Learning and forgetting during posttraumatic amnesia in head injured patients

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SUMMARY To investigate forgetting during recovery from head injury, colour slides were initially projected for long durations to ensure acquisition on a recognition test given 10 minutes later. Patients tested during posttraumatic amnesia (PTA) exhibited accelerated forgetting over 32 hours as compared with head trauma patients studied after the period of PTA and normal controls.

Huppert and Piercy¹ studied forgetting by a new visual recognition memory technique. They first presented slides to amnesic patients at input durations sufficiently long to raise their initial learning to a relatively normal level and then they found that patients with alcoholic Korsakoff amnesia forgot learnt material at a normal rate and over a 7 day period. The investigators inferred that Korsakoff amnesia was primarily a defect in initial learning (that is, acquisition).^{1,2} One patient (HM) thus studied had undergone bilateral excisions of the medial temporal lobe (including the hippocampus)³ to control intractable seizures; he was capable of initially learning material but more rapidly forgot the pictures over 7 days. Huppert and Piercy interpreted the disparity in forgetting rate between the Korsakoff patients and HM as evidence for a qualitative difference between diencephalic and temporal lobe amnesia. Further support for the dissociation of learning and retention, and for the possibility of two forms of amnesia, has been provided by others⁴⁻⁶ but no patient other than HM with a confirmed temporal lobe lesion has been studied with the technique of Huppert & Piercy.

About 25% of patients sustaining moderate to severe closed head injury⁷ have residual memory disturbance. Following the postulation,^{8,9} of an association between traumatic amnesia and temporal lobe damage in closed head injury, we predicted that forgetting would be particularly rapid during posttraumatic amnesia (PTA). Although previous studies have documented persistent impairment of recognition memory after moderate and severe^{10,12} closed

head injury, the retentive capacity of such patients has not been assessed over time with control for initial learning. We therefore have investigated the rate of forgetting at various stages of recovery from head injury. We compared head injured patients still in PTA with those whose PTA had resolved and also with normal control subjects.

Methods

Subjects

The analysis of forgetting is based on a series of 29 closed head injury patients and two cases of gunshot wounds with no antecedent history of neuropsychiatric disorder (including previous head injury), mental deficiency or chronic alcohol/drug abuse. We imposed an age limit of 50 years at the time of injury. Of these injuries, 18 resulted from a motor vehicle accident, one from a fall, two were involved in work-related accidents (involving a blunt object), one had an athletic injury (collision with wall), seven were assaulted with a blunt object and two sustained gunshot wounds (one extracerebral which produced a subdural haematoma secondary to concussive force). The patients were tested while hospitalised in the Neurosurgery Service. To investigate the relationship between PTA and forgetting rate, we administered the Galveston Orientation and Amnesia Test (GOAT)¹³ daily beginning when the patient obeyed commands. This brief bedside examination encompasses orientation to person, place and time, appreciation of the circumstances of injury and evacuation to the hospital. We defined the resolution of PTA as the point when the GOAT score improved to 75 (lower limit of normal) or higher on two consecutive days.^{13,14} Seven additional closed head injury patients were tested but were excluded from further study because of failure to demonstrate initial learning at a level sufficient to evaluate long term retention.

The table summarises the demographic and clinical features of the 31 patients who completed the study. Of this series, 13 head injured patients were studied during PTA and 18 patients were tested after resolution of PTA. These groups, which were comprised predominantly of young men,

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did not differ in age or education (table). We employed the Glasgow Coma Scale (GCS) of Teasdale and Jennett¹⁵ to characterise the severity of initial injury. The table shows the GCS score recorded at the time of admission (or during the intensive care phase in cases of deterioration). The patients studied during PTA had lower GCS scores (that is, more severe impairment of consciousness) at the time of hospital admission, $F(1, 29) = 10.95$, $p < 0.003$. The second measure of severity of head injury was the duration of impaired consciousness (that is, the interval during which the patient was unable to obey commands). The patients studied while in PTA tended to have a longer duration of impaired consciousness than the patients tested after resolution of PTA but this difference was not significant, $F(1, 28) = 2.06$, $p < 0.16$. Patients tested during PTA had longer intervals (mean = 31.7 days, SD = 21.6) during which their GOAT scores were in the defective range (that is, consistent with PTA) as compared with patients in whom PTA had resolved (mean = 4.0 days, SD = 9.0, $F(1, 28) = 22.89$, $p < 0.0001$). Correspondingly, the patients in PTA were studied after a longer interval since injury (mean = 29.9 days, SD = 24.3) as compared with the patients tested after resolution of PTA (mean = 12.2 days, SD = 15.1, $F(1, 29) = 6.30$, $p < 0.02$). A control group of medical centre employees whose age and education were similar to the head injured patients was also tested on the forgetting task and paid for their participation (table).

To evaluate the long term effects of severe closed head injury on forgetting, we tested seven chronic survivors, including three patients who had been hospitalised on the Neurosurgery Service and four trainees in a residential rehabilitation programme (Transitional Learning Community) located in Galveston. The mean age at injury of these patients was 21.9 (SD = 5.9) and their mean education was 13.6 years (SD = 2.9). The mean interval between injury and participation in this study was 4.4 years (SD = 3.0). All seven chronic patients had sustained severe closed head injury (GCS score ≤ 8) with durations of impaired consciousness ranging from 14 to 90 days. Of these seven patients, only one had a documented intracranial mass lesion (a right parietal epidural haematoma). Overall daily functioning of these patients at the time of study was compatible with moderate disability. Although the rehabilitation patients were selected for a specialised programme because of persistent neurobehavioural sequelae, their performance was similar to the other chronic survivors.

Procedures

The forgetting task in previous studies^{1,4} consisted of 120 colour slides of pictures (such as, various objects, still lifes and outdoor scenes) taken from magazines. This presentation series frequently exceeded the attentional capacity of patients examined during their initial hospitalisation for head injury. Consequently, we reduced the initial presentation to 66 slides. A duplicate series of these 66 slides were randomly divided into three sets of 22 slides (targets) for testing recognition (that is, yes/no) memory 10 minutes, 2 hours and 32 hours later. Each recognition test involved discrimination of the target slides from 22 slides which were not shown previously (distractors) for a total of 44 trials. The targets and distractors were randomly inter-

persed and presented successively. At the beginning of each retention test, the subject was instructed to indicate if each slide presented was among the 66 original pictures ("yes") or was a new picture ("no"). The sequence of presenting the three sets of 44 test slides (that is, 22 targets, 22 distractors) across the three time intervals (10 minutes, 2 hours, 32 hours) was counterbalanced across subjects. Responses were untimed.

To ensure comparable initial learning across the three groups, as reflected by retention at 10 minutes, we presented the initial series of 66 slides at a longer duration of exposure per slide to the head injured patients as compared with control subjects. Head injured patients in PTA viewed each slide twice at a presentation duration of 4 seconds (total duration = 8 seconds), whereas closed head injury patients tested after resolution of PTA were exposed to each slide once for 2 seconds (total duration = 2 seconds). The control subjects viewed each of the 66 slides once for durations ranging from 1 second to 1.5 seconds depending on the level of initial learning required to match the head injured patients. Duration of slide presentation was controlled by a tachistoscopic shutter. The slides were projected on a wall in central vision at a distance of about 1.5 metres from the patient.

Results

Analysis of initial learning

We measured retention by calculating d' , an unbiased estimate of discriminability¹⁶ which was based on the relative frequency of correct detections (that is, "yes" responses to pictures that were among the original series of 66 slides) and false alarms (incorrect "yes" responses to distractor pictures which were not among the original series). Based on pilot data, our criterion for initial learning was a d' of greater than or equal to 2.0 (about 70% correct in most cases) on the 10 minute test, whereas values below this level were interpreted as inadequate initial learning for the study. All control subjects attained a d' of 2.0 or greater on the 10 minute test. Seven head injured patients who failed to attain this criterion of initial learning were deleted from further study. Nonlearners did not differ in age (mean = 23.6, SD = 5.7) from the 31 patients who had d' scores ≥ 2.0 (mean = 26.0, SD = 8.1) nor was there a difference in education (mean = 12.1, SD = 2.7 in nonlearners) as compared with learners (mean = 12.0, SD = 0.7). The proportion of patients studied while in PTA was also similar for the learners (42%) and nonlearners (43%). Severity of injury, as reflected by the GCS score, was slightly but not significantly greater in the nonlearners (mean = 9.6, SD = 4.1) as compared with the patients who attained criterion (mean = 10.7, SD = 3.9). Although the duration of impaired consciousness tended to be longer in patients who failed initially to learn the task (mean = 8.6 days, SD = 15.3) than in the patients who reached criterion (mean = 4.6, SD = 8.8), this

Table Demographic features, GCS score, duration of impaired consciousness (IC) and CT findings and recognition performance over a 32 hour retention interval. The head injured patients are divided according to whether they were in post-traumatic amnesia (PTA) at the time of the forgetting study

IN PTA	Age (yr)	Educ	Sex	GCS	IC (Days)	CT Findings
1*	29	12.0	M	5	6-000	Three left frontal intracerebral haematomas
2	31	7.0	M	5	19-000	Right frontotemporoparietal subdural haematoma
3	18	9.0	M	5	24-000	Right frontal, left parietal, and left basal ganglia petechial haemorrhages
4*	20	12.0	M	6	23-000	Bifrontal pneumocephalus
5*	21	15.0	M	7	3-000	Left frontal contusion; whole brain oedema
6	28	9.0	M	7	7-000	Right frontal contusion; left frontal contusion; left frontotemporoparietal subdural haematoma
7	19	12.0	F	8	6-000	Left frontal contusion/haematoma
8*	50	16.0	M	9	0-083	Bifrontal subdural haematoma; right occipital subdural haematoma; right temporal haemorrhage
9	34	14.0	M	9	1-000	Right and left parietal depressed skull fractures; right parietal intracerebral haematoma
10*	21	13.0	M	9	4-000	Whole brain oedema
11*	36	14.0	M	12	0-000	Whole brain oedema
12*	22	11.0	M	13	0-010	Left frontal contusion; whole brain oedema
13*	29	8.0	M	14	0-000	Left parietal depressed fracture with underlying contusion/haematoma and epidural haematoma
Mean	27.6	11.7		8.6	7.161	
SD	8.9	2.8		3.0	8.881	
(Mean)*	(28.5)	(12.6)		(9.4)	(4.5)	
(SD)*	(10.3)	(2.5)		(9.6)	(5.5)	
Out of PTA						
1*	18	11.5	M	5	35-000	Right temporal intracerebral haematoma; whole brain oedema
2*	30	12.0	M	6	2-000	Left temporal contusion/haematoma; left temporoparietooccipital epidural haematoma
3*	19	12.0	M	7	1-000	Normal
4*	21	10.0	M	7	5-000	Left temporal contusion
5*	39	20.0	M	11	1-000	Right temporal linear skull fracture; right temporoparietal epidural haematoma; left temporal and parietal contusions; oedema
6	24	N.A.	M	13	N.A.	Left frontal epidural haematoma
7*	21	12.0	M	13	0-000	Left frontal depressed skull fracture with underlying intracerebral haematoma; left temporal contusion
8*	20	12.0	M	14	0-000	Right temporal gunshot wound with bullet fragments; right frontal, temporal, and parietal haemorrhages
9*	22	15.9	F	14	0-014	Left hemisphere oedema
10	23	12.0	M	14	0-021	Bifrontal intracerebral haematoma
11	15	N.A.	M	15	0-000	Right frontal intracerebral haematoma
12	22	12.0	M	15	0-000	Left parietal contusion
13	42	9.0	F	15	0-000	Normal
14	34	14.0	F	15	0-000	Left temporoparietal subdural haematoma
15	19	10.5	M	15	0-000	Right posterior parietal depressed skull fracture with intact dura
16	33	14.0	F	15	0-000	Right temporoparietal subdural haematoma; (secondary to extracerebral GSW)
17	21	11.0	M	15	0-003	Whole brain oedema
18	22	12.0	M	15	0-021	Bifrontal linear skull fracture w/pneumocephalus
Mean	24.7	12.5		12.4	2.590	
SD	7.6	2.6		3.6	8.450	
(Mean)*	(24.0)	(13.2)		(9.6)	(5.5)	
(SD)*	(7.1)	(3.2)		(3.8)	(12.0)	
Controls						
1	26	10.0	M			
2	18	12.0	M			
3	22	12.0	F			
4	20	15.0	F			
5	24	14.0	F			
6	24	14.0	M			
7	29	12.0	F			
8	23	13.5	F			
9	27	12.0	M			
10	25	12.0	M			
11	29	12.0	M			
12	22	12.0	M			
13	25	14.0	F			
14	31	12.0	F			
15	22	14.0	F			
16	24	13.0	F			
17	30	14.0	F			
18	25	14.0	F			
Mean	24.8	12.9				
SD	3.5	1.3				

†CT = computed tomography; Educ = education (years); GCS = lowest Glasgow Coma Scale Score; IC = impaired consciousness (no. of days until obeying commands); d' is a signal detection measure of discriminability; NA = not available; GOAT = Galveston Orientation and Amnesia Test.

*Subgroups of eight CHI patients matched on severity of acute injury are identified by an asterisk. The means and SDs for these groups appear in parentheses.

GOAT	Percent correct 10 min.	d' 10 min.	Percent correct 2 h	d' 2 h	Percent correct 32 h	d' 32 h
74	86	2.26	61	0.72	61	0.61
67	93	2.98	84	2.00	80	2.00
56	91	3.24	89	3.06	73	1.28
68	70	2.09	70	1.51	55	0.67
14	84	2.79	55	0.26	64	0.74
19	84	2.79	80	1.81	64	1.27
40	100	4.64	100	4.64	93	2.98
52	95	3.28	80	1.81	59	0.56
63	100	4.64	84	2.25	77	2.45
39	93	3.40	66	0.92	73	1.22
62	91	2.77	93	2.98	84	2.25
56	98	4.37	84	2.79	70	2.09
40	82	2.68	80	2.55	75	2.32
50.0	89.8	3.23	78.9	2.10	71.4	1.50
18.6	8.5	0.84	12.8	1.16	10.8	1.00
(50.6)	(87.4)	(2.96)	(73.6)	(1.69)	(67.6)	(1.14)
(19.3)	(8.9)	(0.72)	(12.8)	(1.02)	(9.6)	(1.04)
89	84	2.25	82	1.82	68	1.96
89	93	3.40	89	2.56	70	2.09
95	91	3.24	93	2.98	82	2.11
80	98	3.96	95	3.66	86	2.93
100	98	3.96	95	3.66	93	2.98
100	98	3.96	86	2.93	80	2.55
91	84	2.25	86	2.93	64	1.17
99	82	2.68	75	1.77	68	1.41
88	93	2.98	89	3.06	84	2.25
85	84	2.00	61	0.68	84	2.00
97	80	2.55	82	2.68	77	2.42
100	100	4.64	100	4.64	91	3.55
95	95	3.66	91	3.24	66	1.85
100	89	2.42	75	1.77	61	1.58
99	80	2.55	86	2.93	80	2.55
84	98	3.96	95	3.66	91	2.68
100	73	2.19	64	0.98	64	1.71
100	95	3.66	80	2.55	84	2.25
93.9	89.7	3.13	84.7	2.69	77.4	2.22
6.6	8.0	0.80	10.6	0.99	10.4	0.60
	93	3.40	91	3.24	84	2.79
	86	2.26	77	2.45	77	2.45
	84	2.08	95	3.66	77	1.87
	86	2.26	80	1.66	75	1.35
	91	3.24	95	3.66	86	2.38
	82	2.11	80	2.00	75	2.32
	91	3.24	84	2.25	75	1.57
	95	3.66	70	2.09	70	1.51
	84	2.79	66	0.92	66	0.95
	91	3.24	91	3.24	68	1.96
	93	2.98	91	2.68	68	1.21
	95	3.66	91	3.24	82	2.68
	98	3.96	91	3.24	80	2.00
	86	2.38	77	1.87	82	2.68
	98	3.96	100	4.64	93	2.98
	95	3.66	95	3.66	84	2.08
	95	3.66	98	3.96	82	1.95
	86	2.93	82	2.68	66	1.28
	90.5	3.08	86.3	2.84	77.2	2.00
	5.1	0.64	9.8	0.94	7.6	0.60

difference also fell short of significance, $F(1, 35) = 0.9$. Duration of PTA was similar in the patients excluded because of deficient initial learning (mean = 17 days, SD = 23.0) as compared with patients who reached criterion at the 10 minute test (mean = 16.0 days, SD = 20.8). The corresponding injury-test intervals were also similar (mean = 19.4 days, SD = 24.3 for learners versus a mean of 19.6 days, SD = 21.1 for nonlearners).

Forgetting by head injured patients IN or OUT of PTA

The table includes the d' values obtained at the three test intervals for each head injured patient and control subject. The percent correct responses are shown at each interval for comparison with the d' values. Figure 1 depicts the d' values plotted across the retention intervals for the two groups of head injured patients (in PTA, out of PTA) and control subjects. Retention at 10 minutes appears to be comparable in the three groups, whereas the head injured patients studied during PTA exhibit more rapid forgetting over 32 hours. Consistent with the impression of a divergence in forgetting functions for the 2 hour and 32 hour test intervals, a multivariate, repeated measures analysis of variance (MANOVA) disclosed a significant interaction of groups with time, Wilks lambda = 0.72, $F(4, 90) = 4.00$, $p < 0.005$. The change in mean values of d' from 10 minutes to 2 hours depended on the group, $F(2, 46) = 5.29$, $p < 0.01$, whereas the decrement from 2 hours to 32 hours, $F(1, 46) = 32.43$, $p < 0.0001$, was unrelated to the grouping factor ($F(2, 46) = 1.00$, $p = 0.37$). Post hoc Scheffe comparisons (at the 0.05 level) of d' values at each interval did not show significant group differences at 10 min or 2 hours. However, at 32 hours the contrast between the patients in PTA versus patients out of PTA reached significance. While the

Fig 1 Recognition of pictures indexed by d' and plotted against the log retention interval for the groups of head injured patients in versus out of PTA and a control group.

Fig 2 Recognition of pictures indexed by d' and plotted against the log retention interval for the matched groups of head injured patients in versus out of PTA and a control group.

difference in d' between controls and patients in PTA did not reach significance at 32 hours with the Scheffe contrast, the difference was significant (0.05) by t test. There was a significant effect of time interval on retention, Wilks lambda = 0.23, $F(2, 45) = 75.48$, $p < 0.0001$.

Matched groups of head injured patients IN versus OUT of PTA

Our finding of increased forgetting in patients tested during PTA could have been due to their greater severity of injury (for example, as reflected by their GCS scores) rather than the effects of PTA per se. To mitigate this possible confounding, we matched eight closed head injury patients from each group as closely as possible (see patients with asterisks in the table) on the GCS score and duration of impaired consciousness (that is, the number of days from the time of injury until they consistently obeyed commands). There were no significant differences between these matched groups of patients on age, education, GCS score or duration of impaired consciousness. The interval between injury and date of testing for the patients in PTA (mean = 22.9 days, SD = 21.6) did not differ as compared to the group studied after resolution of PTA (mean = 17.8 days, SD = 21.6). As anticipated, patients who were still in PTA while studied had a longer period marked by GOAT scores below 75 (mean = 26.4 days, SD = 21.5) than head injured patients tested after resolution of PTA (mean = 8.0, SD = 12.2), $F(1, 14) = 4.43$, $p < 0.06$.

Figure 2 depicts the forgetting over 32 hours in the two matched head injured groups and the control group. Initial learning, as measured by retention at 10 minutes, did not differ among the three groups, $F(2,$

31) = 0.11. The pattern in fig 2 for more rapid forgetting over time by the head injured patients studied during PTA was confirmed by a significant interaction of groups with time, Wilks lambda = 0.73, $F(4, 60) = 2.53$, $p < 0.05$. The forgetting rate from 10 minutes to 2 hours depended on the group, $F(2, 31) = 4.91$, $p < 0.02$, whereas the amount forgotten from 2 hours to 32 hours was independent of the group, $F(2, 31) = 0.041$, $p = 0.67$. However, the impression in fig 2 of further forgetting between 2 and 32 hours was significant, $F(1, 31) = 16.48$, $p < 0.001$. Scheffe contrasts ($p < 0.05$ for all pairwise comparisons) at each time interval disclosed that retention by the patients studied during PTA did not differ from the performance of the other two groups at 10 minutes. By 2 hours, the patients tested during PTA exhibited more rapid forgetting than the controls and at 32 hours they performed below the level of both the controls and the head injured patients with resolution of PTA.

Localisation of intracranial mass lesion

The presence and localisation of mass lesions (that is, contusions, haematomas) based on computed tomography (CT) and surgical findings are summarised in the table. Accelerated forgetting (compare decrement of d' values across the three time intervals) was pervasive among the patients tested during PTA irrespective of the type of injury and localisation of mass lesions. In the group tested after resolution of PTA, the presence of a temporal lobe mass lesion appears to be related to rapid forgetting (note patients 2, 7, 8 and 14 Out of PTA Group). However, there are excep-

tions to this pattern (note patients 4 and 5 in the Out of PTA group) suggesting that a temporal lobe lesion may be a sufficient, but not a necessary condition for rapid forgetting.

Forgetting in chronic survivors of severe head injury

Figure 3 depicts the forgetting functions for the seven long term survivors of severe closed head injury. All of these patients attained d' values of 2.0 or greater on the retention test given at 10 minutes. The 95% confidence intervals of the seven control subjects who had comparable d' values at 10 minutes are also shown at each test interval. In comparison with these confidence limits, two head injured patients exhibited accelerated forgetting despite adequate initial learning (fig 3).

Discussion

Our findings extend previous studies of forgetting in patients with anterograde amnesia. Head injured patients exhibited impairment in their acquisition of pictorial information unless it was presented at exposure durations which exceeded the time given to normal controls by a factor of 2 to 8. In this respect they resemble those suffering from Korsakoff's syndrome, dementia of the Alzheimer type, Huntington's disease, thalamic injury or after ECT.^{1 2 4-6} On the other hand, provided that initial learning was raised to a relatively normal level, accelerated forgetting was found in head injured patients studied during PTA. This contrasts with the relatively normal forgetting in patients with amnesic disorder related to diencephalic damage.^{1 2 4-6}

The increased rate of forgetting in the group studied during PTA could have been due to their having sustained a more severe brain injury as compared with the group tested after resolution of PTA. The lower initial coma scores in the first group are in accord with this view. However, our finding of accelerated forgetting during PTA in subgroups of patients matched by initial GCS score and by duration of impaired consciousness is not consistent with the difference being only a reflection of severity of injury. The temporal lobes are vulnerable to the diffuse and focal effects of closed head injury.^{8 9} It is possible, therefore, that temporal lesions contributed to the increased forgetting in patients tested during PTA. Moreover, although retention in the post PTA patients as a group was comparable to that of normal controls, most of the cases who showed rapid forgetting had temporal lobe lesions. This preliminary evidence, which awaits replication, is compatible with the rapid forgetting reported for patient HM who had bilateral hippocampal excisions.² In a previous study our group showed that the latency of the P-300

Fig 3 Recognition memory indexed by d' and plotted as a function of the log retention interval for individual, chronic survivors of severe head injury ($n = 7$). The upper and lower confidence limits were derived from the data of the seven controls whose d' scores on the 10 minute retention test closely matched the initial learning of these chronic patients.

component of the auditory evoked potential was delayed during, but not after resolution of PTA.¹⁷ We suggest that delay of the P-300 and increased forgetting are both attributable to temporal lobe injury or dysfunction. Magnetic resonance imaging and positron emission tomography might identify such temporal lobe lesions, undetected by CT.

The findings in chronic survivors of severe closed head injury indicate that accelerated forgetting can persist for years after head injury. It is unclear if the decay of memory shown in this study can be generalised to other formats (eg verbal material, motor skills). Our findings have implications for understanding traumatic amnesia in relation to other causes of memory disorder. Also, the learning capability of head injured patients during PTA and their capacity for long term retention of information and skills introduced early in rehabilitation are important practical issues.

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