmental trajectories based on injury severity

Of the 47 patients, 16 (34 %) were classified as having mild injuries, 16 (34 %) as having moderate injuries, and 15 (32 %) as having severe injuries. Injury severity was found to be a significant predictor of initial development at the first assessment for all Mullen Scales except fine motor function (Table 3). Specifically, patients with severe injuries had worse early learning composite, visual reception, and receptive language scores than patients with mild or moderate injuries, worse gross motor function than patients with mild injuries, and worse expressive language than patients with moderate injuries at their first assessment (Table 3). The mild and moderate injury groups did not significantly differ in any Mullen Scale scores at first assessment (Table 3).

When controlling for their initial function, injury severity was a significant predictor of the slope of change in development with age for the early learning composite, fine motor function, and expressive language scales (Table 3). Specifically, patients with severe injuries had a greater decline in their early learning composite, fine motor function, receptive language, and expressive language with age than patients with mild injuries and a greater decline in gross motor function with age than patients with moderate injuries (Table 3).

Patients with mild injuries stayed within one SD of age-based norms from 12 to 36 months of age for all Mullen Scales (Fig. 2). Patients with moderate injuries were within one SD of age-based norms at 12 months of age on all Mullen Scales and declined to below one SD of age-based norms in their early learning composite, gross motor function, and expressive language by 18 months of age and in visual reception by 30 months of age (Fig. 2). Their early learning composite and expressive language scores continued to decline to over 2 SDs below age-based norms by 30 months of age (Fig. 2). Patients with severe injuries were over one SD below age-based norms at 12 months of age on all Mullen scales and declined to over 2 SDs below age-based norms in their early learning composite and gross motor function and 3 SDs below age-based norms in expressive language by 36 months of age (Fig. 2).

3.4. Developmental trajectories based on early therapy participation

Of the 47 patients, 24 (51 %) were receiving early intervention, physical therapy (PT), or occupational therapy (OT) at the time of their first assessment. Patients were more likely to be receiving one of these interventions/therapies if they were classified as having severe injuries (80 %, 12/15) than moderate injuries (50 %, 8/16) or mild injuries (25 %, 4/16) (X^2 = 9.38, p = 0.009). When accounting for their initial function and injury severity, early therapy participation was not found to be a significant predictor of the slope of change in function with age for any of the Mullen Scales ($p > 0.05$). Neither was the interaction between therapy participation and injury severity ($p > 0.05$).

3.5. Behavior based on age, injury severity, and early therapy participation

The CBCL was assessed at an average age of 28 (SD = 7) months in 24 (51 %) of the patients. Two patients (8%) were in the

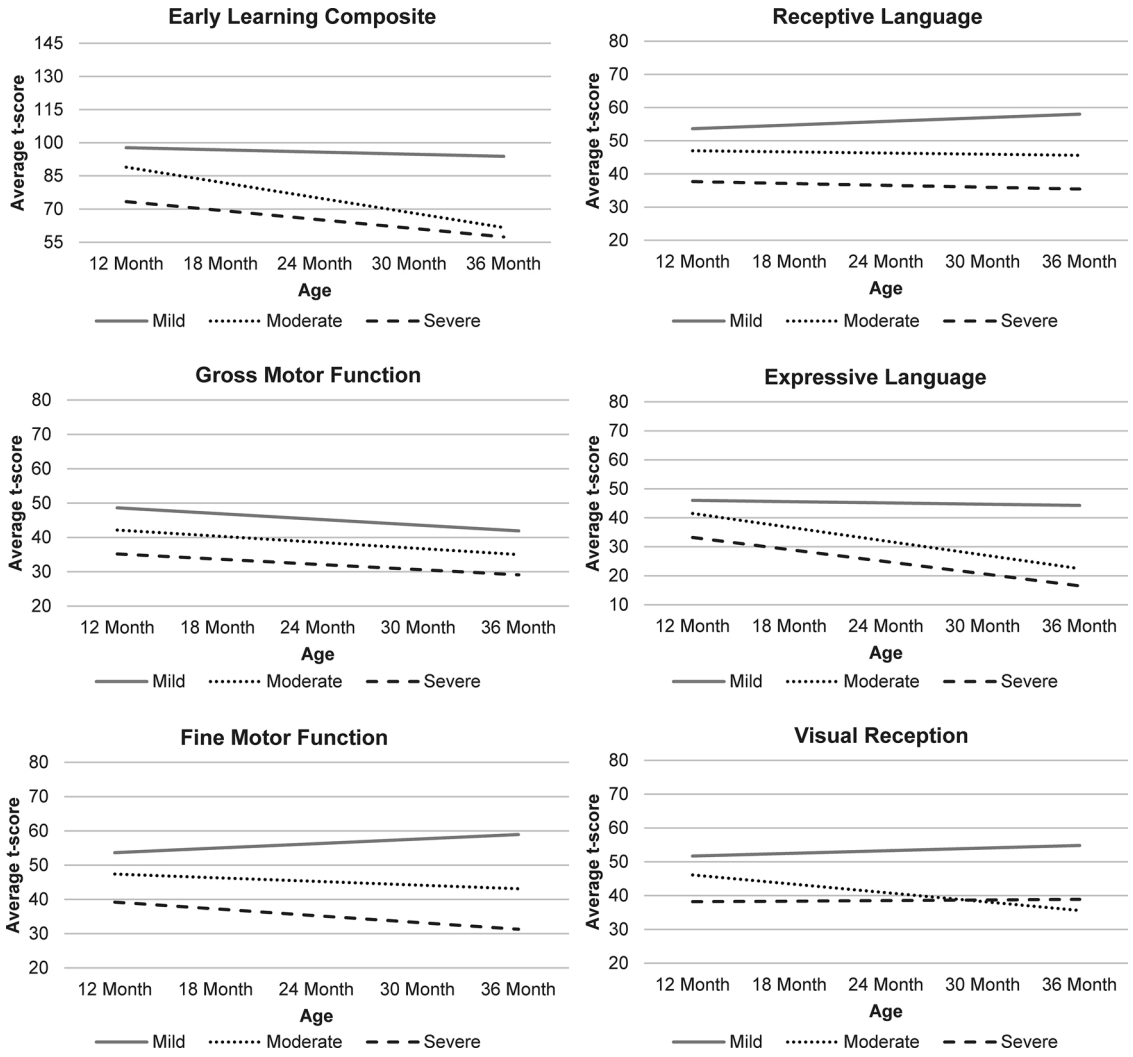

Fig. 2. Change with Age in Mullen Scales of Early Learning Scores Based on Injury Severity among Children Following Abusive Head Trauma Up to 3 Years of Age (n = 47).

borderline clinical range for internalizing behaviors. One patient (4%) was in the clinical range and five patients (21 %) in the borderline clinical range for externalizing behaviors. One patient (4%) was in the clinical range and one patient (4%) in the borderline clinical range for total behavioral problems. The CBCL scores were not significantly associated with patient ethnicity, patient age at the time of injury, whether the patient was living in their home of origin or not, or what type of caregiver completed the survey (Table 4). Male patients had greater internalizing behaviors, externalizing behaviors, and total behavioral problems than female patients (Table 4). Patients of black race had greater externalizing behaviors than patients of white race (Table 4). Patients with public insurance had greater externalizing behaviors and total behavioral problems than patients with private insurance (Table 4). Older age at assessment was significantly associated with greater externalizing behaviors and total behavioral problems, but not with internalizing behaviors (Table 4). When controlling for age, greater injury severity was found to be a significant predictor of greater internalizing behaviors (Table 4). Specifically, patients with moderate injuries had significantly more internalizing behaviors than patients with mild injuries (t = 2.37, p = 0.037). Early therapy participation was not significantly associated with internalizing behaviors, externalizing behaviors, or total behavioral problems, when controlling for age and injury severity (Table 4).

3.6. Quality of life based on age, injury severity, and early therapy participation

The PedsQL™ was assessed at an average age of 24 (SD = 6) months in 27 (57 %) of the patients. The average physical health (86.8), psychosocial health (85.2), and total health-related quality of life scores (85.9) for this patient sample were slightly higher than the normative scores for the healthy population (84.1, 81.2, and 82.3, respectively; Varni et al., 2003). Eight patients (30 %) were considered at-risk for impaired health-related quality of life (total score), with seven patients (26 %) at-risk on both the physical health and psychosocial health scales. The PedsQL™ scale scores did not significantly differ by patient gender, race, age at the time of

Table 4
Differences in Child Behavior Checklist Scores Based on Demographic Characteristics, Injury Severity, and Early Therapy Participation among Children Following Abusive Head Trauma Up to 3 Years of Age (n = 24).

Variables		Internalizing Behaviors		Externalizing Behaviors		Total Problems	
	n	*M (SD)*	*t or F (p-value)*	*M (SD)*	*t or F (p-value)*	*M (SD)*	*t or F (p-value)*
All Patients	24	44.9 (9.2)	–	48.4 (11.5)	–	47.3 (10.3)	–
Age at Injury[a]	24	–	1.13 (0.27)	–	1.58 (0.13)	–	1.28 (0.21)
Age at Assessment[a]	24	–	1.55 (0.14)	–	2.25 (0.035)*	–	2.65 (0.015)*
Gender[b]			2.31 (0.031)*		2.57 (0.017)*		2.56 (0.018)*
Male	13	48.5 (8.6)		53.4 (9.6)		51.7 (9.6)	
Female	11	40.6 (8.3)		42.6 (11.1)		42.0 (8.8)	
Race[b]			1.62 (0.12)		3.39 (0.003)*		1.85 (0.078)
White/Caucasian	18	43.8 (8.7)		46.9 (10.9)		46.2 (9.9)	
Black/African American	5	51.0 (8.8)		58.0 (4.5)		54.8 (5.3)	
Ethnicity[b]			1.28 (0.21)		1.73 (0.097)		1.85 (0.078)
Non-Hispanic/Latino	22	45.6 (9.2)		49.6 (11.0)		48.4 (9.8)	
Hispanic/Latino	2	37.0 (5.7)		35.5 (10.6)		35.0 (9.9)	
Insurance Type at First Assessment[b]			1.66 (0.11)		3.47 (0.003)*		2.57 (0.019)*
Public	16	47.2 (9.5)		52.9 (10.1)		50.6 (10.2)	
Private	4	39.0 (4.0)		34.5 (5.5)		36.8 (6.6)	
Living in Home of Origin[b]			−1.66 (0.11)		−0.40 (0.70)		−0.71 (0.49)
Yes	16	42.8 (8.1)		47.8 (10.7)		46.2 (8.5)	
No	8	49.1 (10.4)		49.8 (13.6)		49.4 (13.7)	
Caregiver Type[c]			0.77 (0.48)		0.91 (0.42)		0.62 (0.55)
Biological Parent	15	43.1 (8.2)		46.9 (10.5)		45.7 (8.6)	
Kinship Caregiver	4	46.5 (14.0)		55.5 (13.8)		52.3 (15.3)	
Foster/Adoptive Caregiver	5	48.8 (8.6)		47.4 (13.1)		47.8 (12.0)	
Injury Severity[d]			2.25 (0.035)*		1.74 (0.097)		1.82 (0.083)
Mild	10	40.4 (7.6)		45.1 (11.7)		44.3 (9.8)	
Moderate	4	49.3 (6.7)		49.8 (9.1)		48.8 (8.2)	
Severe	10	47.6 (10.3)		51.2 (12.3)		49.6 (11.7)	
Early Therapy Participation[c]			−0.88 (0.39)		−0.32 (0.75)		−1.23 (0.23)
Yes	13	46.0 (9.2)		50.5 (11.5)		48.0 (10.2)	
No	11	43.6 (9.5)		46.0 (11.5)		46.4 (10.8)	

Notes: Sample size (n), means (M), and standard deviations (SD) are reported.
[a] Analyzed using linear regression.
[b] Analyzed using independent samples *t*-test.
[c] Analyzed using one-way ANOVA.
[d] Analyzed using multivariable linear regression controlling for age at assessment.
[e] Analyzed using multivariable linear regression controlling for age at assessment and injury severity.
* $p < 0.05$ indicates statistical significance.

injury, age at assessment, injury severity, or early therapy participation (Table 5). Patients with public insurance had worse physical health scores than patients with private insurance (Table 5). Patients not living in their home of origin at the time of assessment had worse physical health and total health-related quality of life scores than patients living in their home of origin (Table 5). The PedsQL™ scale scores significantly differed based on what type of caregiver completed the survey, such that biological parents rated their children as having better physical health, psychosocial health, and total health-related quality of life than kinship caregivers, followed by foster/adoptive caregivers (Table 5). These differences based on caregiver type remained statistically significant after controlling for age at assessment, injury severity, and early therapy participation in multivariable linear regressions predicting physical health (t=-2.54, p = 0.019), psychosocial health (t=-2.68, p = 0.014), and total health-related quality of life (t=-2.91, p = 0.008).

4. Discussion

This study evaluated developmental trajectories up to 3 years of age among children who suffered abusive head trauma prior to 1 year of age and characterized their behavioral and health-related quality of life outcomes. The early learning composite score, representing overall cognitive development, as well as both fine motor function and expressive language were found to significantly decline with age. Delays in overall cognitive development were identified in 23 % of patients shortly after injury, which increased to 32 % of patients after 2 years of age. A prior study of 940 children with abusive head trauma found the rate of developmental delays to be 47 % by 5 years of age (Nuño et al., 2018).

Injury severity was found to be a significant predictor of the change in overall cognitive development as well as fine motor function and expressive language with age. Injury severity was measured based on the length of stay in the PICU. Patients who were never admitted to the PICU or stayed for only one day (mild group) had, on average, normal developmental function by 3 years of age. Patients with PICU stays of 2–3 days (moderate group) had, on average, normal developmental function at 12 months of age and

Table 5
Differences in Health-Related Quality of Life as Measured by the PedsQL™ Based on Demographic Characteristics, Injury Severity, and Early Therapy Participation among Children Following Abusive Head Trauma Up to 3 Years of Age (n = 27).

Variables[a]		Physical Health		Psychosocial Health		Total Quality of Life	
	n	*M (SD)*	*t or F (p-value)*	*M (SD)*	*t or F (p-value)*	*M (SD)*	*t or F (p-value)*
All Patients	27	86.8 (16.5)	–	85.2 (14.4)	–	85.9 (14.2)	–
Age at Injury[b]	27	–	−1.19 (0.25)	–	−0.89 (0.38)	–	−1.08 (0.29)
Age at Assessment[b]	27	–	−0.90 (0.38)	–	−0.40 (0.69)	–	−0.68 (0.51)
Gender[c]			−0.26 (0.80)		−0.36 (0.72)		−0.34 (0.74)
Male	18	86.2 (17.0)		84.4 (15.7)		85.2 (14.8)	
Female	9	88.0 (16.6)		86.6 (12.0)		87.2 (13.6)	
Race[c]			−0.41 (0.69)		0.38 (0.70)		0.03 (0.98)
White/Caucasian	17	86.3 (17.5)		85.9 (12.5)		86.1 (13.8)	
Black/African American	7	89.4 (14.3)		83.3 (20.0)		85.9 (16.2)	
Insurance Type at First Assessment[c]			−2.66 (0.015)*		−0.92 (0.37)		−2.00 (0.071)
Public	20	84.1 (18.4)		83.3 (15.9)		83.7 (15.7)	
Private	4	96.4 (4.2)		91.0 (9.4)		93.4 (6.7)	
Living in Home of Origin[c]			2.29 (0.040)*		2.09 (0.055)		2.39 (0.032)*
Yes	16	93.1 (8.9)		90.1 (9.6)		91.4 (8.3)	
No	11	77.8 (20.9)		78.0 (17.4)		77.9 (17.3)	
Caregiver Type[d]			3.74 (0.039)*		5.52 (0.011)*		5.82 (0.009)*
Biological Parent	15	92.6 (9.0)		90.6 (9.7)		91.4 (8.6)	
Kinship Caregiver	6	86.5 (21.4)		86.0 (16.0)		86.4 (17.5)	
Foster/Adoptive Caregiver	6	72.8 (20.0)		70.8 (14.6)		71.5 (13.6)	
Injury Severity[e]			−0.65 (0.53)		−1.47 (0.15)		−1.15 (0.26)
Mild	11	87.4 (16.7)		88.4 (11.7)		87.9 (13.1)	
Moderate	6	96.6 (3.8)		90.0 (8.7)		92.8 (6.5)	
Severe	10	80.4 (19.0)		78.8 (18.1)		79.5 (16.8)	
Early Therapy Participation[f]			0.21 (0.84)		−0.34 (0.74)		−0.09 (0.93)
Yes	14	86.0 (15.0)		82.5 (15.5)		84.0 (13.8)	
No	13	87.8 (18.6)		88.0 (13.0)		87.9 (14.8)	

Notes: Sample size (n), means (M), and standard deviations (SD) are reported/.
[a] Ethnicity was not evaluated because the PedsQL™ was not completed for any Hispanic patients.
[b] Analyzed using linear regression.
[c] Analyzed using independent samples *t*-test.
[d] Analyzed using one-way ANOVA.
[e] Analyzed using multivariable linear regression controlling for age at assessment.
[f] Analyzed using multivariable linear regression controlling for age at assessment and injury severity.
* $p < 0.05$ indicates statistical significance.

then began to show delays in overall cognitive development, expressive language, and gross motor function around 18 months of age. Patients with PICU stays of 4 or more days (severe group) showed developmental delays across all domains immediately, with declines to two to three standard deviations below age-based norms in overall cognitive development, expressive language, and gross motor function by 3 years of age. The average early learning composite scores of patients in the mild and moderate injury groups went from being within 10 points of each other at 12 months of age to the moderate injury group being over 30 points below the mild injury group by 36 months of age. The implications of these findings include the need for continued developmental evaluation of patients following abusive head trauma.

Previous studies have also found greater severity at the time of injury to be correlated with worse developmental outcomes, as indicated by a variety of measures of injury severity including the Pediatric Trauma Score (Barlow et al., 2005), the Glasgow Coma Scale score (Barlow et al., 2005; Bonnier et al., 2003; Rhine et al., 2012), presence of severe retinal hemorrhages, skull fracture, or cranial deceleration (Bonnier et al., 2003), unresponsiveness on admission or diffuse hypodensity on computed tomography scan (Duhaime et al., 1996), intubation (Duhaime et al., 1996; Greiner et al., 2012), seizures (Greiner et al., 2012; Rhine et al., 2012), neurosurgical intervention, mechanical ventilation for more than 10 days, length of PICU stay more than 10 days, initial hyperglycemia, cerebral edema, and loss of gray-white matter differentiation (Rhine et al., 2012). A benefit of using PICU stay as a measure of injury severity is that it is objective, simple, and available on all patients. Compared to prior studies that assessed development at one cross-sectional follow-up time point, the current study assessed longitudinal changes in development over time and found an association between injury severity and developmental trajectories with age following abusive head trauma.

In general, the prevalence of impairment found in the current study aligns with prior studies on the outcomes of children with abusive head trauma. Visual impairment was identified in 28 % of patients in the current study compared to 23 %–48 % in prior studies (Antonietti et al., 2019; Barlow et al., 2005; Bonnier et al., 1995, 2003; Duhaime et al., 1996; Fischer & Allasio, 1994; Lind et al., 2016; Nuño et al., 2018; Talvik et al., 2007). Receptive language deficits were identified in 30 % of patients and expressive language deficits in 40 % in the current study compared to 11 %–77 % found in prior studies (Barlow et al., 2005; Bonnier et al., 2003; Duhaime et al., 1996; Lind et al., 2016; Nuño et al., 2018; Talvik et al., 2007). Fine motor impairment was identified in 30 % of patients and gross motor impairment in 28 % in the current study, which is slightly less than the range (34 %–70 %) found in prior

studies (Barlow et al., 2005; Bonnier et al., 1995, 2003; Duhaime et al., 1996; Fischer & Allasio, 1994; Lind et al., 2016; Nuño et al., 2018). The variability found in prior studies may be explained by the wide range of follow-up (2–15 years) and the lack of standardized assessment of these outcomes. This study focused on early outcomes at a relatively consistent follow-up of 2–3 years of age using a validated, multi-domain developmental assessment. With the exception of language deficits, the frequency of impairment in the current study was similar but slightly less than the recent larger study of 940 patients with abusive head trauma who were assessed at 5 years of age, suggesting that deficits in all domains may continue to develop with age (Nuño et al., 2018). Further research is needed to understand how early developmental function predicts function into adolescence.

Borderline clinical externalizing behavioral problems were identified in 25 % of patients around 2 years of age, which is within the range (25 %–53 %) of behavioral disorders found in prior studies (Antonietti et al., 2019; Barlow et al., 2005; Bonnier et al., 1995; Duhaime et al., 1996; Lind et al., 2016; Nuño et al., 2018). These studies noted an increased prevalence of issues with temper tantrums, attention, hyperactivity, and impulsivity among children following abusive head trauma (Antonietti et al., 2019; Barlow et al., 2005; Lind et al., 2016). Externalizing behaviors were also found to be more prevalent in older patients in the current study. Barlow et al. (2005) noted that many children did not develop behavioral problems until 2–3 years of age, so it may be that there is a delay in the manifestation of behavioral problems among children following abusive head trauma. Patients with moderate injuries had significantly more internalizing behaviors than patients with mild injuries, which aligns with prior research findings of greater internalizing behaviors among children with developmental delays (Gerstein et al., 2011). Delays in motor and language development may contribute to impaired social skills. Behavioral problems were also found to be greater in patients who were male, black race, or had public insurance. These gender and racial differences have been identified within the general population (Liu, Cheng, & Leung, 2011; Sandberg, Meyer-Bahlburg, & Yager, 1991). Among children with abusive head trauma, Nuño et al. (2018) found those covered by Medicaid insurance to be at an increased risk of behavioral disorders by age 5 than those covered by private insurance. Considerably more children with abusive head trauma were covered by Medicaid than private insurance (Nuño et al., 2018), similar to our sample.

The health-related quality of life of these children following abusive head trauma was slightly better than the average quality of life of healthy children (Varni et al., 2003). Health-related quality of life scores did not differ statistically based on injury severity or early participation in therapy. This finding is incompatible with a prior study that estimated survivors of abusive head trauma to have a reduction in health-related quality of life of 55.5 % if they had a severe injury and 15.5 % if they had a mild or moderate injury (Miller et al., 2014). These estimates were, however, based on disability-adjusted life-years as compared to our one-time assessment of quality of life based on caregiver report around 2 years of age. It is possible that quality of life is more greatly impacted later in development. Interestingly, health-related quality of life was rated significantly higher by biological parents than kinship caregivers or foster/adoptive caregivers, even after controlling for how severe the patient's injury initially was. This finding must be interpreted with caution as it is unclear whether the health-related quality of life of children living with their biological parents was actually better than those living with other caregivers or whether biological parents perceived their child's quality of life differently because of their role in the child's life or potential role related to the injury. It is therefore recommended that observational measures be used in conjunction with caregiver-reported measures in this patient population.

This study has limitations. Although one of the largest longitudinal studies of children with abusive head trauma, the sample size was relatively small (47 patients). Furthermore, many patients were excluded because they did not follow-up in post-injury clinic or they did not complete the Mullen Scales of Early Learning more than one time. The demographic characteristics and injury severity of those included, however, did not significantly differ from those not included. It is unknown whether the developmental function of patients who did not follow-up in post-injury clinic differed, as their development was not able to be assessed. Future investigation of other patient factors may be necessary to better understand the predictors or barriers of following up in a post-injury clinic after abusive head trauma. Although clinic visits were intended to occur every six months, some patients missed one or two developmental assessments because they either did not complete it for various reasons or they missed their visit. The length of developmental follow-up for this sample was also relatively short (up to 3 years), although in many cases more consistent, when compared to prior studies on long-term outcomes of abusive head trauma. This study did not assess other pre-morbid, social, or environmental factors, so their influence on the developmental, behavioral, and health-related quality of life outcomes of these patients following abusive head trauma is not known. Participation in early intervention or physical/occupational therapy was not found to be significantly associated with the recovery of developmental function by 3 years of age or behavior or health-related quality of life around 2 years of age. These statistically non-significant results must be interpreted with caution due to the small sample size, the variability in scores, and the limited statistical power to detect differences. Additional research with larger samples is encouraged to better understand the effectiveness of different types of rehabilitative services for patients following abusive head trauma.

5. Conclusion

Given the results of the present study, long-term comprehensive follow-up is recommended for young children following abusive head trauma to routinely monitor their development and behavior and to evaluate the need for and impact of therapeutic interventions. Anticipating developmental and behavioral sequelae earlier will hopefully result in more timely acquisition of therapeutic and supportive services and reduced impairment and burdens upon the child and family in the long-term.

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Declaration of Competing Interest

None.

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