PAPER

Long-term effect of head trauma on intellectual abilities: a 16-year outcome study

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Background: Intelligence was assessed in a group of 74 people with head injury, 16 years after injury (mean 16.77 years; range 10–32 years), and compared with their performance when assessed at an early stage in recovery (mean 1.05 years).
Aims: To confirm the presence of long-term impairment relative to estimates of pre-accident ability, to confirm signs of deterioration between early (T1) and late (T2) measures, and to examine relationships between severity of injury, time since injury, length of education, sex and age, and performance on intelligence tests at T2.
Expected outcomes: On the basis of evidence from other studies, a significant difference was expected between estimates of pre-accident intelligence and abilities measured at T1 and T2. Deterioration in performance between T1 and T2, and relationships between demographic variables, severity of injury and intellectual performance were also expected.
Results and conclusion: The data supported long-term intellectual impairment, but there was no deterioration in abilities between T1 and T2. Performance on intelligence tests was associated with years of education but not with other factors.

The prefrontal cortex mediates important cognitive functions, such as fluid intelligence, abstract thinking, attention, memory and executive ability, all of which are vulnerable to ageing.[1–8] The prefrontal cortex is also vulnerable to mechanical forces operating at the time of decelerative head trauma.[9] Consequently, people who sustain such injuries are likely to be at risk of premature ageing, one index of which is deterioration in measures of intelligence.[6] However, evidence for this is limited and studies have yielded conflicting results. One source of information has been research on Second World War survivors. Corkin *et al*[10] assessed 57 survivors, 40 years after missile injury, and found that many had become mentally less "sharp". Walker and Blumer[11] also found varying degrees of mental deterioration in 25% of their cohort 45 years after injury, and Plassman *et al*[12] reported a raised prevalence of Alzheimer's disease in veterans with brain injury compared with age-matched controls without head injury. However, Newcombe,[13] using a more rigorous test–retest longitudinal paradigm, failed to find evidence of mental deterioration in her military sample.

In a civilian context, Lewin *et al*[14] reported deterioration in 11% of their sample of 291 severely injured adults seen 10–24 years earlier. However, it is not clear from their methods how a measure of deterioration was obtained. Millar *et al*[15] examined the cognitive status of 396 people with head injury, 18 years after injury, using the Mini-Mental State Examination and composite performance scores from five cognitive tests. A measure of cognitive decline was obtained by comparing composite scores with an estimate of pre-morbid intellectual function based on the National Adult Reading Test (NART).[16] The authors report "profound" cognitive impairment relative to estimates of pre-morbid ability, but they were unable to compare test scores with measures obtained at an earlier stage of recovery, so it was not possible to determine whether cognitive deterioration had taken place over time. The authors also point out that the young age of their cohort (mean age 42.1 years) was a constraint on assessing risks of cognitive deterioration. More recently, Himanen *et al*[17] conducted a 30-year longitudinal study of cognitive changes in 61 patients with head trauma whose injuries ranged from very mild to very severe. Using five subtests from the Wechsler Adult Intelligent Scale (WAIS) and three tests of memory, they found evidence of slight cognitive decline overall, but performance on some tests of memory improved over this time, and both sex and age at injury proved to be independent risk factors affecting long-term cognitive performance.

We examined the long-term effect of head injury on cognitive ability, measured by performance on intelligence tests, by comparing the performance of patients assessed in the early years of recovery (mean 1.05 years) with that assessed at a late stage after injury (mean 16.77 years). The aims of the study were to (a) confirm the presence of long-term intellectual impairment, relative to estimates of pre-accident ability, measured by the NART; (b) confirm measurable changes in test performance between early (T1) and late (T2) assessments, which could act as an index of premature ageing; and (c) examine relationships between factors such as severity of injury, time since injury (TSI), age at injury, sex, years of education and long-term performance on intelligence tests.

METHODS

The data presented in this study were collected as part of a larger study investigating long-term psychosocial outcome after brain injury.[18]

Participants

A total of 512 head trauma cases were identified, 348 from RLlW's medicolegal archive database and 164 from the head injury archive files of a regional neurotrauma centre—Morriston Hospital, Swansea, UK. All patients were judged

Abbreviations: FSIQ, Full-Scale IQ; GCS, Glasgow Coma Score; NART, National Adult Reading Test; PTA, post-traumatic amnesia; TSI, time since injury; WAIS, Wechsler Adult Intelligent Scale; WAIS-R, Wechsler Adult Intelligent Scale—Revised

Table 1 Participants completing each Wechsler Adult Intelligent Scale—Revised subtest given at first assessment after head injury

Cognitive test	n	Percentage
Total participants	74	100
Vocabulary	27	36.49
Similarities	66	89.19
Digit span	71	95.95
Arithmetic	47	63.51
Picture completion	47	63.51
Picture arrangement	46	62.16
Digit symbol	32	43.24
Block design	59	79.73

to have had moderate or severe closed head injury, classified by post-traumatic amnesia (PTA>24 h) and Glasgow Coma Score (GCS<10) on admission to hospital. However, GCSs were available only for 47 patients (63.51%); PTA was therefore used as the measure of severity of injury (PTA>24 h indicates severe injury).[19] Inclusion criteria were as follows: aged at least 16 years at the time of injury and <75 years at follow-up; assessment at T1 not >5 years after injury; at least 10 years between the first assessment (T1) and follow-up (T2); only one neuropsychological assessment at T1 and no repeat assessment until T2; no language or motor deficits that would interfere with test administration or performance; and, from information in the case files, judged able to give informed consent. 351 cases satisfied these criteria and were approached by letter. 133 (37.89%) replied. Of these 133 patients, 74 (55.64%) expressed a willingness to participate (medicolegal group, n = 37; Morriston Hospital, n = 37) and formed the follow-up cohort; 45 (33.83%) declined; and 3 (2.26%) had died. Those who replied positively were assessed in their homes. At the time of assessment, all consented to participate in the study. There was no difference between participants who replied positively and those unwilling to participate in terms of sex (χ^2 0.263, df = 1, p = 0.608), age at T2 (t(117) = −0.880, p = 0.380), severity of injury (t(117) = 0.758, p = 0.450), years of education (t(117) = 0.047, p = 0.963) and TSI at T2 (t(117) = −0.755, p = 0.452).

Of the 74 participants, 57 (77.03%) were men. Mean age at injury was 30.58 (standard deviation (SD) 12.43, range 16–59) years and 46.73 (SD 12.37, range 27–75) years at follow-up (T2). Mean educational level was 11.89 (2.33, 9–19) years. In all, 54 (72.97%) participants were injured in a road traffic accident, 11 (14.86%) had a fall that caused injury, 5 (6.76%) were assaulted and 4 (5.41%) had static concussion. Mean length of PTA was 19.15 (SD 22.56, range 1–150) days and mean GCS was 7.77 (SD 2.18, range 5–10). Mean time between injury and T1 was 1.05 years (SD 1.37, range 1 week to 4.92 years), at T2 it was 16.77 (SD 5.54, range 10.00–32.17) years. Mean time between T1 and T2 was 14.84 (SD 4.50, range 10.00–27.73) years.

Design and procedure

A quasi-longitudinal design compared performance on measures of intelligence at two time points, 10–30 years after injury. To investigate the influence of demographic variables the cohort was divided into subgroups as follows: TSI, <15 or ⩾15 years; influence of age, <50 or ⩾50 years at T2; severity of injury, <14 or ⩾14 days PTA; influence of education, ⩽11 or >11 years of education (the cut-off between secondary school and further education). A correlation analysis examined relationships between cognitive performance at T2 and severity of injury, TSI, age at injury, sex and years of education.

The majority of the cohort (n = 59, 79.73%) were first seen for assessment within 2 years after injury. To examine the influence of spontaneous recovery in this period,[19] an identical analysis was carried out on the 15 participants who were first seen >2 years after injury (mean 3.56 years; SD = 0.75, range 2.15–4.92). To achieve parity of sample size, however, a 20-year post-injury division was used to compare this subgroup.

Measures

Estimates of pre-accident ability were obtained at T2 using the NART—Revised, because it has proved resistant to the effects of normal ageing over a 66-year interval.[20] At T1, 19 patients (25.68%) completed subtests from the WAIS[21] and 55 (74.32%) from the WAIS—Revised (WAIS-R).[22] Owing to clinical exigencies at the time of testing, a variable number of subtests were completed at T1 (table 1).

A missing value analysis was carried out to identify any patterns in the missing data. Little's Missing Completely at Random Test[24] for missing values was carried out for the complete set of cognitive subtests at T1. The test showed no significant deviation from a pattern of values that are missing completely at random (χ^2 = 108.826, df = 105, p = 0.380). Instead of filling in missing values with constants, such as medians or means, the expectation–maximisation method of imputation was used to substitute values for missing data for all variables.[25 26] The Full-Scale IQ (FSIQ) scores for T1 were calculated from the complete database with inputted values.

All participants completed three verbal and three performance subtests of the WAIS 3rd edn (WAIS-III)[27] at T2 (vocabulary, similarities, digit span, digit symbol, block design and matrix reasoning). A composite FSIQ score at T2 was calculated from the six subtests to make comparisons with estimated pre-accident IQ.

Analysis

Participants completed versions of the WAIS appropriate to the time of administration. The Wechsler scales were upgraded three times over the period covered by this study, each upgrading producing a different set of population means. The mean WAIS FSIQ is 8 points higher than the WAIS-R FSIQ, which, in turn, is 2.9 points higher than the WAIS-III FSIQ.[28] However, the scores reported in the technical manual were obtained after short test–retest intervals (12 weeks), whereas in this study there were at least 10 years between administration of the WAIS or WAIS-R and the WAIS-III tests. We therefore believed it was inappropriate to make adjustments to subtest scores when comparing WAIS versions, because the scores accurately represent population means at the time they were obtained.

A ''difference score'' was calculated to assess the significance of different FSIQ scores between T1 and T2 at the 5% significance level. The following formula was used [27]

$$\text{Difference Score} = Z\sqrt{(SE_{ma}^2 + SE_{mb}^2)}$$

Here, Z = 1.96, SE_{ma} and SE_{mb} are the standard errors (SEs) of measurement of two scales—for example, WAIS and WAIS-III. The SE of measurement used for each of the WAIS scales was as follows: WAIS 2.60[21]; WAIS-R, 2.53[22]; and WAIS-III 2.30.[27]

The difference score between WAIS and WAIS-III (6.80) was relevant for 19 patients, and that between WAIS-R and WAIS-III (6.70) was relevant for 55. Difference scores were used to classify patients into ''improvers'' or ''deteriorators''—for example, if patients tested using the WAIS at T1 obtained a score at T2 that was >6.80 points from their score at T1, they were classified as improvers.

Table 2 Comparison of intelligence quotient scores between pre-injury, T1 and T2, when categorised by severity of injury, time since injury, age, sex and years of education

		n	IQ scores			ANOVA results		t values		
			PI	T1	T2	Wilks' λ	F value	PI−T1	PI−T2	T1−T2
Whole cohort		74	99.79	90.96	92.37	0.606	23.431*	6.023**	5.385**	−0.885
Severity of injury (days)	⩽14	50	98.83	92.79	93.96	0.735	8.663*	−3.543*	3.276*	0.623
	>14	24	101.78	87.14	89.04	0.333	22.040*	−5.998*	4.826*	−0.631
Time since injury (y)	<15	33	99.10	87.30	92.42	0.472	17.343*	−5.974*	3.677*	−2.898
	⩾15	41	100.33	93.91	92.32	0.671	9.571*	−3.122*	3.954*	0.663
Age (y)	<50	45	100.30	88.24	92.27	0.511	20.591*	−6.446**	4.441**	−2.423
	⩾50	29	98.99	95.17	92.52	0.688	6.120*	−1.843	3.015*	0.886
Sex	Male	51	99.04	90.13	92.94	0.641	13.695**	−5.059**	−3.692**	−1.583
	Female	23	101.44	90.72	92.83	0.482	11.266**	−4.374**	−3.990**	−0.900
Education (y)	⩽11	44	95.16	86.99	87.96	0.470	23.704**	−5.319**	−5.680**	−0.560
	>11	30	106.57	95.19	100.17	0.620	8.595**	−4.209**	−2.367	−2.105

*p<0.05. **p<0.01.
ANOVA, analysis of variance; PI, pre-injury; T1, first assessment after head injury; T2, follow-up assessment.

A comparison of FSIQ between pre-injury, T1 and T2 was made using repeated measures analysis of variance with a priori planned t test comparisons. α-values were adjusted using the Bonferroni correction for multiple comparisons. The correlation analysis was carried out using Pearson's correlation coefficient.

RESULTS

Long-term intellectual impairment

Table 2 shows significantly different (p<0.001) IQ scores for the whole cohort between pre-injury, T1 and T2, supporting the presence of long-term intellectual impairment. However, when analysing each time point separately, significant differences were evident only between pre-injury and T1 (p = 0.002), and between pre-injury and T2 (p = 0.002). We found no difference between T1 and T2 to suggest deterioration in ability over time.

Table 2 also shows the effect of severity of injury, TSI, age, sex and years of education. A significant age effect was evident between pre-injury and T2 in both age groups(<50, p = 0.002; ⩾50, p = 0.02). However, we found a significant difference only between pre-injury and T1 (<50, p = 0.002) in the younger age group and no significant difference between T1 and T2 in either group. When years of education were included in the calculation, we noted a significant difference between both pre-injury and T1 (p = 0.002), and between pre-injury and T2 (p = 0.002) in the less well-educated group. In the better-educated group, a significant negative difference was evident only between pre-injury and T1 (p = 0.002). Once again, neither group differed between T1 and T2.

A comparison of five subtests given at both T1 and T2 (table 3) showed that the only significant reduction in performance was on the vocabulary subtest (p = 0.003). In contrast, significant improvements were found for digit span (p = 0.003), digit symbol (p = 0.015) and block design (p = 0.002) subtests. We found no difference in scores on the similarities subtest.

Table 3 Comparison of mean (SD) subtest scores for whole cohort between T1 and T2

Subtest	T1	T2	t Values
Vocabulary	9.48 (2.86)	8.48 (2.78)	3.828**
Similarities	8.25 (2.90)	8.56 (3.17)	−0.887
Digit span	8.19 (2.91)	9.41 (3.20)	−3.824**
Digit symbol	6.77 (2.27)	7.73 (3.08)	−3.049*
Block design	8.79 (2.84)	10.16 (3.44)	−4.104**
Arithmetic	9.10 (3.00)	–	–
Picture completion	8.26 (2.67)	–	–
Picture arrangement	8.16 (2.71)	–	–
Matrix reasoning	–	9.84 (2.84)	–

*p<0.05. **p<0.01.
T1, first assessment after head injury; T2, follow-up assessment.

Relationships between severity of injury, TSI, age, sex and years of education on change in performance on intelligence tests between T1 and T2

Using the formula to determine significant difference scores described in the Methods section, we found that at a 95% confidence interval, the scores of 15 (20.27%) patients at T2 had significantly deteriorated, whereas 28 (37.84%) had improved. We used a correlational analysis, using information from the whole cohort (n = 74), to investigate relationships between severity of injury, TSI, age, sex and years of education, with change in performance on intelligence tests between T1 and T2. Only years of education (r = −0.24, p<0.05) had a significant association with change in performance over time. Less well-educated people seem to be at greater risk of cognitive decline.

Controlling for spontaneous recovery

This group comprised 15 patients, of whom 8 (53.3%) were men. Mean age at injury was 27.33 (SD 9.69, range 16–45) years, and at T2 was 48.73 (SD 10.36, range 34–64) years. Mean educational level was 12.27 (SD 2.60, range 10–19) years. Mean length of PTA was 19.33 (SD 20.79, range 3–84) days. The mean TSI at T1 was 3.56 (SD 0.75, range 2.15–4.92) years, at T2 21.74 (SD 4.71, range 15.50–30.75) years. A cut-off of <20 or ⩾20 years was selected to provide more even numbers in the groups for analysis. The mean time between T1 and T2 was 18.18 (SD 4.62, range 12.42–27.73) years. The subgroup did not differ from the original cohort regarding any of the above factors, with the exception of TSI at T1 (t(72) = −22.241, p<0.001), TSI at T2 (t(72) = −4.444, p<0.001) and time between T1 and T2 (t(72) = −2.892, p = 0.005), all of which were expected.

The subcohort showed results similar to the full cohort (table 4). We found a significant difference in IQ between the time points but only between pre-injury and T1 (p = 0.03), not between pre-injury and T2. We also found no differences

Table 4 Comparison of estimated pre-injury IQ scores with performance at T1 (assessed >2 years after injury) and T2, categorised by severity of injury, time since injury, age, sex and years of education

			IQ scores			ANOVA results		t Values		
		n	PI	T1	T2	Wilks' λ	F value	PI−T1	PI−T2	T1−T2
Subcohort		15	97.07	87.78	88.53	0.592	4.472*	−2.994*	2.227	−0.215
Severity of injury (days)	⩽14	9	92.78	86.64	93.00	0.717	1.380			
	>14	6	103.50	89.50	81.83	0.134	12.950*	−2.624*	5.537*	1.887
TSI (years)	<20	6	90.33	84.83	84.83	0.848	0.357			
	⩾20	9	101.60	89.75	91.00	0.344	6.662*	−3.681*	2.080	2.463
Age (years)	<50	8	100.75	88.88	87.00	0.482	3.230			
	⩾50	7	92.86	86.53	90.29	0.705	1.044			
Sex	Male	8	99.50	87.51	90.00	0.549	2.461			
	Female	7	94.29	88.09	86.86	0.601	1.662			
Education (years)	⩽11	7	89.00	80.39	81.71	0.427	3.359			
	>11	8	104.13	94.25	94.50	0.628	1.778			

ANOVA, analysis of variance; PI, pre-injury; T1, first assessment after head injury; T2, follow-up assessment; TSI, time since injury.
*p<0.05; **p<0.01.

in FSIQ or subtest scores between T1 and T2 to suggest intellectual deterioration. When the subcohort was divided into demographic groups as before, significant differences were found only in the most severely injured group (PTA >14 days) and in the subgroup that was ⩾20 years after injury at follow-up (table 4). In both these subgroups, scores differed between pre-injury and T1 (>14 days, p = 0.018; ⩾20 years, p = 0.018). The more severely injured subgroup also showed a score difference between pre-injury and T2 (p = 0.009).

DISCUSSION

The complex pattern of neurobehavioural disability seen at an acute stage of recovery from serious head trauma can have a major effect on mental functioning. Therefore, understandably, many clinicians express pessimism about long-term prospects for neuropsychological recovery and place this group at high risk for abnormal cognitive ageing. However, the results of this study seem to provide scope for optimism regarding long-term outcome of intellectual functions. Although long-term intellectual impairment clearly exists, relative to pre-accident estimates of intelligence, there is no evidence of any generalised decline in performance that might indicate accelerated cognitive ageing. When severity of injury, age, TSI, sex and years of education were taken into account, years of education proved to be correlated with a change in level of intellectual performance between T1 and T2. Those who stayed in education beyond secondary school years showed a trend towards improvement on some measures of ability. Although this trend was not significant, the possibility of continuing improvement cannot be ruled out.

When only data from the small number of cases assessed more than 2 years after injury were analysed, significant differences were seen in the group with the most severe injuries (PTA >14 days) and in those who were >20 years after injury at T2, suggesting that people with more severe injuries may well be at risk of accelerated ageing over extended periods of time. The proportion of our cohort that showed a reduction in intellectual functioning over time was similar to that reported by Himanen *et al*,[17] which seem to provide partial support for Lewin *et al*'s[14] finding of deterioration in a small number of seriously injured patients. However, Himanen *et al* reported an improvement on similarities, deterioration on block design, but no change on digit span or digit symbol. In this study, however, an improvement was recorded on block design, digit span and digit symbol subtests, but no difference was recorded on the similarities test. These differences may be explained by the fact that Himanen *et al*'s sample was generally older and at a later stage after injury than participants in this study. Their cohort also included those with mild injuries, whereas our study specifically focused on those with predominantly severe head injury. Differences also exist in the specific tests given. We used different versions of the WAIS to ensure that current norms were used, whereas Himanen *et al* repeated subtests from the original WAIS and did not control for inflation in scores expected when a participant's performance was referenced to outdated norms.[29–31]

The participants in our study represent a subgroup of patients with severe head injury reported in a larger study assessing long-term psychosocial outcome.[18] The full cohort assessed in that study reported a good quality of life, reasonable satisfaction with life and an absence of psychological morbidity. They were rated by relatives as having good functional skills but limited community integration. The absence of long-term intellectual deterioration in this group probably contributed to their good psychosocial outcome, because it allowed them to develop effective coping skills, facilitating a gradual adjustment to injury sequelae.

The cohort size in this study compares favourably with that in other published studies on long-term outcome. However, the conclusions must be interpreted cautiously, (a) because of the relatively small number of patients that comprised the subgroup first assessed after a time when no further spontaneous recovery was likely, and (b) because those patients from the original cohort who were not available to follow-up may have experienced a poor outcome, making it possible that the patients available for follow-up were not representative of the sample as a whole. The age of the cohort at follow-up was also problematic because many were only in middle or late-middle age. However, studies on normal ageing have shown that although the influence of age on cognitive functioning is generally greater for those >50 years, significant negative age–cognition relationships are evident in 18–50-year olds, indicating that decline in some types of cognitive performance can be identified, even before the age of 50 years.[12] However, this would not explain why scores on vocabulary (a test of "crystallised" ability) declined significantly, whereas three measures of "fluid" ability improved over time. The data raise the possibility that the small decline in test performance recorded between T1 and T2, for the older, more seriously injured patients, although not significant, reflects a slow but progressive change that will eventually become clinically evident. This will require a more detailed and longer term assessment. Another limitation is that the study only examined components of intelligence as measures of cognitive ageing. However, many factors contribute to cognitive functioning in real-life settings. A comparison of memory performance over a similar interval may have yielded different results; unfortunately data were insufficient to conduct such an analysis. It is also regrettable that data were available only on five cognitive subtests common to both T1 and T2, but the number of measures was comparable with other published longitudinal studies[13] and the tests that were used correlated highly with measures of general intelligence. We acknowledge, however, that calculating composite IQ scores from such limited numbers of subtests is far from ideal. The SE measurements used to calculate difference scores for FSIQ are likely to be larger than what we calculated because of the number of subtests given. Therefore, some patients may have been inappropriately judged to have significantly changed when in fact they had not.

Clearly, a prospective long-term follow-up of patients is needed, using a test–retest paradigm that includes both a sufficient number and range of cognitive tests, so that abilities can be compared in detail and over a long term. However, it is encouraging that 16 years after serious head trauma, there were no signs of major intellectual decline that might affect psychosocial outcome.

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