Reaction time after head injury: fatigue, divided and focused attention, and consistency of performance

D T STUSS,* L L STETHEM, H HUGENHOLTZ, T PICTON, J PIVIK, M T RICHARD

From the Schools of Medicine (Neurology), Surgery (Neurosurgery) and Psychology, University of Ottawa; Human Neurosciences Research Unit, University of Ottawa; Department of Psychology, Ottawa General Hospital, Canada

SUMMARY Three groups of patients who had suffered head injury were compared with matched control subjects on reaction time (RT) tasks. Group I consisted of outpatients previously hospitalised for head injury of wide ranging degrees of severity, assessed at varying intervals after injury. Group II was composed of non-hospitalised mildly concussed patients. Group III was made up of head injured patients of varying degrees of severity assessed 7–10 months after initial hospitalisation for their injury. The reaction time tests were graded in difficulty, from a simple RT response to a complex choice RT test. In addition, subjects were compared in their ability to ignore redundant information during one of the choice RT tests. The findings indicate that traumatic brain injury causes slower information processing, deficits in divided attention, an impairment of focused attention, and inconsistency of performance.

Reaction time (RT) tests have consistently revealed slowness of information processing, a deficit in divided attention after head injury.1 In this study, we addressed four specific issues concerning the effects of head injury on reaction time.

The question of fatigue was examined by using the same simple RT test at the beginning and end of experimental sessions to see if head injured patients and normal control subjects changed their performance differently across the session.

A second question addressed the nature of the attentional deficit. While “There can be no controversy . . . about the presence of DADs [divided attention deficit] in head injury”;2 there has been less success in identifying a specific impairment in focused attention.3,4 Focused attention is tested by evaluating the ability to ignore distracting stimuli. A selective involvement of frontal lobe areas has been suggested in head injury5–10 and deficits in focused attention using the Stroop11 test have been described after focal frontal lobe damage.12 Frontal lobe dysfunctions include an inability to use knowledge to guide behaviour and difficulty in ignoring extraneous information.13–14 In this study we examined head injured patients’ ability to ignore redundant information in a RT test.

A third issue was the consistency of performance. Consistency may be reflected in intra-individual variability in reaction time. Increased variability in performance after head injury has been observed,1 but this requires replication. This issue was also addressed by retesting patients at different intervals using the same paradigm.

Finally, variations among different groups of patients, including severity indices, may affect results. Differences in post-traumatic amnesia, for example, appear to correlate with eventual outcome.15 We studied the possible effect of patient differences on our RT tasks by assessing three different groups of head injured patients, all compared with matched control subjects: (1) initially hospitalised head injured patients of varying initial severity referred retrospectively for neuropsychological examination, assessed at varying intervals after head injury; (2) mildly concussed patients, never hospitalised, all assessed at defined intervals within the first three months after injury; (3) initially hospitalised head injured patients of varying initial severity, part of a prospective study, all assessed at 7–10 months post injury. Correlational analyses

*Present address: the Rotman Research Institute of Baycrest Centre, and University of Toronto, Canada.

Address for reprint requests: Dr D T Stuss, Rotman Research Institute of Baycrest Centre, 3560 Bathurst St, Toronto, Ontario M6A 2E1, Canada

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742
examined the relationship between severity indices and RT.

Method

The different patient populations were evaluated in separate experiments. Control subjects were different for each study. In all three studies, the injury in the majority of patients was caused by motor vehicle accidents, with a minority occurring in falls. All were closed head injuries.

Subjects: Study 1

Twenty-six outpatients, who had originally suffered a head injury requiring hospitalisation, were subsequently referred for neuropsychological assessment. All patients referred over a period of approximately 30 months and capable of completing the RT tests (absence of hemiplegia) were examined. Time from injury to assessment ranged from 2–144 months post-injury: 13 within 12 months of injury; 8 were 12 to 36 months; and 5 were more than 36 months. The severity of the head injury was characterised by coma duration, Ommaya and Gennarelli’s clinical classification, duration of post-traumatic amnesia (PTA), Glasgow Coma Scale (GCS) at specified intervals after injury and the presence or absence of a focal or diffuse mass injury as defined by CT. Of the 26, nine had an abnormal CT scan, nine normal, and eight did not undergo CT for clinical reasons. Six of the nine abnormal CT scans reflected a mass lesion. Table 1 outlines the major clinical characteristics of the head injury patients. Patients were matched for age (+/− 3 yr), education (+/− 2 yr) and sex with normal control subjects, none of whom had any history of neurological or psychiatric disorder. No participant was colour blind. Table 2 summarises the major demographic characteristics of the patient and control groups.

Subjects: Study 2

Criteria for inclusion in study 2 were as follows: mild concussion (defined as a head injury with loss of consciousness but without demonstrable focal neurological deficit); no intoxication at the time of injury; no hospitalisation; and no colour blindness. Twenty-two of 36 patients referred completed the experimental protocol. Fourteen other patients did not return for all test sessions. These patients did not differ from the twenty-two on any of the major variables. Each of these patients was evaluated neurologically within an hour of injury. Seven of the 22 reported a previous concussion. Symptoms reported included headache, dizziness, and other various problems. Symptoms persisted on average of 13–2 days (SD = 15, range = 0–89). These patients were off work for a mean of 8–4 days (SD = 10–2, range = 0–89). The Concussed Group was compared with matched control subjects as in Study 1 (see tables 1 and 2).

Subjects: Study 3

Twenty-two subjects involved in a prospective study were administered the RT tests. All subjects (n = 60) hospitalised for head injury over an 18 month period were followed. They were subsequently referred for a neuropsychological examination 7–10 months post-injury. Thirty-eight were not available for the following reasons: deceased = 2; unresponsive/still hospitalised = 5; refused to participate = 12; age (>65) = 7; psychiatric problems = 1; inaccessible or transferred to other hospitals = 3; complete data not available = 8. Tables 1 and 2 describe the remaining patients and their controls.

Apparatus

The stimuli for the Reaction Time Battery were controlled by a personal computer. They were displayed on a 35 cm colour monitor situated 1.5 m from the subject. The stimuli were white or coloured, depending on the test, and the background was dark grey. The testing room was in darkness. The approximate size for each stimulus was 5 × 5 cm. The mean interstimulus interval was 5 s with a range of 2 s. Subjects used one button in the preferred hand for the Simple Reaction Time (SRT) tests and one button in each hand for the Multiple Choice Reaction Time (MCRT) tests.

Reaction time tests

(1) Simple Reaction Time Test (SRT): The subject was asked to press a button in his/her preferred hand, as quickly as possible, in response to the presentation of a stimulus. The stimulus was randomly selected from among four designs (a circle, square, triangle or cross) and was constant throughout the test. Five practice trials were followed by 50 test trials. The dependent measure for this test was the mean reaction time in milliseconds.

(2) Multiple Choice Reaction Time Tests (MCRT): Three MCRT tests—Easy, Complex, Redundant—were administered. The stimuli for each were considered as either “Target” or “Nontarget”. In all conditions, stimuli were randomly presented. The Target stimulus had a 25% probability of presentation and was randomly selected prior to test onset. The subject pressed the button in the preferred hand in response to a Target and the button in the other hand in response to a Nontarget. In each case 10 practice trials were followed by 100 test trials. For each MCRT test, only the Target correct response times were analysed for sake of simplicity.

Easy Multiple Choice Reaction Time Test (MCRT EASY): One of the four white geometric shapes (a circle, square, triangle and cross) was randomly selected as the Target, the remaining three being Nontargets.

Complex Multiple Choice Reaction Time Test (MCRT COMPLEX): Stimuli had three different components (shape,
Table 2  Description of the three TBI and their matched Control Groups

<table>
<thead>
<tr>
<th>Study</th>
<th>Variable</th>
<th>TBI patients</th>
<th>Control subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>M</td>
</tr>
<tr>
<td>I</td>
<td>Sex</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>(male)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(female)</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Sex</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(male)</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(female)</td>
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<td>22</td>
</tr>
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<td>Age</td>
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</tbody>
</table>

Results

Errors and outliers
There was no statistically significant group effect for the number of errors made or outliers removed for any of the three studies for any visit. Range of errors on the MCRT tests was 0-7 to 6-1, the most errors occurring on the Complex MCRT test.

Reliability measures
Reliability results for the different dependent measures ranged from $r = 0.70$ to $0.98$, $p < 0.001$, for the first
versus the second half of the first visit. The first versus second visit correlation results were equally strong with a range of \( r = 0.60 - 0.94 \), \( p < 0.001 \).

**Simple Reaction Time Tests**  
Head injured patients were consistently slower than control subjects on the Simple RT tests (see table 3). However, this difference reached significance only for study 3 \( [F(1,42) = 8.9, \ p < 0.01] \). Both patients and control subjects were slower on SRT2 compared with SRT1. A significant test effect, however, was also observed only for study 3 \( [F(1,42) = 10.2, \ p < 0.001] \). For the second visit (studies 1 and 2), both studies revealed a significant test effect (SRT2 slower than SRT1).

**Multiple Choice Reaction Time Target response**  
There were significant test differences for all three studies, and significant group differences for studies 1 and 2 (see table 4). In study 3 the group difference almost reached significance \( [F(1,42) = 5.3, \ p = 0.03] \). For all three studies, the patients were slower than the control subjects for all three choice RT tests. In addition, for both TBI and control subjects, reaction times were slower for the Complex choice than for either both Redundant or Easy tasks.

Studies 1 and 2 for the second visit both revealed significant group by test interactions (see table 4). In study 1, as in the first visit, the head injured patients were slower than the control subjects for all choice tests. There were significant differences within each group when the tests were compared. Within the control group, as expected, the Complex task results were significantly slower than the Easy and Redundant MCRT measures. For the patients, in addition to the Complex RT being significantly slower than the

### Table 3  
Means, Standard Deviations for all measures for all three studies for the first visit

<table>
<thead>
<tr>
<th>Study Measure</th>
<th>TBI patients</th>
<th>Control subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>I SRT 1</td>
<td>333.9</td>
<td>292.3</td>
</tr>
<tr>
<td>SRT 2</td>
<td>350.5</td>
<td>205.5</td>
</tr>
<tr>
<td>MCRT Easy</td>
<td>559.8</td>
<td>261.4</td>
</tr>
<tr>
<td>MCRT Comp</td>
<td>657.1</td>
<td>292.3</td>
</tr>
<tr>
<td>MCRT Red.</td>
<td>583.8</td>
<td>281.1</td>
</tr>
<tr>
<td>II SRT 1</td>
<td>282.8</td>
<td>108.2</td>
</tr>
<tr>
<td>SRT 2</td>
<td>300.0</td>
<td>66.5</td>
</tr>
<tr>
<td>MCRT Easy</td>
<td>516.1</td>
<td>142.5</td>
</tr>
<tr>
<td>MCRT Comp</td>
<td>617.4</td>
<td>196.1</td>
</tr>
<tr>
<td>MCRT Red.</td>
<td>541.5</td>
<td>171.7</td>
</tr>
<tr>
<td>III SRT 1</td>
<td>286.3</td>
<td>88.6</td>
</tr>
<tr>
<td>SRT 2</td>
<td>322.3</td>
<td>110.6</td>
</tr>
<tr>
<td>MCRT Easy</td>
<td>554.7</td>
<td>198.9</td>
</tr>
<tr>
<td>MCRT Comp</td>
<td>633.7</td>
<td>259.3</td>
</tr>
<tr>
<td>MCRT Red.</td>
<td>571.8</td>
<td>226.6</td>
</tr>
</tbody>
</table>

### Table 4  
Significant differences for the Choice RT tests for all three studies

<table>
<thead>
<tr>
<th>Condition</th>
<th>D.F.</th>
<th>( F )</th>
<th>( \text{Sig.} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>First visit study I Group Test</td>
<td>1.50</td>
<td>7.0</td>
<td>0.01</td>
</tr>
<tr>
<td>II Group Test</td>
<td>1.42</td>
<td>7.6</td>
<td>0.009</td>
</tr>
<tr>
<td>III Test</td>
<td>2.84</td>
<td>43.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Second visit study I Group Test</td>
<td>2.10</td>
<td>4.3</td>
<td>0.016</td>
</tr>
<tr>
<td>II Group Test</td>
<td>2.84</td>
<td>4.8</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Easy and Redundant RT tasks, the Redundant reaction time was also significantly slower than the Easy RT test (fig 1). The study 2 interaction stemmed from the control group reacting more slowly on the Easy than on the Redundant task on the second visit.

### Consistency of performance

Consistency of performance was analysed by comparing the individual standard deviations of the patients and control subjects. For this analysis subjects from all three studies were grouped together on their first visits' results. There was a significant group effect for the SRT analysis \( [F(1,135) = 7.4, \ p < 0.01] \) and the MCRT results \( [F(1,135) = 16.6, \ p < 0.01] \). For all comparisons, the head injured patient showed a significantly greater variability in performance as assessed by his/her standard deviations.

Consistency of performance may be evident in other ways. For example, in the SRT analysis of study 1, in contrast to the control group, patients showed a smaller fatigue effect for the first visit but a greater fatigue effect for the second visit. In this same study, the Redundancy effect was observed only on the second visit. In study 2 concussed patients, while not statistically significant, demonstrated variability of the Redundancy effect over the five visits. For certain visits, the Redundant-Easy RT scores are equivalent; for other visits, the Redundancy effect is more prominent (see fig 2).

### Correlational analyses

The possible influence of patient characteristics was evaluated by correlational analyses. For studies 1 and 2, no correlations exceeded the critical value of \( p < 0.01 \). Two correlations were approximate in study 1. For the second visit only, the Glasgow Coma Scale at 1 week correlated significantly with the difference between the Easy and Redundant RT measures: \( r = -0.43, \ p = 0.016 \). The more severe the head injury the greater the redundancy effect. In addition, time since injury correlated with the standard deviation of the Complex MCRT test: \( r = -0.42, \)
Groups
Fig 1  Study 1, Second Visit: Reaction time for all three Multiple Choice Reaction Time Conditions for both the Control and Head injured groups. This demonstrates the redundancy effect for the Head Injured patients.

p = 0·018. The shorter the time since the TBI, the greater the variability.

In study 3, in which patients of varying levels of initial severity of head injury were evaluated within a defined interval after the injury, all RT results correlated with the following measures at p < 0·01: GCS at 1 week (range −0·57 to −0·71); PTA (range 0·79 to 0·88). GCS at varying intervals after injury and the Ommaya and Gennarelli index also were highly significant, but not with all dependent measures.

Discussion

Fatigue

The Simple RT tests re-evaluated the effect of TBI on visuo-motor response. The repetition of the SRT task assessed the effects of fatigue over one hour on RT visuo-motor speed.

Speed of visuo-motor responsiveness on the Simple RT tasks has a tendency to be slower after head injury. In our study, however, the effect was not consistent, and was significant only in more severe, recent injury (Study 3). This may explain the variability of results in previous studies.4'9 There was no significant fatigue effect for either group.

Consistency of performance

Consistency of performance may consist of several components.1 One is individual variability, measured by the standard deviation. The head injured patients had significantly greater variability in this regard. A second is consistency of performance over longer periods of time, reflected in the differences in results over repeated assessments. Our results indicate that variability, both within a test and across assessments, is greater in the brain injured patients than in the control subjects.

Disturbance in consistency is an overlooked impairment after traumatic brain injury. Even when patients appear to do a task reasonably well, their ability to maintain this level of performance over time appears to be compromised. In this regard, head injured patients as a group may be considered to suffer impairment in sustained attention. Repeated evaluations may be essential to reveal the true nature of the deficit.

Fig 2  Multiple Choice RT results for all three tests across five visits for both the Control and Concussed subjects.
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Attention deficits

The complex tasks confirm that head injured patients have a divided attention deficit, defined as slowness in consciously controlled information processing, an inability to process multiple bits of information rapidly and easily. Our results with the MCRT tasks replicate previous findings, and confirm that tasks of divided attention are sensitive to the effects of injury, even in mildly concussed or apparently recovered patients.

The attentional deficit after head injury consists of more than just impaired divided attention. The redundancy task had been designed to measure the possibility of a focused attention deficit, defined as the inability to suppress an automatic response when a conflicting response is demanded, or as the unnecessary processing of redundant information. The patients appeared to be less able than the control subjects to ignore redundant information. This deficit, however, was somewhat elusive. It was significant only for the hospitalised patients (study 1) on their second visit. The concussed patients (study 2) demonstrated considerable variability, but an analysis of their means (see Figure 2) revealed a tendency for impaired performance on the Redundant RT test which was variable over the five visits.

We propose that the attentional deficit in head injured patients is not a simple one. There is little doubt about the presence of a divided attention deficit. There also appear to be superimposed problems in focused and sustained (consistent) attention. The interactive nature of these latter two deficits makes them elusive, and repeated evaluations appear necessary to elicit them. We propose that the characteristics of our tests and procedure have revealed that head injured patients as a group can rise to meet the demands of a focused attention task but are inconsistent in maintaining an optimal level of performance. Patients can temporarily improve their attentional focus by inhibiting redundant information, as revealed by the first visit results. This "top-down", focused attention, however, is completed at a cost and apparently cannot be maintained by all. The sustained, or more correctly repeated, demands of the task, eventually erodes the patient’s ability to maintain consistent performance. From a practical viewpoint, this finding may reflect the inconsistent work performance and the problems in maintaining attention long enough to learn and use new techniques effectively that is commonly described by head injured patients. Awareness of dysfunction in consistency of effort, even in mildly concussed patients, has important treatment and management ramifications.

Correlational analyses

The lack of correlation of RT performance with other indices of severity of the head injury was somewhat surprising. RT measures have always been sensitive to the effect of head injury. Considering past studies correlating such indices as duration of PTA with outcome, significant correlations were expected but were observed only in study 3.

The characteristics of patients in study 3 may explain these findings. These patients were more severely injured as a group than patients in study 2. Severity of insult may be relevant. Secondly these subjects were assessed at a relatively defined time after insult. Subjects in study 1 were of an equivalent severity to those in study 3, but the differences in time since injury in study 1 may have minimised correlations with severity. This hypothesis is at least partially supported by the fact that time since injury in study 1 was correlated at \( p = 0.018 \) with the Complex MCRT variability results; the shorter the time since injury, the greater the variability. A third possibility is the fact that study 3 was completed prospectively. The evaluation of severity indices in study 3 was likely to be more precise than in the retrospective study.

Conclusion

Head injury does result in deficits in attention and speed of information processing. Our results suggest that the deficits can be divided into several factors. There is overall a generalised slowing in visuo-motor responsiveness, which frequently does not reach the level of significant difference. There is a divided attention deficit. In addition, however, traumatic brain injury may result in impairment in focused attention and consistency of performance, observed only with repeated assessments using a focused attention task. This is a group effect and may not be necessarily revealed in individual subjects.

We acknowledge the need for further replication of these observations, but we believe that we are justified in proposing that inconsistency and impaired focused attention are important deficits following head injury for several reasons. First, the use of different groups has provided some index of replicability. Second, our data are sufficiently strong at least to indicate the need for future research with repeated focused attention tasks. The amount of redundant information to be ignored may be a relevant variable. Third, the findings are compatible with the neuropathology of traumatic brain damage. Our final argument is based on clinical observation. Awareness that inconsistency in performance and impairment in focused attention may be prominent deficits after head injury should radiate into the understanding, management, and treatment of patients.

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References


