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Skull Fracture During Infancy: A Five-Year Follow-Up

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A group of 19 children, who had received a skull fracture during infancy, were assessed at least 5 years following injury. The majority of the group (89%) had received a mild traumatic brain injury (TBI), with the remaining two (11%) having a moderate injury. The neuropsychological, academic, and psychosocial functioning of the TBI group was compared to that of 20 orthopedic subjects. The two groups were matched on the variables of gender, age, and socio-economic status. The TBI group was impaired on tests of visual attention and memory for faces. The two groups did not differ significantly on measures of language, sensorimotor functions, or visuospatial functioning. There were no statistically significant differences between the two groups on academic performance, or parent and teacher reports of psychosocial functioning. It is concluded that while there is an absence of deficits in the vast majority of functions, skull fracture in infancy can result in enduring impairment in specific cognitive skills related to the processing of complex nonverbal stimuli.

Introduction

The probability of sustaining a traumatic brain injury (TBI) varies as a function of age and gender. Incidence is more common in males and 50% of all cases occur to those under the age of 25, with the next highest incidence occurring in pre-school children. There is also a strong association between age and mechanism of injury. Falls constitute a major source of TBI in children less than five years, with a peak incidence rate typically reported at age two. The majority of TBIs are of mild severity. In this regard children are no exception with mild TBI accounting for approximately 89% of all cases (DiScala, Osberg, & Savage, 1997; Duhaime et al., 1992; Kraus, 1995).

The pathology of TBI in children differs from that in adults partly because a child's skull is more flexible and incompletely fused (Bruce, Schut, Bruno, Wood, & Sutton, 1978; Geddes et al., 2001; Spreen, Risser, & Edgell, 1995). In contrast to older children and adolescents, skull fractures are common in infants with the average incidence across studies being approximately 40% (Choux, 1986). While it is generally true that intracranial injury is more likely if a skull fracture is present, the prognostic significance of skull fractures in infants is less clear (Frush, O'Hara, & Kliewer, 1998; Greenes & Schutzman, 2001). Furthermore, obtaining a reliable and valid assessment of injury severity in infants remains a challenge (Durham et al., 2000; Schutzman et al., 2001).

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Recovery from TBI in children and adults also differs (Broman & Michel, 1995; Horton, 1994; Johnson, Uttley, & Wyke, 1989). The effects of childhood TBI are complex with outcome depending, among other factors, upon both the task under study and the normal developmental sequence of that task. An early study by Teuber and Rudel (1962) clearly illustrated the need to consider effects of paediatric TBI within a developmental framework. In children, recovery of function is an issue not only of sparing and restoration of various behaviors, as it is in adults, but also a complex issue of how growth and development proceed in an abnormal brain. Thus, depending on injury severity and lesion location, TBI early in life may not only affect skills already acquired, but also the ability to acquire new skills and to develop an age-appropriate knowledge-base (Dennis, Wilkinson, Koski, & Humphreys, 1995; Fletcher, Miner, & Ewing-Cobbs, 1987; Slomine et al., 2002).

Age at injury is also relevant to understanding the recovery process in paediatric TBI populations (Chapman, 1995; Kieslich, Marquardt, Galow, Lorenz, & Jacobi, 2001; Levin, Ewing-Cobbs, & Eisenberg, 1995). A core question is whether children with early versus late injuries differ in long-term outcome. The early plasticity hypothesis is based on the idea that young children can sustain considerable brain damage with relative impunity resulting in a general sparing of function. This proposition is often referred to as the "Kennard Principle" (Kennard, 1942). The opposing view, the vulnerability hypothesis, is that damage to a rapidly developing brain can be more harmful than equivalent damage in adulthood. A recent survey of research on outcomes of childhood TBI failed to provide unequivocal support for either hypothesis (Taylor & Alden, 1997).

The most consistent finding in TBI outcome research is the dose-response relationship between greater severity of injury and poorer outcome (Anderson, Catroppa, Rosenfeld, Haritou, & Morse, 2000; Donders & Ballard, 1996; Ewing-Cobbs, Prasad, Kramer, & Landry, 1999; Jaffe et al., 1993; McKinlay, Dalrymple-Alford, Horwood, & Fergusson, 2002; Winogron, Knights, & Bawden, 1984), and controversey continues to surround the issue of enduring cognitive deficits following mild TBI in adults (Marsh & Sleigh, 2002). In a review of studies relating to neuropsychological, academic, or social outcome following mild TBI in children and adolescents, Satz et al. (1997) point out that the methodologically stronger studies are generally associated with a null outcome. However, Gronwall, Wrightson, and McGinn (1997) examined evidence that the effect of mild TBI in very young children may differ from adult mild TBI in that the deficits may emerge, rather than diminish, over time. They concluded that there is a need for long-term prospective studies designed within a developmental framework in order to clarify the effects of mild TBI in infancy. It is now accepted that, in contrast to severe injuries, the consequences of mild injuries to the immature brain may not show up as difficulties until many years post-injury (Levin et al., 1997).

The results from studies investigating the sequelae of pediatric TBI suggest a range of outcomes across the whole spectrum of psychosocial functioning (Beers, 1992; D'Amato & Rothlisberg, 1996; Hawley, Ward, Magnay, & Long, 2002; Middleton, 2001; Taylor et al., 1999). Previous research has demonstrated that TBI in childhood can result in deficits in specific cognitive functions such as attention (Dennis et al., 1995; Ewing-Cobbs et al., 1998), language (Ewing-Cobbs, Levin, Eisenberg, & Fletcher 1987; Jordan & Ashton, 1996; Wrightson, McGinn, & Gronwall, 1995; Ylvisaker, 1993), sensory-motor skills (Bawden, Knights & Winogron, 1985; Levin & Eisenberg, 1979), visuospatial processing (Chadwick, Rutter, Shaffer, & Shrout, 1981; Thompson et al., 1994), and memory and learning (Ewing-Cobbs et al., 1989; Levin & Eisenberg, 1979; Ward, Shum, Wallace, & Boon, 2002). Failure to thrive academically has been argued to be one of the most serious sequelae of the cognitive deficits resulting from pediatric TBI (Fay et al., 1994; Jaffe et al., 1993; Knights et al., 1991; Polissar et al., 1994; Taylor et al., 2002). Finally, behavior problems, emotional difficulties, and difficulties in adaptive functioning following pediatric TBI have been reported in several studies (Casey, Ludwig & McCormick, 1986; Fletcher, Ewing-Cobbs, Miner, Levin, & Eisenberg, 1990; Kinsella, Ong, Murtagh, Prior, & Sawyer, 1999; Light et al., 1998; Rivara et al., 1992). But while behavioral morbidity in the mild TBI groups resembles that seen in the severely injured groups, the behaviors seen following mild TBI are thought to be directly related to the experience of an anxiety producing event, rather than reflecting presumed extensive organic pathology (McGuire & Sylvester, 1987).

The brain is continually changing in its anatomy, chemistry, and physiology throughout the years of childhood (Spreen et al., 1995). The same traumatic event is likely to produce a different spectrum of injury to the brain at different ages of infancy and childhood, making comparison very difficult and possibly leading to erroneous conclusions if data from children of different ages is pooled (Bruce, 1995; Goldstein & Levin, 1987). Recognition of this fact is evident in recent studies, which describe their samples in precise age-relevant categories such as infant, preschool, child, and adolescent.

Although some controversy remains, the majority of studies suggest that cognitive and psychosocial morbidity related to mild TBI in childhood resolves in most cases (Levin et al., 1987; Light et al., 1998; McKinlay et al., 2002; Papero, Prigatano, Snyder, & Johnson, 1993; Satz et al., 1997). While it is acknowledged that the effects of mild injuries to the immature brain may not be evident until many years post-injury (Gronwall et al., 1997), there is a paucity of studies focusing specifically on children who sustained TBI in the first two years of life. Such studies would also assist in determining the significance of skull fracture within this population, as well as documenting the long-term sequelae of TBI received during infancy.

Therefore, the principle aim of this study was to investigate the long-term neuropsychological, academic, and psychosocial functioning of children who sustained a TBI resulting in a skull fracture, during infancy. In keeping with recommendations from recent research (Gronwall et al., 1997), reliable and valid assessment instruments that incorporated a developmental framework were used and the emotional impact of injury was controlled for by use of an orthopedic comparison group.

Method

Participants

TBI Group. Subjects were selected from a consecutive series of infants admitted to Starship Children's Hospital, Auckland, with a diagnosis of TBI between January 1992 and December 1993. Criteria for inclusion in the study were: (a) no specific neurological findings, (b) no subsequent neurological deterioration, (c) presence of a skull fracture confirmed by radiography, (d) age at time of injury < 2 years, (e) time since injury > 5 years, (f) no history of other neurological disorder, and (g) English-speaking.

Fifty-six children fulfilled these criteria and were selected for inclusion in the study. One subject was excluded due to an additional diagnosis of meningitis. Inability to contact the parents excluded a further 30 subjects, while the parents of 6 other subjects chose not to participate in the study. Therefore the final TBI sample consisted of 19 children.

Seventeen (90%) of the TBI subjects were right-handed, and the remaining two (11%) were left-handed. All subjects attended normal schools. On admission to hospital, the majority (90%) of the TBI subjects had Glasgow Coma Scale (Teasdale & Jennett, 1974) scores of 15, indicating that they had sustained a mild TBI, while the remaining 2 (11%) had scores within the moderate injury range. Fifteen (79%) of the fractures occurred to the parietal region of the skull, with seven of these being on the left side, seven on the right, and one being biparietal. The remaining four (21%) occurred to the occipital region. The majority (84%) did not require more than 1 day, and only one subject required more than 3 days, of hospitalization. One subject received their injury when struck by a motor vehicle, with all other injuries being received from falls. The vast majority (83%) being falls of less than 2 meters. Further demographic information is presented in Table 1.

Orthopedic Comparison (OC) Group. A comparison group was selected from a sample of 61 candidates who were admitted to Starship Children's Hospital with the diagnosis of an isolated arm fracture between January 1992 and December 1993. Of these 61 candidates, 3 were excluded because the children had suffered from meningitis. In addition, 38 other candidates were not included because of mild cerebral palsy (1), inability to contact the

Table 1
Demographic Characteristics of the Traumatic Brain Injury (N = 19) and Orthopaedic Comparison (N = 20) Groups

	TBI	OC
Gender		
Male	13 (68%)	13 (65%)
Female	6 (32%)	7 (35%)
Age (months)		
Mean	80.89	79.90
SD	8.18	7.79
Range	71–97	70–92
Age at injury (months)		
Mean	12.11	18.50
SD	7.73	4.80
Range	2–24	9–27
Time since injury (months)		
Mean	68.79	61.40
SD	5.38	9.00
Range	62–79	45–77
Socio-economic status*		
1	1 (7%)	1 (6%)
2	6 (40%)	4 (25%)
3	3 (20%)	4 (25%)
4	1 (7%)	1 (6%)
5	3 (20%)	3 (19%)
6	0	0
7	1 (7%)	2 (13%)
8	0	1 (6%)
9	0	0

*TBI (n = 15), OC (n = 16).

parents (23), and decline to participate in the study (14). The final orthopaedic comparison (OC) sample consisted of 20 children.

Eighteen (90%) of the OC subjects were right-handed, and the remaining two (10%) were left-handed. All OC subjects attended normal schools. More than half (55%) of the OC subjects received their fractures to the left forearm, and 75% did not require hospital admission. Almost all (90%) of the injuries were incurred from falls, with the majority (60%) being falls of less than 2 meters. Further demographic information is presented in Table 1.

Matching Variables. There were no statistically significant differences between the TBI and OC groups on the variables of gender, handedness, age ($t(37) = -0.39$, $p > .05$), or socio-economic status ($\chi^2 = 1.85$, $p > .05$). Socio-economic status was based upon the occupation of the primary income earner for each subject's household. This was determined according to the New Zealand Socio-economic Index of Occupational Status (Statistics New Zealand, 1997), which provides graded indices (from upper = 1, to lower = 9). On average, the TBI group was younger at the time of injury ($t(29.79) = 3.09$, $p = .004$) and therefore had a longer average time since injury ($t(31.31) = -3.13$, $p = .004$) (Table 1).

Measures

In this study, the neuropsychological functioning, academic performance, and psychosocial functioning of each participant were assessed.

Neuropsychological functioning. Neuropsychological functioning was assessed by administration of the NEPSY (Korkman, Kirk & Kemp, 1998). When the aim of assessment is to explore the nature of a specific disorder/condition, the design of the NEPSY allows for the selective administration of relevant subtests. Thus, 14 of the 27 NEPSY subtests were chosen to assess the neuropsychological functioning of subjects. Core subtests from each of the five domains were included. The domain of Attention/Executive functions was assessed by the Tower, Auditory Attention and Response Set, Visual Attention, and Design Fluency subtests; Language by the Speeded Naming, Comprehension of Instructions, and Verbal Fluency subtests; Sensorimotor by the Fingertip Tapping; Visuospatial Processing by the Design Copying and Block Construction subtests; and finally the domain of Memory and Learning was assessed by the Memory for Faces, Memory for Names, Narrative Memory, and Sentence Repetition subtests.

Academic achievement. The Wechsler Individual Achievement Test (The Psychological Corporation, 1992) was used to complete an assessment of academic achievement. The three subtests recommended for screening purposes, Basic Reading, Mathematics Reasoning, and Spelling, were administered.

Psychosocial functioning. The Child Behavior Checklist (CBCL; Achenbach, 1991a) and the Teacher's Report Form (TRF; Achenbach, 1991b) were used to assess psychosocial functioning. Only summary scores from these measures are reported in the current study.

Procedure

Ethical approval for this study was obtained as part of a wider study from the North Health Ethics Committee, Auckland. To ensure no families of deceased children were contacted all candidates were checked against the database of the New Zealand Health Information Service, and the database of the Starship Hospital Trauma Service. The search indicated that none of the potential candidates had subsequently died.

Initial contact with subjects was in the form of an invitation to participate letter to the parent/guardian of the child. Along with the letter of invitation was a Participant Information Brochure describing the procedure and rationale of the study. Addresses and phone numbers were identified via the Starship Hospital patient information system . Where a phone number was identified, the family was contacted two weeks following the dispatch of the invitation letter and brochure. Where phone numbers were not available, inclusion in the study depended on the family returning the reply slip in the post-paid envelope. For candidates where letters were returned unopened, due to incorrect address, the families' general medical practitioners were contacted in search of current addresses and phone numbers. New invitation letters and brochures were posted, and candidates contacted by phone, where possible.

All assessments took place at Starship Children's Hospital in various quiet rooms. Prior to testing, informed consent was obtained from the guardian of the child and permission to contact the child's teacher and general medical practitioner was obtained. Guardians were also asked to complete the CBCL at this time. All children received the same 3-hour battery of psychological tests. The tests were administered in the same order, 14 NEPSY subtests followed by 3 WIAT subtests, to each child. In order to minimize fatigue, a 10–20 minute break was scheduled following the NEPSY Fingertip Tapping subtest. The child was also encouraged to request additional breaks if the need arose. In appreciation of the time and cost of participating in the study, all participants received a Starship Hospital carpark voucher, a petrol voucher, and two McDonald's vouchers.

Data Analysis

The majority of the statistical analysis was undertaken using one-tailed *t*-tests for independent groups. Where appropriate, analysis of covariance was also conducted. Raw scores were used for statistical analysis, and the appropriate standard score used for determining clinical significance. Following Cohen (1988), the eta squared (η^2) effect size statistic was interpreted as .01 = small effect, .06 = moderate effect, and .14 = large effect.

Polissar et al. (1994) have demonstrated the Bonferroni corrections for multiple comparisons are too conservative when an injury affects several areas weakly, rather than one single area substantially. The former pattern is the one most likely to be found following mild TBI. Therefore, an alpha level of .05 was used to determine significance for all statistical tests but, in the interests of reducing the probability of Type I errors, comparisons were made on summary scores where appropriate. In those instances where $p < .05$, the obtained alpha level is reported. When conducting *t*-tests, an F test of sample variances was performed for each comparison. If the probability of F was > .05 then it was assumed that the sample variances were equal and t statistics based on pooled variance estimates were used. If the probability of F was < .05 then it was assumed that the sample variances were unequal and t statistics based on separate variance estimates were used.

In determining the clinical significance of individual scores the following procedure was used. Scores that were equal to, or greater than, one standard deviation from the mean of the normative sample were considered to indicate "mild" impairment. Scores two or more standard deviations from the mean were considered to indicate "significant" impairment (Spreen & Strauss, 1998).

Results

Neuropsychological Functioning

A comparison of the two groups' performance on the four tests of attention/executive functions found a statistically significant difference on the Visual Attention subtest, ($t(37) = -1.79$, $p = .041$). On average, the TBI group performed more poorly than the OC group and there was a moderate difference in the means ($\eta^2 = .08$). There was no significant difference between the two groups' performance on the other three subtests of Tower, Auditory Attention and Response Set, and Design Fluency.

Similarly, there were no statistically significant differences between the two groups on the five subtests assessing the domains of Language and Visuospatial Processing. The two groups did differ significantly on the Fingertip Tapping subtest ($t(37) = -1.98$, $p = .028$). The OC group performed more poorly than the TBI group on this measure, and there was a moderate difference in the means ($\eta^2 = .10$).

Finally, a comparison of the two groups' performance on the four subtests of the Memory and Learning domain found a statistically significant difference on the Memory for Faces subtest, ($t(28.76) = -2.41$, $p = .012$). On average, the TBI group performed more poorly than the OC group and there was a large difference in the means ($\eta^2 = .14$). There was no significant difference between the two groups' performance on the other three Memory and Learning subtests of Memory for Names, Narrative Memory, and Sentence Repetition (Table 2).

Impact of Time Since Injury on Group Differences. Given the statistically significant difference between the two groups on the demographic variable of time since injury, the groups' performance on the three neuropsychological measures were reanalysed by ANCOVA with time since injury as the covariate.

The difference between the two groups on the Visual Attention subtest remained statistically significant, $F(1,36) = 5.93$, $p = .020$. Similarly, the difference between the two groups on the Memory for Faces subtest remained statistically significant, $F(1,36) = 5.84$, $p = .021$. However, when time since injury was controlled for, the difference between the two groups on the Fingertip Tapping subtest was no longer statistically significant, $F(1,36) = 0.64$, $p > .05$.

Prevalence of Cognitive Impairment. The clinical significance of the neuropsychological performance of the TBI group was determined by examining the range of obtained scores. On the Visual Attention subtest, eight (42%) subjects obtained scores within the impaired range. Of these, five (26%) displayed mild impairment, while the remaining three (16%) had significant impairment. On the Memory for Faces subtest, a total of four (21%) subjects were impaired with three (16%) having mild impairment and the remaining subject (5%) displaying severe impairment.

Academic Achievement

There were no statistically significant differences between the two groups on the three subtests of Basic Reading, Mathematics Reasoning, and Spelling (Table 3).

Table 2

Means, Standard Deviations, *t* Statistics, Difference Confidence Intervals and Eta Squared for Performance on subtests of the NEPSY by the Traumatic Brain Injury (TBI) and Orthopaedic Comparison (OC) Groups

	TBI		OC				
Subtest	M	SD	M	SD	*t*	*95% CI*	η^2
Attention/executive functions							
Tower	7.32	4.68	8.00	4.30	–0.48	–3.60–2.23	.006
Auditory attention & response set	44.84	26.00	44.05	26.35	–0.09	–16.20–17.78	.0002
Visual attention	9.05	4.58	11.55	4.15	–1.79*	–5.33–0.33	.08
Design fluency	10.16	5.13	12.25	5.66	–1.21	–5.60–1.42	.04
Language							
Speeded naming	15.74	9.61	13.80	9.04	0.65	–4.11–7.99	.01
Comprehension of instructions	18.76	3.53	20.10	3.26	–1.20	–3.60–0.93	.04
Verbal fluency	23.78	11.06	26.15	9.28	–0.72	–9.07–4.32	.01
Sensorimotor functions							
Fingertip tapping	80.11	11.89	88.55	14.59	–1.98*	–17.11–0.22	.10
Visuospatial processing							
Design copying	46.37	9.41	51.05	8.28	–1.65	–10.42–1.06	.07
Block construction	11.58	2.14	11.35	2.06	0.34	–1.13–1.59	.003
Memory and learning							
Memory for faces	22.21	6.51	26.35	3.82	–2.41*	–7.66–0.62	.14
Memory for names	13.47	6.32	13.05	5.85	0.22	–3.53–4.37	.001
Narrative memory	16.32	7.63	16.85	6.10	–0.24	–5.00–3.94	.002
Sentence repetition	16.67	3.71	17.85	3.38	–1.03	–3.51–1.15	.03

*$p < .05$.

Table 3

Means, Standard Deviations, *t* Statistics, Difference Confidence Intervals and Eta Squared for Performance on subtests of the Wechsler Individual Achievement Test by the Traumatic Brain Injury (TBI) and Orthopaedic Comparison (OC) Groups.

	TBI		OC				
Subtest	M	SD	M	SD	*t*	*95% CI*	η^2
Basic reading	16.84	6.90	17.15	7.25	–0.14	–4.90–4.29	.0005
Mathematics reasoning	11.11	4.64	12.45	5.25	–0.85	–4.57–1.88	.02
Spelling	13.37	4.72	13.90	4.70	–0.35	–3.59–2.52	.003

Psychosocial Functioning

The results from the parents and teachers reports of the psychosocial functioning of the subjects are displayed in Table 4. There were no statistically significant differences between the two groups on any of these measures.

Table 4

Means, Standard Deviations, *t* Statistics, Difference Confidence Intervals and Eta Squared for Parent and Teacher Ratings on the Psychosocial Measures for the Traumatic Brain Injury (TBI) and Orthopaedic Comparison (OC) Groups

	TBI		OC				
Scales	M	SD	M	SD	*t*	*95% C.I.*	η^2
Child Behavior Checklist							
Total competence	16.78	4.16	17.44	2.35	–0.58	–3.01–1.68	.01
Internalizing problems	7.42	7.00	9.75	8.90	–0.91	–7.54–2.88	.02
Externalizing problems	11.32	11.56	10.30	7.04	0.33	–5.29–7.32	.003
Total problems	31.47	25.73	33.25	21.20	–0.24	–17.04–13.49	.002
Teachers Report Form							
Academic performance	3.00	0.73	2.81	0.67	0.78	–0.30–0.68	.02
Total adaptive functioning	18.75	4.45	16.65	4.12	1.41	–0.94–5.15	.06
Internalizing problems	4.59	6.82	3.88	4.41	0.36	–3.31–4.72	.004
Externalizing problems	5.35	8.94	6.88	9.24	–0.49	–7.88–4.82	.007
Total problems	20.41	27.70	23.53	22.88	–0.36	–20.87–14.63	.004

Discussion

The purpose of the present study was to document the long-term neuropsychological, academic, and psychosocial outcome for children who had received a TBI resulting in skull fracture, during infancy. In addition, we sought to contribute to the ongoing debate concerning the prognostic significance of an isolated skull fracture sustained during the first two years of life (Greenes & Schutzman, 2001). In recognition of the methodological issues raised by Gronwall et al. (1997), the design of the current study incorporated reliable and valid assessment measures within a developmental framework, a comparatively long-term follow-up, a precise age range for the sample (i.e., infancy), and a comparison group that allowed for the emotional impact of injury to be controlled for.

Skull fractures following TBI are more common in infants than in older children and adolescents (Choux, 1986). The results of the current study indicate that an isolated skull fracture in infants does not indicate extensive cerebral damage, as it can in children and adults. Although establishing severity of TBI in infants can be problematic (Durham et al., 2000), the lack of specific neurological findings and absence of subsequent neurological deterioration supports the validity of the Glasgow Coma Scale scores obtained for the current sample. These scores indicated that the majority of the sample had received a TBI of mild severity. Further, the mechanism by which the majority of the current sample sustained their TBI (i.e., falls) is consistent with both previous findings in pre-school samples and the predominance of mild injuries.

Unfortunately the majority of previous studies have reported results from samples with a wider range of either age at injury (e.g., Frush et al., 1998) or injury severity (e.g., Anderson et al., 2000). The central role of these two variables in determining outcome limits the extent to which findings from the current study can be directly compared with the results from previous research. However it is generally accepted that for the immature brain, injuries of even mild severity may have delayed consequences on neuropsychological functioning (e.g., Levin et al., 1997). Further, the age-at-injury factor remains an important influence on outcome following mild TBI since different cognitive skills may have different developmental rates and ages of acquisition. If this is so, then skills in rapid ascendancy at one age may be more vulnerable to the effects of mild TBI by lowering the threshold for impairment (Fletcher et al., 1987). Ewing-Cobbs et al. (1998) in examining the effects of age at injury in relation to performance on visual attention tasks reported that younger children scored lower than the older group. Finally, it has been suggested that measures of specific cognitive functions may be more sensitive to impairment than overall measures of neuropsychological functioning (Dennis et al., 1995).

In the current study the neuropsychological assessment procedures covered five specific cognitive domains. Results from the four subtests assessing the attention/executive domain showed a statistically significant difference of moderate magnitude, between the two groups on the Visual Attention subtest. On average, the TBI group performed more poorly than the comparison group. The 42% of TBI subjects who obtained clinically significant scores had all received mild TBI, and did not differ from the unimpaired TBI subjects on any other injury-related or demographic variable. There were no significant differences between the two groups' performance on the other three attention/executive subtests. The finding that mild TBI sustained in infancy results in clinically significant impairment in visual attention functioning in a proportion of children more than five years post-injury, is similar to the results reported by Ewing-Cobbs et al. (1998) and Wrightson et al. (1995).

Assessment of memory and learning abilities revealed a large and statistically significant difference between the two groups' performance on the Memory for Faces subtest. On average, the TBI group performed more poorly than the comparison group. The 21% of TBI subjects who obtained clinically significant scores had all received mild TBI. There were no significant differences between the two groups' performance on the other three learning and memory subtests. This suggests that nonverbal recall may be affected in the long term by mild TBI sustained at an early age. Other researchers have also reported a specific deficit in recall of complex nonverbal stimuli following TBI in children (Donders & Ballard, 1996).

The two subtests on which the TBI sample displayed deficits, namely visual attention and memory for faces, share a common element of complex visual stimuli. This suggests that the processing of this type of stimuli may be affected more than five years following mild TBI in infancy. Furthermore, given that all the fractures were sustained to the posterior region of the skull, the possibility exists that these deficits are a consequence of the site of injury. As attention is an important regulator of cognitive activity and persistent difficulties with attention may contribute to observed memory impairment (Dennis et al., 1995), the possibility of a relationship between poor functioning in visual attention and subsequent poor performance on the Memory for Faces subtest seems plausible. That is, within the TBI cohort, deficits in visual attention result in impaired processing, and therefore subsequent poor recall, of the complex visual stimuli that constitute the Memory for Faces subtest. Similar deficits in the processing of complex nonverbal stimuli have been reported by Wrightson et al. (1995).

Sensorimotor functions were assessed by administration of the Fingertip Tapping subtest. Initial analysis indicated that the orthopedic comparison group performed, on average, worse than the TBI group. However when the impact of the difference between the two groups on the time since injury variable was taken into account, there was no significant difference between them. It follows that given the nature of the comparison group's injury (i.e., arm fracture) and the more recent occurrence of their injury, they would be comparatively less able at this task than the TBI group. Bawden et al. (1985) concluded that mild TBI is not associated with long-term deficits in sensorimotor functioning. However, in the present study, the nature of the comparison group used means that no firm conclusion can be drawn concerning the TBI group's sensorimotor performance relative to a normal (i.e., no arm fracture) population. There was no evidence to suggest that the TBI group performed more poorly than the comparison group on any of the measures of language or visuospatial processing.

There were no significant differences between the two groups on the measures of academic achievement. Moreover, the two groups did not differ in ratings by teachers on the Academic Performance subscale of the Teacher's Report Form. These findings are similar to those of previous research (Polissar et al., 1994) that suggest that, in comparison to a matched comparison group and over the long term, children with mild TBI do not exhibit generalized deficits in academic functioning.

With regard to aspects of their psychosocial functioning, the results from parental and teacher reports of behavioral functioning were not significantly different across the two groups. These findings support those from previous research, which suggest that mild TBI is not associated with long-term psychosocial difficulties (Levin et al., 1987).

Previous research has indicated that children with TBI generally exhibit cognitive, academic, and psychosocial difficulties following injuries that are moderate to severe (e.g., Jaffe et al., 1993; Spreen et al., 1995). The results of this study serve to support recent findings that long-term difficulties following mild TBI are infrequent (e.g., Anderson et al., 2000; Kinsella et al., 1999; Light et al., 1998). However there is also recent evidence that outcome for children injured in the pre-school period is not necessarily homogeneous, even within mild TBI groups (McKinlay et al., 2002). For the current sample, even with a high degree of homogeneity of age at injury and injury severity, some individuals with mild injuries exhibited specific cognitive deficits in the processing of complex visual stimuli, more than five years following injury. Wrightson et al. (1995) in their longitudinal investigation of mild TBI in pre-school children also reported the presence of specific cognitive deficits related to the processing of complex visual stimuli. They found a relationship between this deficit and delayed development of reading skills. Such findings illustrate the importance of comprehensive and ecologically valid neuropsychological assessments.

Overall the results from this study indicate that skull fracture during infancy can be associated with mild, as opposed to moderate or severe, TBI. On average, the long-term cognitive, academic, and psychosocial consequences of such injuries in this population appear minimal. However, this is not the same as an absence of long-term consequences. For some individuals within this group, there is evidence for specific cognitive deficits related to the processing of complex visual stimuli. Why just some individuals, rather than all or none, is currently unclear. However progress in our understanding of the effects of mild injury to the infant brain is evident in the recent literature. Further contributions to our knowledge base in this area will come from broad-based longitudinal studies using developmentally appropriate assessments of subjects who are homogeneous with regard to injury severity and age at injury.

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