*Journal of Neurology, Neurosurgery, and Psychiatry* 1981;**44**:889-895

# Memory and information processing capacity after closed head injury

D GRONWALL, P WRIGHTSON

*From the Department of Neurosurgery, Auckland Hospital, Auckland, New Zealand*

SUMMARY The relation between duration of post-traumatic amnesia (PTA), performance on memory tests, and the Paced Auditory Serial Addition Task (PASAT) was examined in two samples of young adult closed head injury patients. Three different effects were isolated: (1) an attention and concentration factor, related to PASAT scores, (2) a deficit in the ability to place material into long-term memory storage, related to PTA durations, and (3) an impairment in the ability to retrieve material once it has been stored, which was not predicted by either PTA or PASAT.

The measurement of recovery and the prediction of outcome after severe closed head injury have been extensively studied.[1-3] However, most of the predictor variables that have been found to be important cannot be applied to cases of less serious head injury, where the patient has usually recovered consciousness before he arrives at hospital. For such patients, following the classical work of Russell and his colleagues,[4 5] the severity of the injury has commonly been defined in terms of the duration of post-traumatic amnesia (PTA). However, when PTA lasts less than 24 hours this may be unsatisfactory, partly because of the difficulty of measuring short durations of amnesia with precision,[6] and partly because there is evidence that this measure is not consistently related to the clinical outcome, whether outcome is examined in terms of time off work,[7] persistence of postconcussion symptoms,[8] or the degree and duration of reduction of information processing capacity.[9]

The reduction of information processing capacity, as measured by the Paced Auditory Serial Addition Task (PASAT) is a possible alternative measure. In this test the subject listens to a recorded series of single digits and is asked to add each number to the one immediately preceding it (the second to the first, the third to the second, and so on). Performance is not significantly correlated with either general intelligence or arithmetic ability. After the second presentation practice effects are minimal, thus patients can be re-tested at intervals throughout the post-traumatic period. In this way standard recovery curves have been derived from large numbers of patients to allow analysis of the rate and completeness of recovery.[10] As scores on this test return towards normal there is a consistent reduction in reports of post-concussion symptoms, and performance on many tests of cognitive functions improves.[11] Recovery of memory, however, does not always follow this pattern. Some patients still perform poorly on memory tests even when their PASAT scores are in the normal range, and they appear otherwise to have made a good functional recovery. It is reasonable to ask, therefore, whether PTA, the disturbance of memory in the early post-traumatic period, could be used as a predictor of later recovery of memory function, and whether some combination of duration of PTA and PASAT scores would then allow a comprehensive prediction of outcome.

This paper examines the relation between general reduction of intellectual function and deficits of memory after simple closed head injury, and the relation of residual memory impairment to the duration of PTA.

## EXPERIMENT 1

### Patients and methods

Seventy-one patients aged 17-30 years who had had simple head injuries were examined. None had had skull fracture, intracranial haematoma, localising neurological signs or other complication. They were given the Wechsler Memory Scale,[12] the PASAT, and, to give an approximation of verbal IQ, the Quick-test.[13] PTA was deter-

Address for reprint requests: D Gronwall, Dept of Neurosurgery, Auckland Hospital, Park Rd, Auckland 1, New Zealand.

Accepted 21 July 1981

mined by retrospective questioning, and the duration defined as the interval from the accident to the return of consecutive memory for events. The durations of PTA ranged from a few seconds to several days. All test results were recorded on the same or consecutive days, and were made within the first week for patients who had been amnesic less than one hour (mean 4 days, range 3 to 5 days after injury), and within the first month for the remainder (mean 26 days, range 24 to 27 days after injury).

## Results

Table 1 gives test results from patients grouped according to the duration of PTA (less than one hour, 1-24 hours, and more than one day). The Wechsler Memory Quotients (MQs) of grades 1 and 2 do not differ significantly; that of grade 3 is

Table 1 *Closed head injury patients grouped into three grades of severity from duration of PTA*

| | *Grade 1 PTA < 1 hour* | *Grade 2 PTA 1-24 hours* | *Grade 3 PTA > 1 day* |
|---|---|---|---|
| N | 20 | 38 | 13 |
| Age (yr) | | | |
| Mean | 21·32 | 21·35 | 19·27 |
| SD | 5·05 | 4·17 | 2·40 |
| *t*-test[1] | ns | ns | |
| Wechsler MQ[2] | | | |
| Mean | 95·3 | 96·78 | 78·64 |
| SD | 11·38 | 13·68 | 19·20 |
| *t*-test[1] | ns | p < 0·001 | |
| Quick-test | | | |
| Mean | 90·91 | 96·93 | 85·57 |
| SD | 9·78 | 10·42 | 9·74 |
| *t*-test | p < 0·05 | p < 0·001 | |
| PASAT Time score | | | |
| Mean | 4·05 | 5·27 | 8·28 |
| SD | 1·42 | 2·05 | 3·81 |
| *t*-test | p < 0·05 | p < 0·001 | |

[1]Comparison with next Grade (two-tailed)
[2]Memory Quotient

significantly lower than grade 2 ($p < 0.001$). In contrast, in table 2 where the patients are grouped according to their PASAT scores, the MQ of each grade differs significantly from the others. The subgroups appear well matched except that the IQ of patients in PTA grade 2 is significantly higher than that of the other grades. This point will be referred to later.

When scores on the individual subtests of the memory scale are examined, similarities and differences emerge that had been obscured by the composite MQ. The two methods of grouping the patient sample produce quite different graphs for three of the subtests in the figure (Information + Orientation, Mental Control and Digit Span), but similar shapes for Logical Memory and Visual Recall and, to a lesser extent, for Associate Learning.

Rank correlation coefficients[14] between the measures are shown in tables 3 and 4. PTA data is

Table 2 *Closed head injury patients grouped into three grades of severity from PASAT time scores*

| | *Grade 1 PASAT ⩽ 3·5 s* | *Grade 2 PASAT 3·6-5·5 s* | *Grade 3 PASAT ⩾5·6 s* |
|---|---|---|---|
| N | 17 | 29 | 25 |
| Age (yr) | | | |
| Mean | 22·88 | 20·79 | 21·00 |
| SD | 3·27 | 3·87 | 3·80 |
| *t*-test[1] | ns | ns | ns |
| Wechsler MQ[2] | | | |
| Mean | 107·12 | 98·97 | 85·64 |
| SD | 11·05 | 13·20 | 14·12 |
| *t*-test | p < 0·05 | p < 0·01 | |
| Quick-test | | | |
| Mean | 98·88 | 94·14 | 93·46 |
| SD | 13·64 | 8·96 | 10·94 |
| *t*-test | ns | ns | ns |
| PTA duration | | | |
| < 1 hour (N) | 8 | 10 | 2 |
| 1-24 hours (N) | 9 | 15 | 14 |
| > 1 day (N) | 0 | 4 | 9 |

[1]Comparison with next Grade (two-tailed)
[2]Memory Quotient

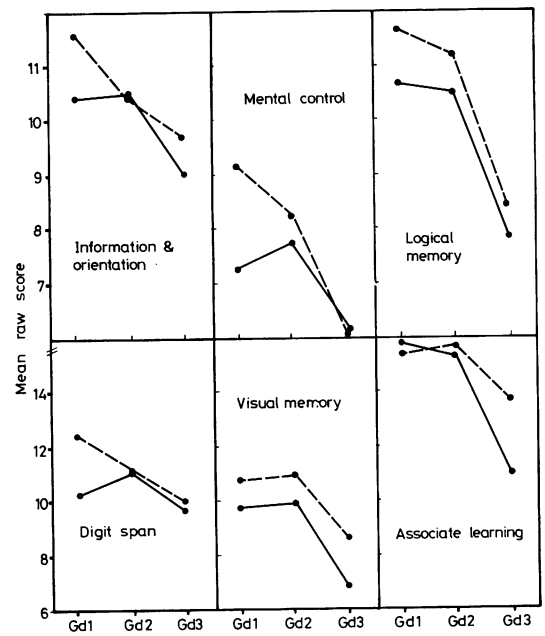


Figure *Raw scores on Wechsler Memory Scale subtests from patients grouped into three grades of severity according to duration of PTA (solid lines) and PASAT scores (broken lines).*

omitted from table 3, since it was not possible to rank the shorter durations of amnesia with confidence. The Varimax rotated factor solution[15] is given beneath each correlation matrix. Three main factors were isolated. Factor I loaded most highly on

PASAT and Mental Control, Factor II on Associate Learning, and Factor III on the Quick-test and Information + Orientation.

Another factor analysis was done on the data from the subgroup of 51 cases whose amnesia had lasted for at least an hour, to examine the relation between PTA durations and the other measures. The correlation matrix in table 4 shows moderate, but significant, correlations between PTA and the tests measuring the first two factors. However, as the factor solution below the table shows, PTA loadings on all the factors were relatively low.

Table 3 *Rank correlation coefficients and factor matrix for full sample (N = 71)*

| | *I + O* | *MC* | *LM* | *DS* | *VM* | *AL* | *Q-test* |
|---|---|---|---|---|---|---|---|
| PASAT | 0·45‡ | 0·66‡ | 0·40‡ | 0·48‡ | 0·40‡ | 0·24 | 0·16 |
| Information + Orientation | — | 0·40‡ | 0·49‡ | 0·45‡ | 0·10 | 0·24 | 0·43‡ |
| Mental control | — | — | 0·40‡ | 0·31† | 0·23 | 0·08 | 0·18 |
| Logical memory | — | — | — | 0·37† | 0·25* | 0·24 | 0·30* |
| Digit span | — | — | — | — | 0·14 | 0·36† | 0·39‡ |
| Visual memory | — | — | — | — | — | 0·36† | 0·10 |
| Associate learning | — | — | — | — | — | — | 0·15 |

*p < 0·05
†p < 0·01
‡p < 0·001

*VARIMAX Rotated Factor Matrix*

| | *Factor I* | *Factor II* | *Factor III* |
|---|---|---|---|
| PASAT | 0·8034 | 0·2813 | 0·2386 |
| Information + Orientation | 0·3023 | 0·0632 | 0·7128 |
| Mental control | 0·7179 | 0·0255 | 0·2597 |
| Logical memory | 0·3386 | 0·1852 | 0·4783 |
| Digit span | 0·2480 | 0·2683 | 0·5547 |
| Visual memory | 0·3028 | 0·4869 | 0·0098 |
| Associate learning | −0·0090 | 0·7277 | 0·2471 |
| Quick-test | 0·0366 | 0·0592 | 0·5887 |

Table 4 *Rank correlation coefficients and factor matrix for patients with PTA greater than one hour (N = 51)*

| | *PTA* | *I + O* | *MC* | *LM* | *DS* | *VM* | *AL* | *Q-test* |
|---|---|---|---|---|---|---|---|---|
| PASAT | 0·30* | 0·48‡ | 0·78‡ | 0·47‡ | 0·45‡ | 0·49‡ | 0·27 | 0·19 |
| PTA | — | 0·20 | 0·35* | 0·12 | 0·23 | 0·23 | 0·28* | 0·23 |
| Information + Orientation | — | — | 0·40† | 0·43† | 0·46‡ | 0·19 | 0·29* | 0·41† |
| Mental control | — | — | — | 0·43† | 0·32* | 0·25 | 0·12 | 0·11 |
| Logical memory | — | — | — | — | 0·37† | 0·42† | 0·28* | 0·28* |
| Digit span | — | — | — | — | — | 0·18 | 0·33* | 0·45‡ |
| Visual memory | — | — | — | — | — | — | 0·42† | 0·09 |
| Associate learning | — | — | — | — | — | — | — | 0·18 |

*p < 0·05
†p < 0·01
‡p < 0·001

*VARIMAX Rotated Factor Matrix*

| | *Factor I* | *Factor II* | *Factor III* |
|---|---|---|---|
| PASAT | 0·7446 | 0·3562 | 0·2694 |
| PTA | 0·2492 | 0·1960 | 0·2274 |
| Information + Orientation | 0·3321 | 0·1497 | 0·5891 |
| Mental control | 0·9881 | 0·0557 | 0·1271 |
| Logical memory | 0·3506 | 0·3505 | 0·3596 |
| Digit span | 0·2412 | 0·1625 | 0·6532 |
| Visual memory | 0·2108 | 0·8864 | 0·0108 |
| Associate learning | 0·0625 | 0·4650 | 0·3159 |
| Quick-test | 0·0262 | 0·0632 | 0·6557 |

## Discussion

This analysis suggests two different consequences of simple closed head injury. The first effect can be measured by PASAT. Factor I seems to be concerned with attention, concentration and information processing capacity, and, like PASAT,[11] is probably related to the subjective complaints of patients during the post-concussion period. Factor II clearly involves learning and memory. The third factor can be tentatively identified as general knowledge and verbal competence, and could, perhaps, reflect the level of pre-morbid ability. Since this factor has very small loadings on the main Factor II tasks (Paired Associates and Visual Recall) the contribution of IQ level to the learning and memory factor can be assumed to be low. This means that the higher IQ of patients in PTA grade 2 is unlikely to have biassed the results.

It is surprising that Factor II, concerned with memory and learning, should show so low a loading on PTA. Experiment II was designed to examine this second factor in more detail. The approach was to select memory tests on which head injured patients might score more poorly than controls. If these scores did not relate either to PASAT or to the duration of PTA, it would then be reasonable to suppose that the tasks measured some aspect of the same memory factor that was tapped by the Associate Learning and Visual Recall subtests.

EXPERIMENT II

## Patients and methods

Another 20 head injury patients who met the same age and injury criteria as were set for the first experiment, but who all had durations of PTA longer than one hour (range 2-56 hours) were given the PASAT, the Selective Reminding Task,[16] and the Visual Sequential Memory subtest from the Illinois Test of Psycholinguistic Abilities.[17] The Selective Reminding Task was used because it is a verbal learning test on which deficits have already been demonstrated in more severely injured patients,[1] and because it allows separate analysis of storage and retrieval mechanisms. It resembles the Associate Learning subtest from the Wechsler Memory Scale in that the patient is asked to recall words from a list read aloud to him. The difference is that in the Selective Reminding Task he is reminded before each subsequent trial only of any words he did not recall on the previous trial. Twelve trials of a 12 word list are given. Words that are recalled without reminder are assumed to have been stored in long-term memory. When words that had already been stored are not recalled on a subsequent trial this is classed as a failure to retrieve material from memory storage. The Visual Sequential Memory task resembles Visual Recall from the Wechsler Memory Scale in that patients are required to recall geometric patterns immediately after viewing them. It is a more difficult task since successive trials use sequences of increasing length, and patterns of increasing complexity. Patients were given all tasks on the same or consecutive days, and after the same interval as in Experiment I (mean 25·5 days, range 24-27 days after injury).

Thirty normal subjects in the same age group were also given the two memory tests. Half of these control subjects were unskilled workers (hospital orderlies or warehouse packers) and the rest were university students.

## Results

Table 5 gives results from the Visual Sequential Memory task, and rank correlation coefficients between patients' scores and PASAT and PTA durations. The patient group scored significantly below the control ($t = 8{\cdot}94$, $p < 0{\cdot}001$). PASAT scores were significantly correlated with results from the memory test ($p < 0{\cdot}01$). PASAT and PTA durations also correlated significantly ($p < 0{\cdot}05$), but there was an insignificant correlation between PTA durations and scores on the Visual Sequential Memory test. Incomplete scores on the Selective Reminding Task were obtained from three of the patients, so data from only 17 cases are given in table 6. Three measures were calculated for this test, and for simplicity data from the 12 trials are collapsed into three blocks of four. PASAT scores are not significantly correlated with any of these learning test measures.

Table 5 *Means and standard deviations of scores on the ITPA Visual Sequential Memory test for head-injured ($N = 20$) and control ($N = 30$) subjects*

| | *Head-injured* | | *Control* |
|---|---|---|---|
| Mean | 23·10 | | 38·33 |
| SD | 4·18 | | 6·79 |
| *t* | 8·94 | ($p < 0{\cdot}001$) | |
| Rho v PASAT | −0·571 | ($p < 0{\cdot}01$) | |
| Rho v PTA | −0·193 | (ns) | |
| Rho (PASAT v PTA) | 0·530 | ($p < 0{\cdot}05$) | |

The first measure is the total number of words correctly recalled on each trial. Part (a) of table 6 shows the mean number of words recalled on each block of four trials by the two groups. By the second block the head-injured patients are significantly worse than the controls, and the difference is greatest by the end of the task. PTA durations correlate significantly with scores throughout the test.

The second measure is the cumulative number of words in memory storage. Words were assumed to have been stored in long term memory on the trial preceding the first time the word was recalled without

Table 6 *Performance on the Selective Reminding Task of head-injured (N = 17) and control (N = 30) subjects*

| | *Trials 1-4* | | *Trials 5-8* | | *Trials 9-12* | |
|---|---|---|---|---|---|---|
| | *HI* | *C* | *HI* | *C* | *HI* | *C* |
| (*a*) Total correct | | | | | | |
| Mean | 29·06 | 32·83 | 37·29 | 41·33 | 39·65 | 44·30 |
| SD | 7·22 | 6·15 | 5·88 | 5·93 | 5·35 | 4·94 |
| *t* (HI v C)‡ | | 1·874 ns | | 2·245* | | 2·975† |
| Rho v PTA | | −0·560* | | −0·695† | | −0·541* |
| Rho v PASAT | | −0·194 ns | | −0·420 ns | | −0·408 ns |
| (*b*) Long-term storage | | | | | | |
| Mean | 7·53 | 8·33 | 10·53 | 10·93 | 11·06 | 11·37 |
| SD | 2·48 | 3·10 | 1·38 | 1·91 | 1·09 | 1·38 |
| *t* (HI v C)‡ | | 0·945 ns | | 0·814 ns | | 0·694 ns |
| Rho v PTA | | −0·704† | | −0·632† | | −0·641† |
| Rho v PASAT | | −0·307 ns | | −0·258 ns | | −0·310 ns |
| (*c*) Retrieval | | | | | | |
| Mean | 1·00 | 1·65 | 2·11 | 2·95 | 2·85 | 3·55 |
| SD | 0·86 | 0·86 | 1·07 | 1·18 | 0·82 | 0·63 |
| *t* (HI v C)‡ | | 2·484† | | 2·448† | | 3·033† |
| Rho v PTA | | −0·571* | | −0·452 ns | | −0·280 ns |
| Rho v PASAT | | −0·262 ns | | −0·349 ns | | −0·241 ns |

*p 0·05
*† p 0·01
‡Two-tailed

reminder. For example, a word was taken as stored on trial 3 if the subject produced it without its being presented on trial 4. Correlations in part (b) of table 6 show a significant inverse relation between the number of items in long-term memory storage and the duration of PTA, although the patients' mean scores do not differ significantly from controls' on this measure.

The last measure is the consistent retrieval of material from memory storage. As an example, a word recalled on trial 6 and on *all subsequent trials* was scored as consistent retrieval on all trials from six to 12. At each trial the *proportion* of words in memory storage that were consistently retrieved was calculated. Thus the retrieval measure can be used to compare subjects who have entered different numbers of words into long-term storage. This ability to retrieve material from memory store does differentiate the two groups. Part (c) of table 6 shows that patients are poorer than controls throughout the task, but retrieval is not related (except on the first block of trials) to the length of the amnesic period.

## Discussion

Results from the Visual Sequential Memory test add little new information, since even though the patients score significantly below the control group, there is a high correlation with PASAT scores. It appears that the information processing factor has masked any effect the memory factor may have had on the results. This failure of the task to meet the requirements outlined in the design of this experiment is probably due to the very restricted presentation time that is used, and the rather complex sequential coding that seems necessary to achieve high scores. However, results from the Selective Reminding Task are very different. Here, despite the relation between PASAT and PTA durations, there is no significant correlation between PASAT and any of the memory measures on this test, while PTA is correlated with several. Presumably, then, the task does incorporate some aspect of memory which was isolated as Factor II from the Wechsler Memory Scale, but it also depends on another factor, related to the length of time the patient was amnesic after his accident. Although as a group the patients do not show a significant deficit in the ability to store items in long term memory, the number of items they store is significantly related to the duration of PTA. Because the patients were tested at a constant time after the accident, the period between the test session and the end of PTA was shortest for those patients who had had the longest durations of PTA, and thus ranking the intervals "end of PTA to test session" produces a similar, but opposite-signed, correlation with the number of items stored. These results suggest that inability to put material into long-term memory store, which is so evident *during* the period of PTA, may persist to a diminishing degree *after* the clinical amnesia is ended.

It is unlikely, however, that this storage deficit related to PTA is the aspect of memory which influenced scores on the Associate Learning subtest of the Wechsler Memory Scale. Patients in Experiment I were tested at the same time after the accident as those in Experiment II, but duration of PTA had only a small loading on the memory factor. A clue to this

factor may come from the retrieval measure of the Selective Reminding Task. This measure is based on consistent retrieval of material from long-term memory storage, and is not dependent on the total number of items stored. The patients are poorer than the controls throughout the task but, in contrast to the measure of memory storage, retrieval is not significantly related to the length of the amnesic period after the first block of four trials, where the correlation reaches the $p < 0.05$ level. Note that the correlations between PTA durations and the number of items in memory *storage* are significant at the $p < 0.01$ level throughout the task. Note also that ability to consistently retrieve material from storage is increasingly more stringently tested as the number of trials is increased. Thus there is a suggestion that a third effect, a deficit in the ability to retrieve material from memory store, is occurring apparently independent of PTA. Examination of other aspects of these data, and of other research, provides some support for this suggestion.

Only 4 of the 17 cases had retrieval scores which were more than 1 SD below the control mean over each block of four trials. At 24% this is close to the incidence of clinically impaired scores on the Associate Learning subtest in Experiment I (18 out of 71; 25%). Using the same Selective Reminding Task with a group of young adults more than a year after severe head injury, Levin *et al*[1] found that more than 36% had impaired retrieval scores. However, if the three patients in their series who were severely disabled are excluded (since with IQs in the "mentally defective" range they are not comparable to the remainder of their cases, nor to the subjects in our sample) the incidence of retrieval deficits falls to 26%. Results from these three samples suggest that approximately one closed head injury patient out of every four may have reduced ability to retrieve material from memory storage, even though each sample represented a different range of severity of injury in terms of duration of PTA or coma. Experiment I in the present study included cases with PTA durations shorter than one hour, while Experiment II did not, and all except five patients in the Levin *et al* series had coma durations longer than one day.

In summary, it appears that closed head injury seems to have at least three different effects on memory. The first, a deficit in information processing ability, is related to performance on memory tasks only when the tasks require complex processing, or where time constraints are imposed. PASAT scores predict the degree of this impairment. PTA durations do not. The second effect is a deficit in the ability to place material into long-term memory store. It is related either to the duration of PTA or to the time interval between the test session and the end of the amnesic period. It is not related to PASAT scores. A third effect is suggested. This appears to be a deficit in the ability to retrieve material from memory once it has been stored. It seems to occur in about one quarter of closed head injury cases, regardless of how "severe" the injury was. Neither PASAT scores nor PTA durations predict this impairment.

This study was designed to examine the relation between information processing capacity, PTA and memory impairment after head injury. The variable relation found between these measures suggests that it may be simplistic to expect to find one single measure of severity. Even when memory, a comparatively well-defined function, is examined, it appears possible to isolate at least three factors which are variably and independently affected. These findings have important implications for prognosis and measurement of recovery from closed head injury. The possibility of multiple loci of damage is also important in considering the pathological physiology and anatomy.

This research was supported by the Medical Research Council of New Zealand.

**References**


[1] Levin HS, Grossman RG, Rose JE, Teasdale G. Long-term neuropsychological outcome of closed head injury. *J Neurosurg* 1979;**50**:412-22.

[2] Mandelberg IA. Cognitive recovery after severe head injury 3. *J Neurol Neurosurg Psychiatry* 1976;**39**: 1001-7.

[3] Mandelberg IA, Brooks DN. Cognitive recovery after severe head injury 1. *J Neurol Neurosurg Psychiatry* 1975;**38**:1121-6.

[4] Russell WR, Nathan PW. Traumatic amnesia. *Brain* 1946;**69**:280-300.

[5] Russell WR, Smith A. Post-traumatic amnesia in closed head injury. *Arch Neurol* 1961;**5**:16-29.

[6] Gronwall D, Wrightson P. Duration of post-traumatic amnesia after mild head injury. *J Clin Neuropsychol* 1980;**2**:51-60.

[7] Wrightson P, Gronwall D. Time off work and symptoms after minor head injury. *Injury* 1981;**12**:445-54.

[8] Rutherford WJ, Merrett JD, McDonald JR. Symptoms at one year following concussion from minor head injuries. *Injury* 1979;**10**:225-30.

[9] Gronwall D, Wrightson P. Delayed recovery of intellectual function after minor head injury. *Lancet* 1974;**2**:995-7.

[10] Gronwall D. Paced auditory serial addition task: a measure of recovery from concussion. *Percept Mot Skills* 1977;**44**:367-73.

[11] Gronwall D. Performance changes during recovery from closed head injury. *Proc Aust Assoc Neurol* 1976;**13**:143-7.

[12] Wechsler D. A standardised memory scale for clinical use. *J Psychol* 1945;**19**:87-95.
[13] Ammons RB, Ammons CH. The Quick test (QT): provisional manual. *Psychol Rep* 1962; Monograph supplement I-VIII.
[14] Siegel S. *Nonparametric statistics for the behavioural sciences.* Tokyo: McGraw-Hill, 1956.
[15] Gorsuch RL. *Factor analysis.* Philadelphia: WB Saunders, 1974.
[16] Buschke H. Selective reminding for analysis of memory and learning. *J Verb Learning Verb Behav* 1973;**12**: 543-50.
[17] Kirk SA, McCarthy JJ, Kirk WD. *Examiner's manual, Illinois Test of Psycholinguistic Abilities,* Revised Edition. Urbana: University of Illinois Press, 1968.