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Long-term effects of severe closed head injury on memory: evidence from a consecutive series of young adults

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ABSTRACT – Long-term cognitive sequelae of severe closed head injury were studied in a consecutive series of 39 young head-injured adults without gross intellectual deficits. Testing was carried out 2–5 years post-injury. Patients with a post-traumatic amnesia (PTA) > 3 weeks were impaired on a wide range of tests, particularly those requiring long-term retention of complex materials or where time constraints were a salient feature. Patients with a PTA of 1–3 weeks were unimpaired on all tasks. The results suggest that in young adults a threshold of brain damage related to long-term cognitive impairment operates at around a 2–3 week PTA duration.

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It is now well-established that, following severe closed head injury, patients tend to show deficits on a wide range of cognitive tasks. The nature and severity of these deficits have been reported to vary according to: 1) severity of injury, whether assessed by length of post-traumatic amnesia (PTA) or duration of coma (1, 2, 3, 4, 5, 6, 7, 8); 2) time since injury (3, 4, 9); 3) the particular function being tested (2, 3, 4, 5); 4) age at injury (1, 7); and 5) site of impact (4, 10). IQ of the patient (11) has also been reported to affect the extent of the deficits though this finding may be contaminated by design problems (12). In other studies, however, these variables have either been unrelated, or inconsistently related to the extent of cognitive deficit (4, 5, 6, 13). It would appear that the presence or absence of a main effect for any one of these variables (e.g. time since injury) is dependent on the extent to which the other variables (e.g. PTA, age and IQ) are held constant, the sensitivity of the particular test (e.g. verbal IQ vs. performance IQ) to the range in which this variable is being studied (e.g. 1 month post-injury vs 3 months; 6 months vs 1 year), and the design of the study (cross-sectional vs longitudinal).

The present study examines the long-term consequences of severe closed head injury on memory and related functions 2–5 years post-injury. There are few parallel studies in the literature; most have examined memory function only during the first post-injury year. Though it has been claimed from cross-sectional studies (6, 7) that memory recovery after closed head injury reaches asymptote (albeit at a deficient level) within a few months post-injury, clinical experience and results from several recent longitudinal studies (3, 4, 14) indicate that, for some patients, a more gradual recovery of cognitive function may continue for at least a further year or two. Studies on other brain-damaged groups also attest to evidence for cognitive recovery over a more extended time period than is generally supposed (15, 16). These findings suggest that results from early post-injury studies may not represent absolute levels of recovery. If this argument is correct, some of our assumptions regarding prognosis, treatment strategies and after-care services may be in need of re-evaluation. It was thus the first aim of the present study to examine the long-term consequences of severe closed head injury on cognitive function more than 2 years post-injury.

A second, subsidiary aim of the study was to determine whether persisting cognitive deficits are present in all groups of patients labelled as "very severe" head injuries by Russell & Smith (1). These authors termed all those injuries where the PTA was more than one week as "very severe", and concluded that a majority of this group suffered permanent "memory and calculation defect", and had a poor prognosis. Russell & Smith did not make any further differentiations between sub-groups of different PTAs above this one-week threshold, but following them, many clinicians use a criterion of PTA > one week as a rule-of-thumb to determine likely prognosis. However, there is a suggestion in some published studies (2, 3), though not others (10, 17), that patients with a coma duration of less than one week, or PTA less than 3 weeks, may recover to within normal limits on cognitive tasks sensitive to the effect of head injury. Patients with longer comas or PTAs invariably have persisting memory deficits at long-term follow-up. The present study, therefore, investigated whether there might be a threshold of brain damage at around a 3-week-PTA duration above which patients would be highly suceptible to long-term cognitive deficits in contrast to patients below that threshold. For this purpose, it was deemed important to study a consecutive series of young head-injured adults (in contrast to many previous studies of selected patients specifically referred for psychological testing).

The third aim of the study was to determine the nature and quality of any persisting memory deficits after closed head injury. Previous studies of long-term cognitive outcome have either concentrated on aspects of performance other than memory (2, 3, 17), or on a narrow range of memory tasks (4, 18). The tests selected were designed to examine verbal and nonverbal memory, short-term and long-term memory, and recall and recognition. Additional tasks measured aspects of memory not so far reported in the head-injury literature and other cognitive functions which it was assumed might aid in the interpretation of the memory test data. It was hoped that by examining memory and other cognitive performance over a wide range of tasks, conclusions could be drawn about the relative susceptibility of different cognitive functions to the effects of head injury.

Methods

Subjects

The study was designed to analyse the long-term consequences of severe closed head injury in a consecutive series of young head-injured adults, for whom there was no evidence of premorbid intellectual impairment, or of gross intellectual deterioration post-injury. Thus, all those patients were selected from hospital records who met the following criteria: (i) were admitted after their accidents to the Radcliffe Infimary (i.e. not transfer cases) during the 3 years 1976–1978; (ii) were under 35 at the time of injury; and (iii) has a post-traumatic amnesia (PTA) of more than one week recorded by the neurosurgeons. A lower limit of one week PTA was chosen since Russell & Smith (1) termed all patients above this threshold as "very severe" head injuries. A previous study from this centre has shown a high degree of concordance between the neurosurgeons' estimate of PTA, and PTA as assessed by a simple quantitative test designed to chart the return of continuous day-to-day memory (19). A total population of 46 cases met these criteria. Of these, 7 were omitted from the final sample: 2, with PTAs of more than 6 months, who were permanently institutionalized and had suffered severe intellectual handicap; 2 who were tested by the author and found to have an estimated IQ of less than 80, which further enquiry revealed was almost certainly a reflection of premorbid intellectual status; 2, who at the time of testing, were resident abroad, and, lastly, one who was untraceable.

39 patients (32 male, 7 female) therefore comprise the experimental sample of this study. Failure to co-operate with follow-up studies of this kind has been reported (9), but interestingly all 39 patients complied with the request to be seen by the researcher either at home or in the hospital. It was, however, necessary to repeat the request either by telephone or letter, for several patients.

Testing was carried out between 2 and 5 years post-injury. All patients had a negative pre-injury history for alcoholism, drug abuse or neurological disorder. 2 patients (1 quadriplegic, 1 personality/memory change) would be described as "severely disabled" according to the Glasgow Outcome Scale (20); a further 10 were "moderately disabled", while the remainder had made a "good recovery", though some of these did have minor persisting deficits (notably memory problems). For the purposes of data analysis, the patients have been divided into 2 groups; the first with a PTA of between one and 3 weeks, the second with a PTA of more than 3 weeks; all except 2 of this latter group had a PTA of less than 8 weeks. The distribution of PTA among the head-injured patients is shown in Table 1.

Table 1
Distribution of PTA among the head-injured patients

Days in PTA	7–21	22–42	43–63	> 64
Number of cases	18	11	8	2

Table 2
Subjects

		n	Age	Estimated IQ (reading)	Time since injury (months)
Head injury	CHI I PTA < 3 weeks	18	21.4 (3.74)	103.8 (9.13)	39.5 (10.2)
	CHI II PTA > 3 weeks	21	23.6 (3.76)	104.4 (10.16)	39.1 (9.3)
Controls		32	22.7 (5.1)	105.0 (9.25)	–

Control subjects were 32 orthopaedic patients (25 male, 7 female) under assessment for surgical intervention as a result of limb injuries. They were closely matched to the head-injury group in occupational status, age and the reading-based estimated IQ measure (see Table 2). No member of the control group had suffered a head injury, or had a history of epilepsy.

Procedure

Tests selected for inclusion in the study were designed to examine which aspects of memory and cognitive function would be most affected by closed head injury. They cover the distinctions between verbal and nonverbal memory, short- and long-term memory, recall and recognition and laboratory and self-report measures, as well as areas previously unresearched by workers in in this field (remote memory, verbal recognition memory, memory for faces, and face-name learning). Some tests of cognitive function other than memory were also included to aid in the interpretation of the nature of any persisting deficits.

The following tests were administered in random order, with the exception that the test session always started with the Subjective Memory Questionnaire followed by Logical Memory (Immediate Recall), Face Name Learning Test (Trials 1–5) and the Rey-Osterrieth copy task:

1. Schonell Graded Word Reading Test and Nelson Adult Reading Test (21, 22). These tests were selected because they correlate highly with WAIS, IQ, and can be used to predict an Estimated IQ score (22) as reported here. It was thought that they would most accurately reflect pre-injury IQ, since the authors report that the reading tests "hold" even better than the WAIS Vocabulary sub-test in patients suffering from senile dementia. It was unclear whether the patient's results on these tests should also reflect post-injury IQ since some authors report recovery of IQ to "normal" levels 1–2 years after an accident (14) while others (18) report persisting deficits.

2. Logical Memory, from the Wechsler Memory Scale. Subjects are asked for immediate recall of the 2 short stories, and, one hour later, without forewarning, are asked for delayed recall. A "percent forgetting score" is also reported here (5).

3. Face-Name Learning Test (Chadwick, unpublished). 8 faces (4 female, 4 male) are presented by the examiner at the rate of one every 3 seconds, and "introduced" by name to the subject. In subsequent trials, the 8 faces are re-presented in random order, and the subject is asked to put a name to the face. The subject is immediately corrected if she or he (s/he) volunteers the wrong name. 5 test trials are presented immediately after the initial "introduction", and 5 more test trials after a one-hour delay. Scores are reported separately for the first 5 trials and the second 5 trials.

4. Word Recognition (Artiola i Fortuny, unpublished). 40 common words are presented on cards at the rate of one every 2 seconds. Subjects are asked to remember them. Following presentation, there are 4 recognition trials at 0, 10, 20 and 30 min delay. At each trial 10 target words are intermingled with 20 distractors, 5 of which are semantically related to words in the original list, 5 of which are acoustically rerelated, and 10 unrelated. Results are reported for the total number of words correct, summed across the 4 trials.

5. Keeping Track. This task was designed by R. Saan, and is based on the work of Yntema (23); essentially, it measures short-term or working memory, capacity under conditions of overload and interference. The subject is required to remember which one of the 4 examplars (e.g. hot, cold, wet, dry) from 4 classes of stimuli (weather, number,

directions, colours), s/he last read out from the pre-arranged pack of cards. The task is self-paced, but interrupted at intervals by question cards asking, for example, "The last direction? North, West, East, South?" The number of intervening items varies between 0 and 7, and is balanced between categories. The maximum possible score is 48.

6. Famous Personalities Test (24). This test was included to assess whether head-injured patients might have a remote memory impairment for information acquired prior to their injuries. Subjects are presented with a list of 100 names, 50 of whom have been famous in the past, or are currently famous, and 50 of whom are distractor items, not known ever to have been famous. Subjects indicate with a cross whether or not they recognise the name. Scores for subjects in their 20's and 30's are mostly relatively low, since the list contains a number of personalities who were famous between 1930 and 1960, but are no longer well known.

7. Figure-Ground Test of Discrimination and Memory. This test was designed to measure discriminaton of "noisy" patterns under conditions of short exposure, followed by a short-term recognition test. It is an adapted version of a pattern recognition task designed by Lawler (25). Before the start of the test, the subject (S) is shown undergraded picture-forms of the 4 classes of item: square, circle, cross, triangle. The test itself falls into 2 parts. On each trial, S is first exposed to a 9 × 7 cm card, on which one of these stimuli has been degraded to a certain level of difficulty. S is asked to identify the stimulus as soon as s/he has "seen" the figure (Discrimination test), whereupon it is immediately removed from sight. The stimulus is exposed for a maximum of 3 sec. Approximately 2 sec after the stimulus has been removed, another larger card is presented, and S is asked to recognise the exact figure s/he had seen from an array of 4 figures differing only in their levels of degradation (Recognition test). The test is completed after 20 trials.

8. Mooney Faces (26). This test of visual closure was added as a second test of pattern recognition, where, unlike Figure-Ground Discrimination, subjects would not be constrained by time. The pictures in this test are transformed pen-and-ink drawings of human faces with the shadows rendered in black and highlights in white. The S has to decide whether a face is that of a boy or girl, grown-up man or woman, or an old man or old woman. For several items, either of 2 responses are allowable. As in an earlier study (27), a sub-test of 40 of the original faces has been used. Each picture is exposed until S has made a response, or remains quite unable to "see" the face for at least 30 sec. Data were obtained for 12 control Ss only on this test.

9. Recurring Faces Test (Newcombe, unpublished). In this test of facial recognition, S is first shown 8 photographs of young men for about 2 sec each, and is told that s/he will be asked to identify them again in a second larger pack. This latter pack consists of 60 faces of young men of which 36 are "new" and 24 are the original "old" 8 faces which recur in each block of 20 trials. A maximum score of 60 can therefore be obtained if "old" and "new" faces are correctly identified.

10. Rey-Osterrieth Complex Figure Test (28, 29). In this test, S must copy a complex geometrical drawing "as accurately as s/he can"; 40 min later, without forewarning, s/he is asked to recall the figure. 2 measures of performance are traditionally derived from this test: copy score, reflecting accuracy of copy, and recall score. Copy score data reported in this paper are lower than those customarily obtained by researchers; this merely reflects the use of stricter criteria

of accuracy by the author, since he found in pilot studies that inter- and intra-rater reliability was thereby increased (30).

11. Speed of Information Processing. This test was adapted from the British Abilities Scale subtest of the same name and was designed to test the hypothesis that head-injured patients might have deficits in sustained attention and cognitive speed. Each of the 4 sheets of the test consists of 15 rows of 5 numbers (first sheet, 2-figure numbers; second, 3-figure numbers; third, 4-figure numbers; and fourth, 5-figure numbers). The S has to cancel the highest number of each row as fast as possible. The time is taken for completion of each sheet. It was hypothesized that, as the task demands increase in complexity, from 2- to 5-figure numbers, the disparity in the performance of head-injured and control Ss should grow.

12. Subjective Memory Questionnaire (31). This 43-item questionnaire asks Ss to rate their memories on a 5-point scale for number of different "everyday memory" situations. It was included to assess whether head-injured subjects might rate themselves as having poorer memories than controls on a well-standardized self-report inventory. The Subjective Memory Questionnaire was always administered at the start of the test session to avoid contamination from the subject's performance on the tests.

Table 3
Results on the verbal memory tests (Logical Memory, Keeping Track, Word Recognition), paired associate learning (Face-Name Test) and remote memory test (Famous Personalities)

Test	Group				F ratios and significance levels			
	Total CHI group (n = 39) X_1	CHI I PTA < 3 weeks (n = 18) X_2	CHI II PTA > 3 weeks (n = 21) X_3	Controls (n = 32) X_4	X_1–X_4	X_2–X_4	X_3–X_4	X_2–X_3
Logical memory immediate recall	11.4 (3.2)	12.6 (2.4)	10.3 (3.5)	12.8 (2.6)	4.05 $P < 0.05$	0.64 n.s.	9.38 $P < 0.02$	5.98 n.s.
Logical Memory delayed recall	9.5 (3.9)	11.4 (2.7)	8.0 (4.2)	11.5 (2.8)	5.85 $P < 0.02$	0.29 n.s.	15.43 $P < 0.002$	10.74 $P < 0.01$
Logical Memory % forgetting	18.8 (18.4)	10.0 (9.1)	26.2 (21.2)	10.5 (9.7)	5.20 $P < 0.05$	0.01 n.s.	16.06 $P < 0.001$	13.06 $P < 0.005$
Keeping Track	29.2 (4.5)	31.0 (3.9)	27.6 (4.6)	31.6 (3.8)	5.77 $P < 0.02$	0.25 n.s.	12.29 $P < 0.005$	6.8 $P < 0.05$
Word Recognition number correct	24.7 (8.0)	24.4 (7.5)	24.9 (8.6)	25.2 (8.4)	0.05 n.s.	0.07 n.s.	0.01 n.s.	0.02 n.s.
Word recognition false positives	8.8 (9.4)	8.7 (8.4)	8.8 (10.4)	10.2 (8.9)	0.35 n.s.	0.26 n.s.	0.25 n.s.	0.01 n.s.
Face-Name Learning Trials 1–5	23.8 (7.9)	26.1 (7.9)	22.0 (7.6)	26.6 (7.2)	2.3 n.s.	0.59 n.s.	4.86 n.s.	2.91 n.s.
Face-Name Learning Trials 6–10	30.6 (8.2)	31.9 (8.6)	29.4 (7.9)	33.6 (5.4)	3.19 n.s.	0.62 n.s.	4.47 n.s.	1.27 n.s.
Famous Personalities Test	20.0 (5.5)	21.2 (6.8)	18.9 (4.0)	21.9 (4.4)	2.57, n.s.	0.22 n.s.	4.56 n.s.	2.08 n.s.

Results

Results for the 3 verbal-memory tests, plus the cross-modal associative learning test (Face-Name), and the test of remote memory (Famous Personalities) are given in Table 3.

As in previous studies (5, 7), Table 3 shows that there is a closed head injury (CHI) deficit on recall of the Logical Memory short-stories. This deficit is accentuated after one-hour delay, and the percentage forgetting scores indicates that more is forgotten by the CHI group between immediate and delayed recalls. However, the Logical Memory deficit is confined to the PTA > 3-week group (CHI II); there is no evidence of deficit in the PTA 1–3 week group (CHI I).

Similar results are obtained on the Keeping Track task; CHI II, but not CHI I, showing marked deficits. In contrast, though, no significant differences between groups are obtained on the Word Recognition, Face-Name Learning Test, and Famous Personalities tasks. There appear to be no other reports of the effects of closed head injury on verbal recognition memory tasks, excepting one single-case study (32). The results from the Word Recognition task indicate little in the way of long-term deficits in verbal recognition memory. On the Face-Name Learning Test, differences between the CHI II and control group, on the first 5 trials, and between the total CHI group and controls on the second 5 trials almost attain significance at the 5% level ($P < 0.1$). Many of the subjects (especially controls) reached asymptote (correct naming of all 8 faces) during the second 5 trials, which may have attenuated differences between groups. Remote memory, as measured by the Famous

Table 4
Results on the nonverbal tests

Test	Group				F ratios and significance levels			
	Total CHI group (n = 39) X_1	CHI I PTA < 3 weeks (n = 18) X_2	CHI II PTA > 3 weeks (n = 21) X_3	Controls (n = 32) X_4	X_1–X_4	X_2–X_4	X_3–X_4	X_2–X_3
Figure-Ground Discrimination	15.6 (1.8)	16.3 (1.2)	15.0 (2.8)	16.7 (1.5)	7.13 $P < 0.01$	0.66 n.s.	13.6 $P < 0.005$	6.16 n.s.
Figure-Ground Memory	13.3 (2.4)	13.9 (2.5)	12.7 (2.2)	14.6 (1.8)	7.03 $P < 0.02$	1.38 n.s.	10.3 $P < 0.01$	2.97 n.s.
Mooney Faces	33.1 (4.1)	33.6 (3.7)	32.7 (4.4)	33.7* (3.0)	0.20 n.s.	0.00 n.s.	0.52 n.s.	0.52 n.s.
Recurring Faces	50.4 (5.1)	50.0 (5.9)	50.8 (4.5)	53.1 (4.6)	5.1 $P < 0.05$	4.42 n.s.	2.75 n.s.	0.23 n.s.
Rey-Osterrieth Copy	27.4 (2.8)	27.1 (3.1)	27.6 (2.5)	28.6 (4.5)	1.86 n.s.	1.77 n.s.	0.85 n.s.	0.15 n.s.
Rey-Osterrieth Recall	19.7 (5.9)	22.1 (4.4)	17.5 (6.3)	23.3 (5.2)	7.22 $P < 0.01$	0.57 n.s.	14.3 $P < 0.005$	6.96 $P < 0.05$

* Controls n = 12.

Personalities Test, is intact in the CHI groups, though the lower score of the CHI II group suggests that differences may have been found if a recall, rather than a recognition, procedure had been used.

The results from the tests of nonverbal function are shown in Table 4. The head-injured group is impaired on all the memory tests, and the Figure-Ground Discrimination task. However, visuo-constructive skills (Rey-Osterrieth Copy) and visual closure function (Mooney Faces) are unimpared. Deficits on the Figure-Ground test (discrimination and memory) are entirely due to the performance of CHI II; CHI I is unimpaired.

Comparing the 2 pattern recognition tasks, the patients are severely impaired on one (Figure-Ground Discrimination) but unimpaired on the other (Mooney Faces). This contrast is probably not explained by differences in form of the test materials. These 2 tests were previously used in a study of spatial vision after temporal lobectomy (25), and it was concluded from results that "similar mechanisms may underlie the perception of these different types of stimuli". However, whereas in that study, both sets of stimuli were exposed for unlimited duration, here exposure to the Figure-Ground stimuli was subject to severe time constraints (3 sec maximum). It seems possible that differences in duration of stimulus exposure account for the differences in CHI performance on the 2 tests. Severely head-injured patients may be unable to process the Figure-Ground stimuli at sufficient speed to fully analyse (discriminate), and remember them. Further evidence that the deficit is one, not of visual pattern recognition *per se*, but rather speed of processing these materials comes from intercorrelations between test results in the head-injury group. Figure-Ground Discrimination is correlated with only 2 other tests, Mooney Faces ($r = 0.39$, $P < 0.02$) and Speed of

Table 5
Results of the Speed of Information Processing Task

Test	Group				F ratios and significance levels			
	Total CHI group (n = 39) X_1	CHI I PTA < 3 weeks (n = 18) X_2	CHI II PTA > 3 weeks (n = 21) X_3	Controls (n = 32) X_4	X_1–X_4	X_2–X_4	X_3–X_4	X_2–X_3
Speed of Information Processing – Total (sec)	194.2 (47.6)	181.7 (36.5)	205.5 (54.2)	170.2 (48.2)	4.37 $P < 0.05$	0.68 n.s.	6.83 $P < 0.05$	2.39 n.s.
2-Figure Numbers	33.3 (8.8)	30.7 (5.6)	35.6 (10.5)	27.7 (8.1)	7.42 $P < 0.01$	1.48 n.s.	10.87 $P < 0.01$	3.20 n.s.
3-Figure Numbers	47.8 (11.2)	45.0 (9.1)	50.3 (12.5)	41.6 (12.7)	4.64 $P < 0.05$	0.94 n.s.	6.60 $P < 0.05$	1.89 n.s.
4-Figure Numbers	52.4 (14.2)	48.4 (10.3)	56.1 (16.4)	45.3 (13.2)	4.75 $P < 0.05$	0.62 n.s.	7.85 $P < 0.03$	3.02 n.s.
5-Figure Numbers	60.8 (15.6)	57.5 (13.6)	63.7 (17.1)	55.5 (16.7)	1.84 n.s.	0.17 n.s.	3.20 n.s.	1.42 n.s.

Information Processing ($r = -0.46$, $P < 0.005$); clearly cognitive speed, as well as pattern discrimination, is an important component of this task.

On the Recurring Faces test, a deficit in face-recognition memory is found when the 2 head-injury groups are combined, though neither group alone is impaired, when compared with controls. In contrast to other memory tests, the mean number correct is lower in CHI I group than CHI II. This is partly accounted for by the performance of one patient who had a score of 36, some 8 points below the next lowest score in this group.

There is no CHI deficit in the copy of the Rey-Osterrieth figure in contrast to the severely impaired performance at 40 min delayed recall. If copy score can to some extent be equated with quality of the initial encoding, the inference is that information about nonverbal stimuli is lost at a later stage in memory processing by severely head-injured patients.

Table 5 shows the results for the groups of the Speed of Processing Task. In complete contrast to the hypothesis that, with increasing task demands, head-injured patients would be progressively impaired, the most significant difference is found for the 2-figure cancellation, while on the 5-figure task, the differences failed to reach significance. As for other tasks, only the CHI II group is impaired. Clearly, the increasing task demands in no way differentially affected the head-injured patients since both the patient groups' and the controls' mean times increased by constant amounts between 2 and 5 figures. Differences in a more basic function which contribute maximally to the variance in the eaiser conditions were seemingly responsible for these results. Most probably, this function is a slowing of reaction time, which has been demonstrated on both simple and choice reaction-time tasks after severe head injury (2, 3, 33).

On the Subjective Memory Questionnaire, the mean scores of the 3 groups are: CHI I, 145.9; CHI II, 124.5; controls, 138.5. The difference between CHI I and CHI II groups is significant ($F = 10.15$, $P < 0.01$), while the difference between the controls and CHI II approaches significance ($F = 5.9$, $P < 0.06$). Thus, on a standardized memory questionnaire, the impaired memory test performance of the more severe group of head injuries is reflected in their self-report. In contrast, the less severe group rate their memories slightly, though not significantly, more favourably than the control group. One possible explanation for this effect is that the CHI I group were contrasting their current "recovered" memories with their early post-injury impaired memories, while the controls obviously have little recourse to such a contrast. However, the results for both these groups are well within the range of "normal" results from previous studies (16, 30), while the self-report score of the CHI II group is typical of other memory-impaired populations (16).

The effect of time since injury have been analysed in the 2 head-injury groups by correlation with the test results. Only one significant correlation emerges, a positive correlation with word recognition in the CHI II group ($r = 0.52$, $P < 0.02$). Since correlations with other tests are just as likely to be negative as positive, this is probably a chance result, and it may be concluded that, if there is any further recovery of the functions tested during the 3rd, 4th and 5th years post-injury, the effects are masked by individual variation in a cross-sectional study. Age at injury, also, is significantly correlated with only one test, the Famous Personality Test ($r = 0.40$, $P < 0.05$). The older patients recognise more of the personalities than the younger patients; a similar result is obtained in the control group. Thus, within the narrow age range of the patients in this study, there is no evidence that older patients are more impaired after head injury than younger patients.

Discussion

From a clinical perspective, the most outstanding finding reported here has been the absence of memory deficits at long-term follow-up after "very severe" head injury, in the PTA 1–3 week group. This contrasts with the finding of both wide-ranging memory deficits and subjective memory complaints in the PTA > 3-week group, and suggests that a threshold of brain damage may operate at around a 3-week duration of post-traumatic amnesia. Patients above this threshold are likely to exhibit persistent cognitive impairment, while patients below this threshold are unimpaired in the long term.

In previous research on closed head injury in adults, there is little indication to suggest the existence of this threshold, though supporting evidence may be derived from the research by Norrman & Svahn (2) and van Zomeren & Deelman (3). These studies appear to reveal little or no cognitive impairment in PTA < 3-week groups 2 or more years post-injury, in contrast to more severely injured groups.

However, a recent study of head injury in children (34) provides striking support for the present findings. The authors reported that only a very small percentage of children with PTA of less than 2 weeks showed even short-term cognitive deficits and none showed deficits at 2-year follow-up; children with PTA duration of 2–3 weeks tended to show "transient" impairment, with deficits at initial assessment, but not in the long-term; children with a PTA duration of more than 3 weeks showed both short- and long-term deficits. The authors invoked the "threshold effect" to explain their results. The present study indicates that the notion of a threshold of brain damage at around a 2–3 week post-traumatic amnesia is as appropriate for young adults as for children. Unfortunately, the composition of the present sample does not allow for a more fine-grained comparison between PTA 1–2 and PTA 2–3 week groups, since 14 of the 18 patients in the less severely injured group had PTAs of 1–2 weeks. Future research should determine whether a different threshold of brain damage might operate in older patients, in the light of Russell's observation that "the age of the patient seems to be the most important single factor in estimating the prospect of recovery" (35).

Differences between the present results and earlier studies (6, 7, 13) showing memory deficits at shorter follow-up intervals in groups with PTAs equivalent to the PTA 1–3 week Oxford sample, may be accounted for by several factors. First, recovery of function may after all continue beyond the first few post-injury months. Though this possibility was examined and rejected by Brooks (6, 7), he did not examine the effects of time since injury within groups of different ages and PTAs. It appears likely that different groups of patients do indeed recover at different rates on different tasks, as Brooks himself found in another study (13). Deficits may be more transient, and recovery effects greater, in younger patients, and in the less severely injured. Second, the different sampling procedures used in different studies undoubtedly contribute to discrepancies in results. For example, the Glasgow series may be contrasted to the present Oxford series. The Glasgow patients extend over a wide age-group (16–60), are mostly specially referred for psychological assessment, and include patients who have been transferred to Glasgow because their condition has deteriorated. The Oxford sample is a consecutive series of admissions; is constituted exclusively from patients who have had accidents in the immediate vicinity; includes only young patients up to the age of 35; excludes those of low IQ; and most probably differs from the Glasgow patients on variables relating to socio-economic status, educational attainments and pre-injury history. Furthermore, only one patient in the Oxford PTA 1–3 week group was in contact with hospital services beyond 6 months because of head-injury related symptoms. It seems reasonable to conclude that population differences and recovery effects may account for discrepancies in results between studies undertaken in different centres at different follow-up intervals.

The other main aim of the study was to determine the nature of any persisting memory deficits after head injury. Such deficits were found only in the PTA > 3-week group, so discussion is confined to a consideration of their results.

Analysis of verbal and nonverbal memory test performance indicates that memory deficits after closed head injury tend not to be material-specific. Though differences in test materials and procedure preclude direct comparison of relative levels of deficit using these different kinds of materials, there seems no reason to suggest that there are any differential effects of materials within the head-injury group. Other authors have also reported deficits using both kinds of material (4, 5, 6, 7, 10).

There was also evidence of impaired performance after head injury on both short-term memory (Keeping Track, Figure-Ground Memory) and long-term memory (Logical Memory, Rey-Osterrieth recall) tasks. The Keeping Track task required subjects constantly to update items in their short-term (or "working memory") store, under conditions where rehearsal of earlier items was effectively prevented by their having to verbalise new items and answer question cards. The task proved difficult for all subjects, but especially so for the PTA > 3-week group. In an earlier study in our laboratory (Saan, unpublished), this was the one task in a battery of tests which gave some evidence of being sensitive to deficits after minimal head injury (PTA 0–24 hours). Deficits were also found on the Figure-Ground Memory test, a rather more straight-forward test of forgetting from the short-term nonverbal memory store (but see later in Discussion).

Long-term memory was greatly impaired by the effects of closed head injury. The deficits found at immediate recall of the Logical Memory passages were accentuated at one hour delay, and the results showed that more material was forgotten by the head-injured subjects during the interventing period, replicating the findings of a previous study (5). Deficits were also marked on the Rey-Osterrieth Complex Figure Test at 40 min delayed recall. However, these effects may not be a simple function of increased delay between presentation and recall. Another characteristic common to both tests is that each requires recall of complex material without forewarning. Several patients commented that they felt they had to "make more effort" to remember things. When recall is unexpected, there is no apparent need to engage in "effortful processes" (36), e.g. rehearsal, imagery. It seems possible that the performance of head-injury patients is differentially affected by this procedure. Evidence for this supposition may be adduced from the patients' relatively unimpaired performance on the Face-Name Learning and Recurring Faces test. The stimuli are repeatedly presented on both of these tasks, allowing patients the opportunity to rehearse and remember previously forgotten items. For both practical and theoretical reasons, future studies should investigate the extent to which deficits in both short-term and long-term memory may be ameliorated by allowing patients the opportunity to engage in appropriate mnemonic strategies.

In the present study, recognition memory seemed relatively less susceptible to the effects of head injury than recall tasks. No deficit was found for word recognition at any of the delays (0–30 min), and, on the face recognition task, significant differences were found only when the 2 head-injury groups were combined. The PTA > 3-week group were significantly deficient in the recognition of the figure-ground stimuli but this effect is in part (but not wholly) explainable by a failure of identification at the discrimination stage of the task. Since previous studies of head injury have reported nonverbal (though not verbal) recognition memory deficits at shorter follow-up intervals (6, 37), the present results suggest that these effects become attenuated at long-term follow-up, though they do not completely disappear. A recognition procedure was also used to assess remote memory (Famous Personalities Test). Patients in the more severely head-injured group showed a non-significant trend towards poorer performance on this task. Observations made by the authors since the conclusion of this study have suggested that there may indeed be some impairment of remote memory after very severe head injury, when remote memory is tested by recall method. If this impression is substantiated by future studies, it would suggest the presence of retrieval deficits after head injury, and indicate that recall tasks may be relatively more sensitive to head-injury deficits than recognition tests.

3 tasks examined the effects of closed head injury on nonverbal skills without a memory component. No deficits were found on the Mooney Faces test, or the copy of the Rey figure, in contrast to the markedly impaired Figure-Ground Discrimination performance. This difference is probably explainable in terms of the time constraints operating on the Figure-Ground Discrimination test. The head-injured patients are simply unable to process these stimuli at the required speed. Slowing of cognitive function is a salient feature of head-injury sequelae; reaction time deficits have been reported in other studies (2, 3, 33) and deficits on the Speed of Information Processing task were found here. However, the present results indicate that, when allowed to proceed at their own pace, head-injured patients may accomplish visuo-constructive and pattern recognition tasks quite successfully at long-term follow-up.

A few words should be said on the use of the reading tests to match groups for IQ. As a check on this measure, the patients completed the first 20 items of the Mill Hill (Senior) Synonyms Test. The close correspondence between their results (Mill Hill = 14.5; Estimated IQ = 104.1) and the results from a similarly aged group of 38 normal adults tested as part of a different study (Mill Hill = 14.7; Estimated IQ = 104.9), indicates that the Estimated IQ measure is probably an accurate reflection of post-injury, as well as pre-injury, verbal IQ in the head-injured group.

In sum, the results of the study show that not all groups of patients termed "very severe" head injuries (PTA > 1 week) by Russell & Smith (1) suffer permanent cognitive impairment. Patients whose PTA does not exceed 2–3 weeks recover to within normal limits on tests of verbal and nonverbal memory, and cognitive speed. In contrast, patients with PTA duration of more than 3 weeks show wide-ranging deficits on these tests. The data provide strong evidence that a threshold of brain damage related to cognitive impairment operates at around a 2–3 week PTA duration in young adults, as in children (34). Tasks which require the long-term retention of complex materials and prevent use of mnemonic strategies, and those in which time constraints are a salient feature, seem particularly sensitive to head-injury deficits.

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