Outcome and Predictors of Functional Recovery 5 Years Following Pediatric Traumatic Brain Injury (TBI)

Cathy Catroppa,[1,2,3] PhD, Vicki A. Anderson,[1,2,3] PhD, Sue A. Morse,[2] BAppSci, Flora Haritou,[2] BAppSci and Jeffrey V. Rosenfeld,[4,5] MD, MS, FRACS

[1]Australian Centre for Child Neuropsychology Studies, Murdoch Childrens Research Institute, [2]Royal Children's Hospital, [3]University of Melbourne, [4]Alfred Hospital, and [5]Monash University

Objectives The aim was to examine functional outcomes following traumatic brain injury (TBI) during early childhood, to investigate impairments up to 5 years postinjury and identify predictors of outcome. **Methods** The study compared three groups of children (mild = 11, moderate = 22, severe = 15), aged 2.0–6.11 years at injury, to a healthy control group ($n = 17$). Using a prospective, longitudinal design, adaptive abilities, behavior, and family functioning were investigated acutely, 6, 30 months and 5 years postinjury, with educational progress investigated at 30 months and 5 years postinjury. **Results** A strong association was suggested between injury severity and outcomes across all domains. Further, 5-year *outcomes* in adaptive and behavioral domains were best predicted by preinjury levels of child function, and educational performance by injury severity. **Conclusion** Children who sustain a severe TBI in early childhood are at greatest risk of long-term impairment in day-to-day skills in the long-term postinjury.

Key words behavior; children; functional outcome; traumatic brain injury.

Introduction

It is not surprising that functional abilities may be compromised following brain injury at a critical developmental stage. Identified acute and long-term impairments in behavior, attention, memory, education, and adaptive deficits have been reported following traumatic brain injury (TBI) in school-aged children and adolescents, (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005; Catroppa & Anderson, 2002, 2005; Donders, 1993, 1994; Ewing-Cobbs & Barnes, 2002; Hawley, 2003, 2004; Hawley, Ward, Magnay, & Long, 2004; Savage, DePompei, Tyler, & Lash, 2005; Ylvisaker et al., 2005), with only limited research conducted with preschool and early primary school age-groups. Furthermore, the most common, and perhaps least investigated, outcomes are adaptive dysfunction and behavioral disturbance (Goldstrohm & Arffa, 2005; Max et al., 1999, 2004; Taylor et al., 2002; Yeates et al., 2002). It is often these disturbances that cause children and families most distress. These difficulties have been shown to increase over time, potentially resulting in poor

long-term adjustment (Yeates et al., 2004). Not surprisingly, high rates of psychiatric disturbance, family disruption, and divorce are evident following childhood TBI (Rivara et al., 1992; Wade, Taylor, Drotar, Stancin, & Yeates, 1996).

Educational performance following school-aged TBI has received considerable attention, demonstrating that children who had suffered a TBI perform more poorly than peers, and that arithmetic is often most compromised (Berger-Gross & Schackelford, 1985; Catroppa & Anderson, 1999; Slater & Kohr, 1989). Literature (Barnes, Dennis, & Wilkinson, 1999; Ewing-Cobbs et al., 2004) suggests that age and developmental level at the time of injury influences outcome in educational areas, with children who sustained injuries during preschool years or in early primary grades, most at risk for global reading difficulties, and demonstrating a deceleration in growth curves over time when compared to children injured at an older age.

Following from the impact of developmental issues on outcome, an important predictor of functional

outcome is age at injury (Anderson & Moore, 1995). A number of factors such as a larger head supported by a smaller neck (Amacher, 1988), greater flexibility of cranial bones, which may minimize focal brain injury and result in diffuse injury (Begali, 1992), and thinner cortex, contribute to poorer outcomes following early trauma. Once cerebral development is interrupted, this in turn influences brain regions required for the emergence and maturation of functional skills (Anderson et al., 2001; Eslinger & Biddle, 2000; Stuss & Anderson, 2004).

Injury severity has also been identified as predictor of functional outcome, with more severe TBI related to greater problems (Catroppa & Anderson, 1999; Dennis, Barnes, Donnelly, Wilkinson, & Humphreys, 1996; Ewing-Cobbs et al., 2004, 2006; Fletcher, Ewing-Cobbs, Miner, Levin, & Eisenberg, 1990). In the behavioral domain, environmental factors, such as socioeconomic status (SES), and family functioning contribute significantly to long-term outcome, of particular relevance for the young child who is strongly influenced by the family context (Anderson et al., 2001; Donders & Nesbit-Greene, 2004; Rivara, et al., 1993, 1994; Taylor et al., 1995; Yeates et al., 2002, 2004). A ''double hazard'' effect has also been reported, where social disadvantage combined with severe injury leads to poorest long-term outcome (Taylor et al, 1995). Premorbid factors (e.g., child and family function) have also been identified as important for outcome (Anderson et al., 2000; Catroppa & Anderson, 1999; Fletcher et al., 1990; Goldstrohm & Arffa, 2005; Kinsella et al., 1997; Max et al., 1998, 2000).

The unique features of this research include the ascertainment of a preschool TBI sample and a prospective longitudinal design following children to 5 years postinjury. To date, no other study has serially assessed this age group in a systematic manner up to 5 years postinsult. Further, no previous research has examined the contribution of the various parameters identified as important to long-term outcome in this age group. Therefore, the present study aimed to (a) address the impact of TBI during early childhood on functional skills (adaptive ability, behavior, and educational performance) at 5 years postinjury; and (b) to identify predictors of functional recovery at 5 years post-TBI.

It was hypothesized that more severe TBI would be associated with persistent and severe functional deficits. In addition, based on findings from adult and school-aged samples, it was expected that injury severity, premorbid child ability levels (adaptive function, behavior) and social/environmental factors (SES, family functioning) would influence recovery and outcome in the 5 year postinjury period.

Method
Participants

During the initial recruitment period 109 children were admitted to the Royal Children's Hospital (RCH), Melbourne, Australia, with a diagnosis of TBI. Seven were ineligible for the study due to preexisting developmental, behavioral, or neurological problems ($n = 2$), previous head injury ($n = 1$), or had sustained injury due to abuse ($n = 4$). One child had sustained such severe injuries that he was unable to participate in the assessment at any time point. Initial approaches were made to 101 families, with 17 declining to participate. Reasons for refusal included inconvenience of time requirements ($n = 6$), residing outside the state ($n = 6$), and lack of interest in the study ($n = 5$). Eighty-four children were recruited into the study during the initial recruitment period.

At the 5-year time point, a further 36 children were either unable to be located, were not interested in further involvement in the study, or had incomplete data sets at the 5-year phase. Forty-eight children (57% of the original sample) participated in the 5-year follow-up. These children had a diagnosis of closed head injury and had been originally recruited from consecutive admissions to the neurosurgical ward at RCH, between June 1993 and June 1997, immediately following their injury. Inclusion criteria were: (a) age at injury 2.0–7.0 years; (b) documented evidence of TBI, including period of altered consciousness; and (c) medical records sufficiently detailed to determine injury severity; (d) able to complete study protocol; (e) completed 5-year evaluations; and (f) English speaking. Exclusion criteria were: (a) TBI as a result of child abuse; (b) penetrating head injury; (c) documented history of previous TBI; (d) evidence of preexisting physical, neurological, psychiatric, or developmental disorder. Comparison of the demographic and injury characteristics, preinjury adaptive and behavioural functioning, and initial cognitive functioning, of participating and nonparticipating groups identified no significant group differences. Of note, high attrition rates are common in longitudinal research (Ewing-Cobbs, et al., 2006; Yeates et al., 2005), particularly in the field of TBI, and in young samples, where families are more likely to be mobile and difficult to locate with time.

Table I. Demographic Information

	Control	Mild TBI	Moderate TBI	Severe TBI
Number of subjects	17	11	22	15
Gender (Number of males)	9	5	15	11
Age at acute assessment M (SD)	4.9 (1.7)	4.7 (1.3)	5.0 (1.7)	5.3 (1.8)
Age at 5 years post-TBI M (SD)	10.3 (1.9)	9.8 (1.2)	10.5 (1.9)	10.3 (2.0)
SES[a],^^^,*,#,b,c,				
Preinjury M (SD)	3.6 (0.9)	3.7 (0.9)	4.0 (0.7)	4.3 (1.0)
5 years post-TBI M (SD)	3.2 (0.7)	3.4 (0.8)	4.3 (0.8)	3.9 (0.7)
Number of intact families (%)	94	91	82	60
VABS: preinjury M (SD)	112.4 (18.3)	109.8 (15.0)	110.9(16.0)	105.8 (17.5)
PIC: preinjury M (SD)	53.3 (7.1)	55.4 (12.4)	55.0 (8.5)	54.0 (10.5)
FFQ: preinjury M (SD)^,d	66.5 (4.1)	68.8 (3.0)	66.3 (4.8)	63.3 (7.2)
FSIQ^^,c,e,f,g,h				
Acute M (SD)	109.7 (18.5)	101.2 (15.0)	98.1 (12.8)	88.1 (20.0)
5 years post-TBI M (SD)	113.2 (16.8)	108.6 (15.7)	97.1 (11.5)	81.7 (20.9)

^Main effect of group, $p < .05$; ^^$p = .001$; ^^^$p < .001$; *Main effect of time, $p < .05$; Time × severity interaction, $p < .05$.

[a]Daniel, 1983; VABS, Vineland Adaptive Behaviour Scale; PIC, Personality Inventory for Children; FFQ, Family Functioning Questionnaire; FSIQ, Full Scale IQ.

[b]Significant difference between mild and moderate groups at 5 years postinjury.

[c]Significant difference between control and moderate groups at 5 years postinjury.

[d]Significant difference between mild and severe TBI group preinjury.

[e]Significant difference between moderate and severe groups at 5 years postinjury.

[f]Significant difference between control and severe groups at 5 years postinjury.

[g]Significant difference between control and severe groups in the acute stage.

[h]Significant difference between mild and severe groups at 5 years postinjury.

Seventeen children (57% of the original control sample) comprised the noninjured control group. The remainder of the control sample was not able to be located at this follow-up period. These children were identified 5 years earlier via preschools and childcare centers, during the initial stage of the study, to match the TBI group as closely as possible with respect to age, gender, SES, and preinjury characteristics. Often the cause of injury in the age group included in this study is closely related to SES (e.g., family environment, parental supervision) and so controls were chosen to match for these potential confounds. Control children have been reviewed, along with children with TBI, at all time points through the study. Inclusion criteria (a), (d), (e), and (f) and exclusion criteria (c) and (d), described earlier also applied to controls. As with the TBI sample, comparison of demographic, and initial cognitive functioning of participating and nonparticipating children, identified no significant group differences.

Children with TBI were divided into severity groups based on several measures, as no single measure has been found to be reliable in this age group. Severity groups were derived as follows: (a) mild TBI ($n = 11$): GCS on admission 13–15 (Glasgow Coma Score: Teasdale & Jennett, 1974), indicating some alteration of conscious level (e.g., drowsiness, disorientation), with no evidence of mass lesion on CT/MRI, and no neurologic deficits; (b) moderate TBI ($n = 22$): GCS on admission 9–12, indicating significantly altered consciousness, with reduced responsiveness; and/or mass lesion or other evidence of specific injury on CT/MRI, and/or neurological impairment; and (c) severe TBI ($n = 15$): GCS on admission 3–8, representing coma, and mass lesion or other evidence of specific injury on CT/MRI, and/or neurological impairment. No child was on medication at this time point postinjury. Implementation of this categorization procedure for severity successfully classified most children with TBI; however, where categorization was not clear further information from the child's medical file (e.g., presence of neurological signs) was taken into account.

As can be seen in Table I, there were no significant differences across TBI and control groups with respect to age at acute or at 5-year assessment, initial SES, preinjury adaptive abilities, family structure, family functioning, or child behavior. There was a significant difference between the severe TBI and control group for full-scale intellectual quotient (FSIQ) in the acute stage, as well as significant differences between the moderate and severe TBI groups and the control group at the 5-year assessment stage. At 5-year follow-up the severe TBI group also had significantly lower FSIQ scores than the mild and moderate TBI groups. There was also a significant difference between the mild and moderate TBI groups, and the control and moderate TBI groups for SES at the 5-year assessment time.

Table II. Injury and Medical Characteristics

	Mild TBI ($n = 11$)	Moderate TBI ($n = 22$)	Severe TBI ($n = 15$)
Cause of injury			
Passenger (n, %)	1 (9)	5 (23)	5 (33)
Pedestrian (n, %)	–	4 (18)	6 (40)
Falls (n, %)	9 (82)	11 (55)	2 (13)
Blows/other (n, %)	1 (9)	2 (9)	2 (13)
Medical characteristics			
Abnormal CT (n, %)	–	15 (68)	14 (93)
Coma (>1 h) (n, %)	–	8 (36)	15 (100)
Skull fracture (n, %)	4 (linear)	10 (45)	9 (60)
Neurological signs (n, %)	–	8 (36)	12 (80)
Surgical intervention (n, %)	–	9 (41)	11 (73)
GCS on admission $M(SD)$*,a	14.1 (1.4)	9.8 (3.7)	4.7 (1.8)
Frontal (n, %)	–	2 (9) ^	6 (61)
Extrafrontal (n, %)	–	1 (5)	1 (7)
Diffuse (n, %)	–	2 (9)	5 (33)

*$p < .001$

a Significant difference between all TBI groups.

^ Scan indicates a cerebro-vascular event.

GCS scores (on admission) were recorded by the admitting medical officer. Following admission, half-hourly neurosurgical observations were recorded and these increased to four hourly observations, with recordings continuing until the child had regained consciousness. CT/MRI scans were reported by a pediatric neuro-radiologist and neurosurgeon, with classification of pathology (frontal, extrafrontal, and diffuse) conducted on the basis of radiological reports. As can be seen in Table II, most injuries for the mild TBI group occurred as a result of falls (>3 m), with motor car accidents (either passenger or pedestrian) more common in the severe TBI group.

Materials

Parent Questionnaires
Families agreeing to participate completed the following questionnaires at the acute (preinjury measure), 6, 30 month, and 5 year stage post-TBI.

Injury and Demographic Variables
Data were collected on each child's medical and developmental history, occupation, and family constellation. During inpatient stay, medical records were reviewed daily and GCS, length of coma, neurological abnormalities, and surgical interventions were recorded. SES was coded using Daniel's Scale of Occupational Prestige (1983), which rates parent occupation on a 7-point scale, where a high score represents low SES.

Adaptive Functioning
The Vineland Adaptive Behavior Scale (VABS: Sparrow, Bella, & Cicchetti, 1984) has a questionnaire format, which provides information on a child's level of adaptive function. Alpha coefficients for internal consistency range from .94–.99, test–retest reliability over 17 days was .88, with inter-rater reliability of .74. Communication, Daily Living Skills, Socialization, and a Total Adaptive Behavior scores (VABS:TOT) were derived ($M = 100$, $SD = 15$), and used in analyses. Impairment rates at 5 years post-injury (i.e., scores > 1 SD below the mean) were also calculated and used in analyses.

Behavioral Functioning
The revised format version of the Personality Inventory for Children (PIC: Lachar, 1992) was employed, which included 131 items for which parents responded either true or false. Four factors are derived from the scale: Factor I: Undisciplined/Poor Self-control; Factor II: Social Incompetence; Factor III: Internalization/Somatic Symptoms; and Factor IV: Cognitive Development. Evidence has been found for the construct validity of the PIC, showing that it correlates with other measures of personality and behavior in children such as Walker Problem Behavior Identification Checklist (Clarke, Kehle, Bullock, & Jenson, 1987). Factor scores have a mean of 50 and standard deviation of 10 points, with a higher score indicating greater behavioral disturbance, and scores of 70 or more considered to represent behavioral difficulties of clinical significance. A summary, behavioural function variable (PIC: AVERAGE) was calculated, by averaging scores from the four factors. Impairment rates (i.e., scores > 1 SD above the expected mean) were also investigated at 5 years postinjury.

Family Functioning
Family functioning was measured using the Family Functioning Questionnaire (FFQ: Noller, 1988). Each item was rated on a 6-point scale, ranging from 1 = totally agree to 6 = totally disagree. Three factors are derived from the measure: Conflict (scored out of 60 points); Intimacy (72 points), and Parenting Style (30 points). Alpha coefficients for internal consistency are .82 for Conflict, .92 for Intimacy, and .68 for Parenting Style, with test–retest reliability coefficients.79 for Conflict, .77 for Intimacy and .81 for Parenting Style, with high construct validity also reported (Noller, Seth-Smith, Bouma, & Schweitzer, 1992). For each factor, a higher score reflects more of that characteristic reported by families. The Intimacy factor was chosen for inclusion in statistical analyses, due to its high correlation, in our sample, with both other factors, and is comparable to a family cohesion factor.

Child evaluations

Initial evaluation for each child occurred within the first 3 months after injury, as soon as the child was able to participate in test procedures.

Intellectual Abilities

The Wechsler Preschool and Primary Intelligence Scale-Revised (WPPSI-R—Wechsler, 1987) or the Wechsler Intelligence Scale for Children—III (WISC-III- Wechsler, 1991) was administered, depending on the age of child (WPPSI-R < 6.5 years, WISC-III ≥ 6.5 years). Full Scale IQ (FSIQ: $M = 100$, $SD = 15$) was used in analyses.

Educational Skills

Educational tasks were administered at 30 months and 5 years post-TBI (when the children were at an age to complete the educational measure):

The Wide Range Achievement Test-3 (WRAT-3: Wilkinson, 1993) assessed reading, spelling, and arithmetic subtests, ($M = 100$, $SD = 15$) and was administered to tap this domain. Percentage Impairment rates, as described earlier, were calculated at 5 years.

Procedure

Children were enrolled in the study during their initial hospital admission. Families were given a detailed description of the study and asked to provide written consent, in keeping with hospital ethics procedures. Once they had agreed to participate, parents were requested to complete the demographic questionnaire and the VABS, PIC, and FFQ based on child's preinjury abilities, and then again at each assessment point, based on current function.

Children were evaluated at four data points: acute (0–3 months postinjury), 12 months, 30 months, and 5 years post-injury. Each assessment occurred over two 1 hr sessions, to ensure optimal performance in this age group. A qualified child psychologist conducted assessments on an individual basis, with IQ measures administered in the first session and functional measures in the second session. Order of test presentation was fixed within each session.

Statistical Analysis

Initially the four groups (mild, moderate, severe TBI, and controls) were compared on demographic, preinjury and psychosocial measures to identify any differences across groups that might influence postinjury performance. Repeated measures analysis of covariance was then conducted, covarying for SES at the 5-year stage, to examine the association between injury severity and functional measures at 5 years postinjury. Separate analyses were conducted for each functional domain. Additionally, for each functional domain, chi-squared analysis was used to investigate impairment ratings. The aim of the cut-off of 1 SD from the expected mean, was to identify those children who were presenting with some degree of difficulty, consistent with that identified as having "clinical significance" (Tabachnick & Fidell, 2000). Although not necessarily sufficiently severe to qualify for special services, these children were scoring below the "Average" range as described for each measure.

Hierarchical multiple regressions were performed to investigate predictors of outcome at 5 years postinjury. Correlations among independent variables were calculated, to identify multicollinearity. Not unexpectedly, given the design of the study, age at injury and age at testing correlated highly ($r = 0.99$, $p < .001$). As a result, variables used in these analyses were: injury variables (24 hr GCS), developmental factor (age at acute assessment), social/environmental factors (SES, FFQ-Intimacy Factor), and preinjury abilities relevant to specific regression analysis (VABS: TOT score, PIC-AVERAGE score). The Block function was utilized where preinjury measures (VABS and PIC) were entered in the first Block, as these were anticipated to be most predictive of longer-term outcome in these same areas of adaptive function and behavior, and then all predictor variables were entered in Block 2. For those outcome variables without a preinjury measure, all predictor variables (injury, age, SES, and family functioning) were entered simultaneously (ENTER method).

Results
Demographic Information

As illustrated in Table I, no group differences were found for most demographic variables, suggesting that post-injury differences could not be accounted for by these variables. However, a significant difference was indicated between the mild and moderate ($p = 0.02$) and moderate and control groups ($p < 0.01$) for SES at 5 years postinjury, $F(3,61) = 6.51$, $p < 0.01$, $\eta^2 = 0.24$, with the moderate group recording a significantly lower SES. There was a significant difference in acute FSIQ, $F(3, 61) = 4.55$, $p = .006$, $\eta^2 = .18$, which indicated that the severe TBI group had significantly lower IQs than the control group ($p = .003$). As expected, at the 5-year assessment stage there were significant differences in FSIQ between the groups, $F(3, 61) = 11.44$, $p < .001$, $\eta^2 = .36$, which indicated that the moderate and severe TBI groups had significantly lower IQs than the control group (p's < .05), and that the severe TBI group also had

significantly lower IQs than the other two TBI groups (p's < .05). Data presented in Table II show that children with severe injuries were more commonly in motor vehicle accidents as a passenger or pedestrian, were more likely to demonstrate multiple areas of cerebral pathology, with a higher number presenting with neurological signs and surgical intervention.

Adaptive, Behavioral, and Family Functioning Results

Results for adaptive, behavioral, and family functioning measures are seen in Table III and Fig. 1. Repeated measures ANCOVA revealed significant main effects of Severity for adaptive, $F(3,60) = 4.05$, $p = 0.01$, $\eta^2 = 0.17$, 95% CI for $\eta^2 = (.01, .31)$, behavioral, $F(3,60) = 4.00$, $p = 0.01$, $\eta^2 = 0.17$, 95% CI for $\eta^2 = (.01, .30)$, and family functioning measures, $F(3,60) = 3.38$, $p = 0.02$, $\eta^2 = 0.15$, 95% CI for $\eta^2 = (.00, .28)$, suggesting poorest outcome in adaptive and behavioral areas for the severe

TBI group, and with the largest decrement in performance from preinjury to 5 years post-TBI.

For the behavioral measure a significant Time × Severity interaction was also evident, $F(9,180) = 4.06$, $p < 0.001$, $\eta^2 = 0.17$, where the severe TBI group tended to present with more behavioral problems at 5 years post-TBI compared to preinjury status. Similarly, for the family functioning measure, a significant Time × Severity interaction was also evident, $F(9,180) = 2.25$, $p = 0.02$, $\eta^2 = .10$, where the moderate TBI group appeared to have the largest discrepancy from preinjury to 5 years post-TBI, with a suggestion of poorer family functioning at 5 years post-injury. A chi-squared test-for-independence was used to compare rates of impairment between the severity groups for adaptive, $\chi^2(15) = 29.40$, $p = 0.01$, and behavioral, $\chi^2(6) = 14.63$, $p = 0.02$, outcomes (Fig. 1). For both outcome measures, impairment rates were highest at 5 years post-TBI, for the severe group.

Table III. Adaptive, Behavioral, and Family Functioning results

	Controls	Mild TBI	Moderate TBI	Severe TBI
Adaptive skills				
VABS:TOT *,a,b,c,d,e				
Preinjury M (SD)	112.4 (18.3)	109.8 (15.0)	110.9 (16.0)	105.8 (17.5)
6 months M (SD)	113.9 (14.9)	110.0 (14.7)	101.1 (16.1)	96.0 (18.3)
30 months M (SD)	113.9 (10.7)	101.7 (13.1)	98.0 (11.1)	90.8 (18.2)
5 years M (SD)	110.2 (10.2)	101.9 (8.0)	98.7 (11.6)	92.8 (14.6)
Behavioural skills				
PIC:AVERAGE*,^^,b,c,d,e,f,g				
Preinjury M (SD)	53.3 (7.1)	55.4 (12.4)	55.0 (8.5)	53.3 (7.1)
6 months M (SD)	56.9 (16.0)	57.5 (12.3)	55.7 (8.3)	62.5 (14.9)
30 months M (SD)	50.3 (7.6)	53.2 (6.8)	61.3 (7.2)	69.7 (11.5)
5 years M (SD)	48.1 (6.1)	54.7 (5.2)	56.9 (12.2)	64.1 (12.2)
Family functioning				
FFQ: intimacy*,^,h,i,j,k				
Preinjury M (SD)	66.5 (4.1)	68.8 (3.0)	66.3 (4.8)	63.3 (7.2)
6 months M (SD)	61.9 (8.6)	70.1 (1.1)	62.1 (7.8)	65.9 (4.8)
30 months M (SD)	65.9 (5.5)	67.2 (4.2)	62.2 (3.6)	65.9 (5.5)
5 years M (SD)	64.6 (8.6)	67.8 (2.4)	63.2 (7.9)	62.8 (6.5)

Main effect of severity, *p < .05;

Significant Time × Severity interaction, ^p = .02; ^^p < .001.

[a]Significant difference between control and severe groups at 6 months post-TBI.

[b]Significant difference between control and severe groups at 30 months post-TBI.

[c]Significant difference between control and moderate groups at 30 months post-TBI.

[d]Significant difference between control and severe groups at 5 years post-TBI.

[e]Significant difference between control and moderate groups at 5 years post-TBI.

[f]Significant difference between mild and severe groups at 30 months post-TBI.

[g]Significant difference between moderate and severe groups at 30 months post-TBI.

[h]Significant difference between mild and severe groups preinjury.

[i]Significant difference between mild and moderate groups at 6 months post-TBI.

[j]Significant difference between mild and control groups at 6 months post-TBI.

[k]Significant difference between mild and moderate groups at 30 months post-TBI.

M, mean; SE, standard error; VABS:TOT, Vineland Adaptive Behavior Scales Total score; PIC:AVERAGE, Personality Inventory for Children Average score; FFQ, Family Functioning Questionnaire—Intimacy score.
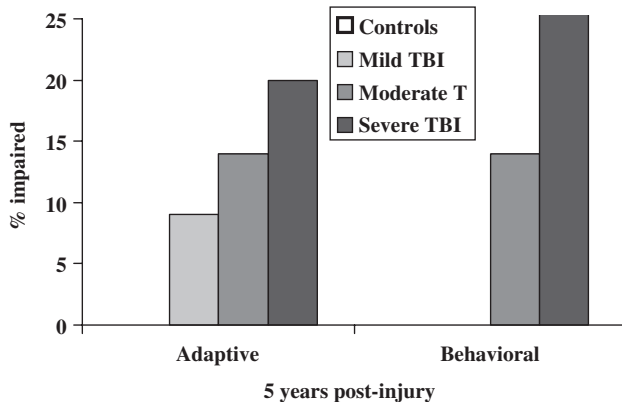
Figure 1. Percentage impaired adaptive and behavioural measures.

Table IV. Educational Performance Results

	Controls	Mild TBI	Moderate TBI	Severe TBI
WRAT-3 reading*,a,b				
30 months M (SD)	109.0 (17.5)	102.6 (17.0)	96.4 (12.7)	86.0 (24.1)
5 years M (SD)	108.2 (17.0)	100.7 (15.5)	97.6 (10.3)	85.7 (19.7)
WRAT-3 spelling**,a,b,c				
30 months M (SD)	103.2 (13.1)	100.1 (16.3)	92.0 (14.9)	87.3 (23.0)
5 years M (SD)	110.9 (16.3)	103.0 (12.3)	95.1 (9.8)	89.3 (20.7)
WRAT-3 arithmetic#,**,a,b,c,d,e				
30 months M (SD)	96.4 (12.2)	100.0 (15.8)	94.1 (15.8)	80.4 (19.1)
5 years M (SD)	99.0 (13.4)	100.1 (10.3)	94.9 (10.7)	82.4 (22.1)

Main effect of Severity, $*p < .05$; $**p < .01$; Main effect of Time, $p < .05$;
[a]Significant difference between severe and control groups at 30 months post-TBI.
[b]Significant difference between severe and control groups at 5 years post-TBI.
[c]Significant difference between moderate and control groups at 5 years post-TBI.
[d]Significant difference between mild and severe groups at 30 months post-TBI.
[e]Significant difference between mild and severe groups at 5 years post-TBI.
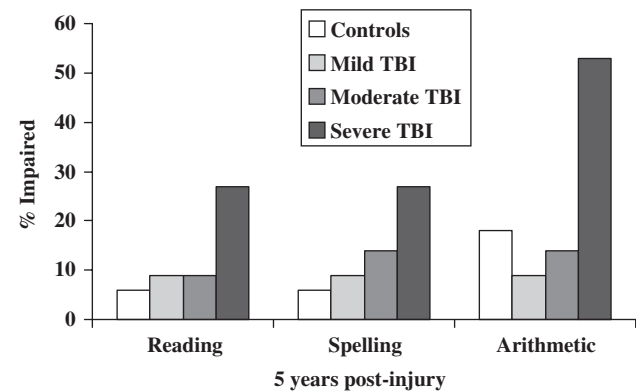WRAT-3, Wide Range Achievement Test–3.

Educational Performance

Results for all educational measures are seen in Table IV. Repeated measures ANCOVA revealed a significant effect of Severity for reading, $F(3,60) = 4.65$, $p = 0.01$, $\eta^2 = 0.19$, 95% CI for $\eta^2 = (.02, .33)$, and spelling, $F(3,60) = 3.62$, $p = 0.02$, $\eta^2 = 0.15$, 95% CI for $\eta^2 = (.00, .29)$. In general, the control group achieved the highest scores, and the severe group performed poorest. For arithmetic, repeated measures ANCOVA revealed a significant main effect of Severity, $F(3,60) = 4.77$, $p < 0.01$, $\eta^2 = .19$, 95% CI for $\eta^2 = (.02, .33)$, and Time $F(1,60) = 5.38$, $p = 0.02$, $\eta^2 = .08$, 95% CI for $\eta^2 = (.00, .23)$, where the mild TBI group achieved the highest score and the severe group the poorest, with all groups generally remaining stable or showing some increment in scores over time. Figure 2 reflects the impairment rates at 5 years post-injury: WRAT-3 reading, $\chi^2(12) = 28.48$, $p = 0.01$, WRAT-3 spelling, $\chi^2(12) = 21.18$, $p = 0.05$, WRAT-3 arithmetic, $\chi^2(12) = 22.29$, $p = 0.03$.

Predictors of Outcome

Adaptive and Behavioral Outcome

With regard to adaptive ability, hierarchical regression analysis (Table V) indicated that preinjury ability in the adaptive area was a significant predictor of performance, accounting for 20% of the variance in Block 1. When the other predictors were entered in Block 2, no other significant predictors were identified. Behavioral outcome was similar, with the regression indicating that preinjury behavioral characteristics best predicted outcome (19% of the variance in Block 1). In contrast, preinjury behavior and injury severity accounted for 38% of the variance in Block 2, with a significant R-squared change indicating

Figure 2. Percentage impaired WRAT-3.

that Block 2 did significantly improve the amount of variance predicted by Block 1.

Educational Outcome

Educational tasks were best predicted by injury severity (Table VI). Furthermore, for arithmetic, additional variables, SES, and preinjury family functioning, were also significant predictors, and together accounted for 47% of the variance.

Discussion

Our findings generally supported the prediction that more severe TBI would be associated with greater functional deficits in all domains. Furthermore, 5 year adaptive and behavioral outcomes were best predicted by preinjury levels of child function, and educational performance by injury severity.

Table V. Summary of Hierarchical Multiple Regression Analyses for Variables Predicting Adaptive Skills and Behaviour at 5 years post-TBI

	VABS: Total			PIC: Average		
	B	$SE\ B$	β	B	$SE\ B$	β
Step 1						
Pre-injury VABS/PIC	0.34	0.10	.45**	0.51	0.16	.43**
	$F(1,45)=11.20, p=.002$			$F(1,41)=10.23, p=.003$		
	$R^2=.20$			$R^2=.19$		
	Adjusted $R^2=.18$			Adjusted $R^2=.17$		
Step 2						
Preinjury VABS/PIC	0.21	0.11	.27	0.57	0.16	.48***
GCS (24 h)	0.81	0.43	.26	−1.09	0.38	−.38**
Age at acute assessment	−1.33	0.98	−.18	1.23	0.94	.18
SES	−1.12	1.94	−.08	−1.90	1.68	−.15
FFQ	0.24	0.31	.11	−0.14	0.28	−.07
	$\Delta F(4,41)=2.08, p=.10$			$\Delta F(4,41)=3.26, p=.02$		
	$\Delta R^2=.14$			$\Delta R^2=.20$		
	$F(5,41)=4.11, p=.004$			$F(5,41)=5.06, p=.001$		
	$R^2=.33$			$R^2=.38$		
	Adjusted $R^2=.25$			Adjusted $R^2=.31$		

$**p < .01$; $***p < .001$.

VABS:Total, Vineland Adaptive Behavior Scales Total score; PIC:Average, Personality Inventory for Children Average score.

Table VI. Summary of Multiple Regression Analyses for Variables Predicting Educational Performance at 5 years post-TBI

	WRAT-reading			WRAT-spelling			WRAT-arithmetic		
	B	$SE\ B$	β	B	$SE\ B$	β	B	$SE\ B$	β
GCS (24 h)	1.90	0.55	.48***	1.54	0.54	.41**	1.54	0.49	.38**
Age at acute assessment	−0.59	1.26	−.06	−0.74	1.23	−.08	0.31	1.12	.03
SES	−0.91	2.43	−.05	−3.57	2.36	−.21	−4.97	2.16	−.27*
FFQ	0.42	0.39	.15	0.17	0.38	.06	0.93	0.35	.32**
	$F(4,42)=4.93, p=.002$			$F(4,42)=4.17, p=.006$			$F(4,42)=9.12, p<.001$		
	$R^2=.32$			$R^2=.28$			$R^2=.47$		
	Adjusted $R^2=.26$			Adjusted $R^2=.22$			Adjusted $R^2=.41$		

$*p < 0.05$; $**p < 0.01$; $***p < 0.001$.

WRAT, The Wide Range Achievement Test–3.

Functional Outcomes

Study results are consistent with previous literature, where adaptive abilities in children were found to be influenced by injury severity (Fletcher et al., 1990). While all groups recorded mean scores within the average range or higher at all time points, children with more severe injuries were more likely to perform at lower levels, with greater decrement in performance for the moderate and severe groups after 5 years. Findings also indicate that injury severity is associated with residual behavior problems, supporting previous literature (Donders, 1992; Yeates et al., 2004). At 30 months and at 5 years post-TBI, the severe TBI group mean scores were close to the clinical range, suggesting that, for those with more severe injury, behavioral difficulties are significant and increase

with time since injury. When considering the Intimacy Index of the FFQ, results were less clear. For the moderate TBI group, family functioning did not improve over time, similar to the severe TBI group. Perhaps, as in the severe TBI group, where deficits persist and/or worsen over time, this pattern is also evident in some areas for the moderate TBI group, resulting in a higher level of stress for the family.

Consistent with previous research (Catroppa & Anderson, 1999; Ewing-Cobbs et al., 2004, 2006), greater injury severity was also linked to poorer educational performance in the areas of reading (decoding words), spelling and arithmetic, with all groups, apart from the severe TBI group, performing within the Average range at 5 years post-injury. A significant difference between the

mild and severe groups for arithmetic at 5 years postinjury supports the claim that arithmetic may be most compromised (Berger-Gross & Schackelford, 1985; Slater & Kohr, 1989). With regard to reading accuracy, results suggests that mild TBI has little impact on educational progress, but that severe injury is characterized by persistent and global problems. These findings support past literature stating that children who sustained injuries in the preschool years or early primary grades, were at risk for global impairments in reading, as the development of these skills had been interrupted (Barnes et al., 1999; Ewing-Cobbs et al., 2004). Severe injury in early childhood may also influence the development of general cognitive skills, which may then also impact on the development of more specific skill areas.

Predictors

For adaptive and behavioral outcomes, preinjury adaptive function was the strongest predictor, with injury severity (GCS at 24 hr) also of importance in the behavioral domain. While using the same instrument (VABS, PIC) as a predictor and an outcome measure, one may overestimate this association, however, this does not diminish the strong relationship between pre- and post-injury functioning. These results highlight the importance of preinjury status, with injury perhaps exacerbating pre-injury status, supporting past literature (Cattelani, Lombardi, Brianti, & Mazzucchi, 1998; Max et al., 1998; Wade et al., 1996; Yeates et al., 1997; 2004). Results failed to support the significant contribution of SES and family factors, often reported in past literature (Donders & Nesbit-Greene, 2004; Rivara, et al., 1993, 1994; Taylor et al., 1995; Yeates et al., 2002, 2004), perhaps due to the sample size and to the inclusion of only one measure of family functioning.

Supporting past literature (Catroppa & Anderson, 1999; Dennis, et al., 1996; Fletcher et al., 1990; Ewing-Cobbs et al., 2004), injury severity was a significant predictor of educational outcome in the reading and spelling areas. Performance on the arithmetic task was also predicted by SES and FFQ-Intimacy, suggesting that while injury severity plays a role in educational performance, psychosocial and family variables are also important, perhaps reflecting parental educational levels or degree of support in the family.

Long-term outcome in the areas of adaptive skills, behavior, and educational performance, are best predicted by preinjury status and injury severity. These findings assist in identifying the most vulnerable children and families post-TBI and argue that children in the high-risk category of lower preinjury functioning and greater injury severity should be followed-up closely and long-term post-TBI, with such processes incorporated into standard clinical practice, allowing for appropriate intervention before secondary difficulties may follow. Our results also indicate that follow-up should continue long-term (at least 5 years) and look more broadly than the typical neuropsychological domain, and incorporate areas of day-to-day function including behavior, adaptive abilities, and educational progress.

Limitations and Future Directions

Interpretation of results from this study is somewhat limited due to the small sample size, which does not allow for the use of more sophisticated statistical techniques. Another limitation is the use of only one parent completed measure for each of adaptive and behavioral functions. Future studies may include a larger sample size, and more specific tests, questionnaires or video-taping of adaptive and behavioral indices, as well as teacher completed questionnaires. Such research is valuable, as children are followed-up at outpatient clinics and then in the community, allowing for intervention and rehabilitation to be implemented and findings to be incorporated into clinical practice. Knowledge gained via such research allows outpatient and community reviews to (a) better identify those children most as risk for cognitive and social problems; (b) focus their review assessment on areas known to be problematic postinjury.

References

Amacher, A. L. (1988). *Paediatric head injuries: A handbook*. St. Louis, MO: Warren H. Green, Inc.

Anderson, V., Catroppa, C., Haritou, F., Morse, S., Pentland, L., Rosenfeld, J., and Stargatt, R. (2001). Predictors of acute child and family outcome

following traumatic brain injury in children. *Pediatric Neurosurgery, 34,* 138–148.

Anderson, V., Catroppa, C., Morse, S., Haritou, F., & Rosenfeld, J. (2000). Recovery of intellectual ability following traumatic brain injury in childhood: Impact of injury severity and age at injury. *Pediatric Neurosurgery, 32,* 282–290.

Anderson, V, Catroppa, C., Morse, S., Haritou, F., & Rosenfeld, J. (2005). Attentional and processing skills following traumatic brain injury in early childhood. *Brain Injury, 19*(9), 699–710.

Anderson, V., & Moore, C. (1995). Age at injury as a predictor of outcome following pediatric head injury. *Child Neuropsychology, 1,* 187–202.

Barnes, M. A., Dennis, M., & Wilkinson, M. (1999). Reading after closed head injury in childhood. Effects on accuracy, fluency, and comprehension. *Developmental Neuropsychology, 15*(1), 1–24.

Begali, V. (1992). *Traumatic head injury: Establishing the parameters. Head Injury in Children and Adolescents.* Brandon, VT: Clinical Psychology Publishing Company, Inc.

Berger-Gross, P., & Schackelford, M. (1985). Closed head injury in children: Neuropsychological and scholastic outcomes. *Perceptual and Motor Skills, 61,* 254.

Catroppa, C., & Anderson, V. (1999). Recovery of educational skills following pediatric head injury. *Pediatric Rehabilitation, 3*(4), 167–175.

Catroppa, C., & Anderson, V. (2002). Recovery in memory function in the first year following TBI in children. *Brain Injury, 16*(5), 369–384.

Catroppa, C., & Anderson, V. (2005). A prospective study of the recovery of attention from acute to 2 years post pediatric traumatic brain injury. *Journal of the International Neuropsychological Society, 11,* 84–98.

Cattelani, R., Lombardi, F., Brianti, R., & Mazzucchi, A. (1998). Traumtic brain injury in childhood: Intellectual, behavioural and social outcome into adulthood. *Brain Injury, 12*(4), 283–296.

Clark, E., Kehle, T. J., Bullock, D., & Jenson, W. R. (1987). Convergent and discriminant validity of the Personality Inventory for children. *Journal of Psycheducational Assessment, 5*(2), 99–106.

Daniel, A. (1983). *Power, privilege and prestige: Occupations in Australia.* Melbourne: Long-man-Cheshire.

Dennis, M., Barnes, M. A., Donnelly, R. E., Wilkinson, M., & Humphreys, R. P. (1996). Appraising and managing knowledge: Metacognitive skills after childhood head injury. *Developmental Neurospychology, 12*(1), 77–103.

Donders, J. (1992). Premorbid behavioral and psychosocial adjustment of children with traumatic brain injury. *Journal of Abnormal Child Psychology, 20*(3), 233–246.

Donders, J. (1993). Memory functioning after traumatic brain injury in children. *Brain Injury, 7*(5), 431–437.

Donders, J. (1994). Academic placement after traumatic brain injury. *Journal of School Psychology, 32,* 53–65.

Donders, J., & Nesbit-Greene, K. (2004). Predictors of neuropsychological test performance after pediatric traumatic brain injury. *Assessment, 11*(4), 275–284.

Eslinger, P. J., & Biddle, K. R. (2000). Adolescent neuropsychological development after early right prefrontal cortex damage. *Developmental Neuropsychology, 18*(3), 297–329.

Ewing-Cobbs, L., & Barnes, M. (2002). Linguistic outcomes following traumatic brain injury in children. *Seminars in Pediatric Neurology, 9*(3), 209–217.

Ewing-Cobbs, L., Barnes, M., Fletcher, J. M., Levin, H. S., Swank, P. R., & Song, J. (2004). Modeling of longitudinal academic achievement scores after pediatric traumatic brain injury. *Developmental Neuropsychology, 25*(1 and 2), 107–133.

Ewing-Cobbs, L., Prasad, M. R., Kramer, L., Cox, C. S., Baumgartner, J., Fletcher, S., et al. (2006). Late intellectual and academic outcomes following traumatic brain injury sustained during early childhood. *Journal of Neurosurgery, 105*(4 Suppl), 287–296.

Fletcher, J. M., Ewing-Cobbs, L., Miner, M. E., Levin, H. S., & Einsberg, H. M. (1990). Behavioral changes after closed head injury in children. *Journal of Consulting and Clinical Psychology, 58*(1), 93–98.

Goldstrohm, S. L., & Arffa, S. (2005). Preschool children with mild to moderate traumatic brain injury: An exploration of immediate and post-acute morbidity. *Archives of Clinical Neuropsychology, 20,* 675–695.

Hawley, C. A. (2004). Behaviour and school performance after brain injury. *Brain Injury, 18*(7), 645–659.

Hawley, C. A. (2003). Reported problems and their resolution following mild, moderate and severe traumatic brain injury amongst children and adolescents in the UK. *Brain Injury, 17*(2), 105–129.

Hawley, C. A., Ward, A. B., Magnay, A., & Long, J. (2004). Outcomes following childhood head injury: A population study. *Journal of Neurology, Neurosurgery, and Psychiatry, 75*(5), 737–742.

Kinsella, G. J., Prior, M., Sawyer, M., Ong, B., Murtagh, D., Eisenmajer, et al. (1997). Predictors and indicators of academic outcome in children 2 years following traumatic brain injury. *Journal of the International Neuropsychological Society, 3,* 608–616.

Lachar, D. (1992). *Personality Inventory for Children (PIC) (Revised formal manual supplement).* Los Angeles CA: Western Psychological Services.

Max, J. E., Castillo, C. S., Robin, D. A., Lindgren, S. D., Smith, W. L., Sato, Y., et al. (1998). Predictors of family functioning after traumatic brain injury in children and adolescents. *Journal of the Academy of Child and Adolescent Psychiatry, 37*(1), 83–90.

Max, J., Lansing, A., Koele, S., Castillo, C., Bozura, H., Schachar, R., et al. (2004). Attention deficit hyperactivity disorder in children and adolescents following traumatic brain injury. *Developmental Neuropsychology, 25,* 159–178.

Max, J. E., Roberts, M. A., Koele, S. L., Lindgren, S. D., Robin, D. A., Arndt, S., et al. (1999). Cognitive outcome in children and adolescents following severe traumatic brain injury: Influence of psychosocial, psychiatric, and injury related variables. *Journal of the International Neuropsychology Society, 5,* 58–68.

Max, J., Koele, S., Castillo, C., Lindgren, S., Arndt, S., Bozura, H., et al. (2000). Personality change disorder in children and adolescents following traumatic brain injury. *Journal of the International Neuropsychological Society, 6,* 279–285.

Nelson, J. E., & Kelly, T. P. (2002). Long-term outcome of learning and memory in children following severe closed head injury. *Pediatric Rehabilitation, 5*(1), 37–41.

Noller, P. (1988). *ICPS family functioning scales,* Unpublished manuscript. University of Queensland.

Noller, P., Seth-Smith, M., Bouma, R., & Schweitzer, R. (1992). Parent and adolescent perceptions of family functioning: A comparison of clinic and non-clinic families. *Journal of Adolescence, 15*(2), 101–114.

Rivara, J., Fay, G., Jaffe, K., Polssar, N., Shurtless, H., & Liao, S. (1992). Predictors of family functioning one year following traumatic brain injury in childhood. *Archives of Physical Medicine and Rehabilitation, 73,* 899–910.

Rivara, J. M. B., Jaffe, K. M., Fay, G. C., Polissar, N. L., Fay, G. C., Martin, K. M., et al. (1994). Family functioning and children's academic performance and behaviour problems in the year following traumatic brain injury. *Archives of Physical Medicine and Rehabilitation, 75,* 369–379.

Rivara, J. M. B., Jaffe, K. M., Fay, G. C., Polissar, N. L., Martin, K. M., Shurtleff, H. A., et al. (1993). Family functioning and injury severity as predictors of child functioning one year following traumatic brain injury. *Archives of Physical Medicine and Rehabilitation, 74,* 1047–1055.

Savage, R. C., DePompei, R., Tyler, J., & Lash, M. (2005). Paediatric traumatic brain injury: A review of pertinent issues. *Pediatric Rehabilitation, 8*(2), 92–103.

Slater, E. J., & Kohr, M. A. (1989). Academic and intellectual functioning of adolescents with closed head injury. *Journal of Adolescent Research, 4*(3), 371–384.

Sparrow, S., Balla, D. A., & Cicchetti, D. V. (1984). *Vineland adaptive behavior scales: Interview edition. Survey form manual.* Circle Pines, MN: American Guidance Services.

Stuss, D., & Anderson, V. (2004). The frontal lobes and theory of mind: Developmental concepts from adult focal lesion research. *Brain and Cognition, 55,* 69–83.

Tabachnick, B. G., & Fidell, L. S. (2000). *Using Multivariate Statistics (4th Edition).* Boston: Allyn & Bacon.

Taylor, H. G., Drotar, D., Wade, S., Yeates, K., Stancin, T., & Klein, S. (1995). Recovery from traumatic brain injury in children: The importance of the family. In S. H. Broman, & M. E. Michel (Eds.), *Traumatic head injury in children* (pp. 188–218). New York: Oxford University Press.

Taylor, H. G., Yeates, K., Wade, S., Drotar, D., Stancin, T., & Minich, N. (2002). A prospective study of short- and long-term outcomes after traumatic brain injury in children: Behavior and academic achievement. *Neuropsychology, 16,* 15–27.

Teasdale, G., & Jennett, B. (1974). Assessment of coma and impaired consciousness: A practical scale. *The Lancet, 2,* 81–83.

Wade, S., Taylor, H. G., Drotar, D., Stancin, T., & Yeates, K. (1996). Childhood traumatic brain injury: Initial impact on the family. *Journal of Learning Disabilities, 29,* 652–666.

Wechsler, D. (1987). *Manual for the preschool and primary intelligence scale-revised*. New York: Psychological Corporation.

Wechsler, D. (1991). *Manual for the Wechsler intelligence scale for children -111*. San Antonio, TX: The Psychological Corporation.

Wilkinson, G. S. (1993). *Wide range achievement test administration manual*. Wide Range Inc. Delaware, USA.

Yeates, K., Armstrong, K., Janusz, J., Taylor, G. H., Wade, S., Stancin, T., et al. (2005). Long-term attention problems in children with traumatic brain injury. *Journal of the American Academy in Child and Adolescent Psychiatry, 44*(6), 574–584.

Yeates, K. O., Taylor, H. G., Drotar, D., Wade, S. L., Klein, S., Stancin, T., et al. (1997). Pre-injury family environment as a determinant of recovery from traumatic brain injuries in school-age children.

Journal of the International Neuropsychological Society, 3, 617–630.

Yeates, K., Swiift, E., Taylor, H. G., Wade, S., Drotar, D., Stancin, T., et al. (2004). Short- and long-term social outcomes following pediatric traumatic brain injury. *Journal of the International Neuropsychological Society, 10*, 412–426.

Yeates, K. O., Taylor, G. H., Wade, S. L., Drotar, D., Stancin, T., & Minich, N. (2002). A prospective study of short-and long-term neuropsychological outcomes after traumatic brain injury in children. *Neuropsychology, 16*(4), 514–523.

Ylvisaker, M., Adelson, P. D., Braga, L. W., Burnett, S. M., Glang, A., Feeney, T., et al. (2005). Rehabilitation and ongoing support after pediatric TBI twenty years of progress. *The Journal of Head Trauma Rehabilitation, 20*(1), 95–109.