Memory and head injury severity

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SUMMARY One hundred and two consecutive head injured patients were studied at 1 and 12 months after injury. Their performances were compared with a group of uninjured friends. The results indicate that impairment in memory depends on the type of task used, time from injury to testing, and on the severity of head injury (that is, degree of impaired consciousness). Head injury severity indices are more closely related to behavioural outcome early as compared with later after injury. At 1 year, only those with deep or prolonged impaired consciousness (as represented by greater than 1 day of coma, Glasgow Coma Scale of 8 or less, and post traumatic amnesia of 2 weeks or greater) are performing significantly worse than comparison subjects.

Problems remembering new information following head injury are the most frequently reported difficulties by patients and those associated with them. Researchers have investigated memory problems more than any other neuropsychological deficit in the area of head injury. The focus of the investigative work has been to determine the nature and severity of the problems and to identify factors (for example, different indices of head injury severity or neurological complications) responsible for or associated with the problems observed.1–3 The work done to date has made us aware that memory problems are frequent; yet, we are just beginning to understand their nature and are still far from fully understanding the aetiology of memory difficulties of head injured patients. In general more severe injuries are associated with greater cognitive impairments. However, there is less specific information and consistent empirical documentation of the relationships between various indices of head injury severity and cognitive outcome, how these relationships hold over time, and what level of head injury severity is associated with impaired cognitive performance. Part of the problem is the determination of the complex nature of the constructs of memory and how to go about measuring them. The other part of the problem is the multitude of factors that may influence memory and the determination of memory impairment following head injury.

In the present study we define memory as what the Wechsler Memory Scale4 and the Selective Reminding Procedure measure. We do not specifically deal with different memory systems and how they are affected by head injury (for example, short vs long term, semantic vs episodic etc.). Rather, we focus on the importance of different head injury severity indices and the impact of time from injury to evaluation on memory. In addition, considerable effort was expended to rule out or control for the effects on memory functioning of as many confounding variables as possible. To that end, consecutive cases were selected and every attempt was made to reduce attrition over the follow-up period in order to obtain as representative a sample of head injured patients as possible. Cases with pre-existing neurological or neuropsychiatric conditions were excluded to avoid confusing pre-injury memory problems from those resulting from the head injury. And finally, a group selected from friends of the head injured cases was used for comparison purposes. The general purpose of this study was to examine the effects of injury severity, time from injury to testing, and type of tasks on memory performance following head injury with specific emphasis on head injury severity.

Methods

SUBJECTS Head injured The subjects were 102 consecutive, acute,
adult head injured patients who were admitted to Harborview Medical Center in Seattle. The criteria for subject selection included all of the following: (1) any period of loss of consciousness or post-traumatic amnesia (PTA) > 1 hour or objective evidence of cerebral trauma; (2) head injury sufficiently serious to require hospitalisation; (3) no history of prior central nervous system insult or involvement or significant neuropsychiatric difficulties; (4) age range between 15 and 60 years; (5) residence allowing availability for 12 month follow-up; (6) English speaking; and (7) willingness to participate in the study.

All patients had sustained blunt head injuries. Moving vehicle accidents were responsible for the injury in 79 cases, falls in 10, fights/assaults in eight and five cases were the result of other causes. The group consisted of a broad spectrum of severity of head injury with mild and moderate cases constituting the majority of the group. Table 1 presents the distribution of time from injury to consistently following commands, Glasgow Coma Scale (GCS) scores within 24 hours of injury, and post traumatic amnesia (PTA) represented in the sample. Time to following commands (TFC) is operationally defined by the motor response of the Glasgow Coma Scale.

Non-injured comparison group The comparison group also consisted of 102 cases selected from friends of the head injured. Methods suggested by Pocock and Simon and Taves were used to match the non-injured group to the head injured on the variables of age, education, race and sex. A pool of pre-injury friends were used as potential controls based on the assumption that one usually chooses friends similar to oneself, and therefore, the friends and the head injured subjects will be roughly similar on potentially important cognitive and psychosocial characteristics. The non-injured subjects were recruited around the time of the 1 month examination of the head injury subjects, rather than during the course of the one-year follow-up. This was done to insure a sample as comparable as possible to the pre-trauma status of the head injury subjects.

The demographic features of the two groups are presented in table 2. In summary, men exceed women by a factor of two. The majority of the subjects are single, in their early to mid-twenties and have a high school education. The head injured subjects were examined at 1 and 12 months post injury. Thirteen cases were neurologically too impaired (for example, in coma) to be testable at 1 month. The non-injured subjects were also tested twice with the same test–retest interval. Ninety seven of the 102 head injured and 88 of the 102 non-injured subjects were seen for 1 year follow-up.

Table 1 Indices of severity at one month

<table>
<thead>
<tr>
<th>Category</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-traumatic amnesia</td>
<td></td>
</tr>
<tr>
<td>&lt; 24 h</td>
<td>23</td>
</tr>
<tr>
<td>1–6 days</td>
<td>29</td>
</tr>
<tr>
<td>7–13 days</td>
<td>26</td>
</tr>
<tr>
<td>≥ 14 days</td>
<td>33</td>
</tr>
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<td>Unknown</td>
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</table>

Table 2 Subject demographic characteristics at 1 month

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Head Injured</th>
<th>Friends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Age</td>
<td>26.33</td>
<td>24.52</td>
</tr>
<tr>
<td>Mean Education</td>
<td>12.05</td>
<td>12.39</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>69</td>
<td>65</td>
</tr>
<tr>
<td>Female</td>
<td>33</td>
<td>37</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>Non-White (Blacks &amp; Asians)</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Marital Status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single</td>
<td>61</td>
<td>73</td>
</tr>
<tr>
<td>Married</td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td>Divorced</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Separated</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Widowed</td>
<td>1</td>
<td>0</td>
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</tbody>
</table>

Measures

A. Head injury severity measures
(1) Glasgow Coma Scale (GCS), as assessed within 24 hours of the injury, was used as an index of depth of coma.
(2) Time from injury to consistently following simple commands (TFC) was used as an index of length of coma. The operational definition for following commands is the same as that specified in the motor response category of the GCS.
(3) Post-traumatic amnesia (PTA), defined as the interval between the injury and regaining continuous day to day memory, was used as another index of length of impaired consciousness.

B. Memory measures
(1) Wechsler Memory Scale (WMS) attempts to examine various aspects of memory and memory related abilities. Because of this, it continues to be one of the more widely used measures in spite of some of its reported weaknesses. It assesses knowledge of personal and current information, orientation, mental control (that is, counting backwards, recalling the alphabet, and counting by three’s, all under time pressure), logical memory (that is, recalling the number of details from two short passages), attention span (that is, recalling digits forward and backward), visual reproduction (that is, reproducing from memory geometric designs), and associate learning (that is, learning easy and hard word pairs). In addition to the immediate recall, 30-minute delayed recall was tested for logical memory and visual reproduction. Two alternate forms of the test were counterbalanced and administered at the two evaluation pe-
Memory and head injury severity

Periods. A total of 11 scores representing different abilities were derived from this measure.

(2) Selective Reminding Procedure (SRP) is a multiple trial, free-recall memory and learning procedure which has gained considerable popularity in the area of head injury. It examines storage and subsequent retention and retrieval from long-term storage of new verbal information. For the present study, 10-item unrelated word lists were used and 10 trials were given. Four alternate forms of the Selective Reminding Procedure were counterbalanced and administered at the two evaluation periods. Eight scores were derived from this procedure.

Data analysis

The data were analysed to answer the following questions:

(1) Are there memory difficulties at 1 and 12 months post injury and, if so, are they related to time following commands? To address the question of memory difficulties at 1 and 12 months, the entire group of head injured patients was compared with the non-injured group at the two time periods on each score derived from the Wechsler Memory Scale and the Selective Reminding Procedure. Wilcoxon rank sum tests were used for this purpose. In order to examine the relationship between memory impairment and TFC, the performance of the head injury subgroups divided on the basis of TFC and the uninjured group were compared using Kruskal-Wallis distribution-free analysis of variance. Significant overall differences on a test were followed by post hoc comparisons among all of the pairs of groups using Tukey’s method. A significance level of 0.05 was used.

(2) Is the relationship between degree of memory impairment and impaired consciousness similar across different indices of impaired consciousness? The head injury group was divided into subgroups on the basis of TFC, PTA, and GCS. The performances of these subgroups were compared with those of the uninjured and among all pairs of groups as described above. These comparisons were restricted to only one measure derived from the Selective Reminding Procedure (that is, sum, of consistent long-term retrieval).

Results

The results will address each of the two questions posed in the Data Analysis section.

(1) Memory difficulties at 1 and 12 months after injury and as a function of time to following commands. Memory impairments are clearly present at 1 and 12 months after injury as seen in Table 3. At 1 month, the head injury group performed significantly worse than the uninjured group ($p < 0.001$) on each of the subscales extracted from the Wechsler Memory Scale and the Selective Reminding Procedure. Most subscales continue to show significant impairment for the head injury group as a whole at 1 year. The degree of impairment is influenced by time from injury to following simple commands (TFC). Table 4 summarises the results that are in support of this conclusion. Presented are the percentage of the 11 tests of the Wechsler Memory Scale and the eight scores of the Selective Reminding Procedure on which the head injured subgroups were significantly more impaired than the comparison subjects at 1 and 12 months post injury. The head injury group was divided into four

<table>
<thead>
<tr>
<th>Measures</th>
<th>Head Injured</th>
<th></th>
<th></th>
<th></th>
<th>Friends</th>
<th></th>
<th></th>
<th></th>
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<tr>
<td></td>
<td>1 month (102)</td>
<td>12 months (97)</td>
<td></td>
<td></td>
<td>1 month (102)</td>
<td>12 months (88)</td>
<td></td>
<td></td>
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<tr>
<td>Wechsler Memory Scale</td>
<td></td>
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<td></td>
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<tr>
<td>Personal, Current Info</td>
<td>5*</td>
<td>6†</td>
<td></td>
<td></td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
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<td>Orientation</td>
<td>5*</td>
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<td></td>
<td></td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mental Control</td>
<td>7*</td>
<td>8‡</td>
<td></td>
<td></td>
<td>9</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logical Memory Immed.</td>
<td>9*</td>
<td>11*</td>
<td></td>
<td></td>
<td>12</td>
<td>13</td>
<td></td>
<td></td>
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<tr>
<td>Logical Memory Delayed</td>
<td>7*</td>
<td>9*</td>
<td></td>
<td></td>
<td>10</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digits Forward</td>
<td>6*</td>
<td>7</td>
<td></td>
<td></td>
<td>7</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digits Backward</td>
<td>4*</td>
<td>5‡</td>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
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<tr>
<td>Vis. Reprod. Immed.</td>
<td>11*</td>
<td>12</td>
<td></td>
<td></td>
<td>13</td>
<td>13</td>
<td></td>
<td></td>
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<tr>
<td>Vis. Reprod. Delayed</td>
<td>10*</td>
<td>12‡</td>
<td></td>
<td></td>
<td>12</td>
<td>12</td>
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<tr>
<td>Assoc. Learn. Easy</td>
<td>16*</td>
<td>17‡</td>
<td></td>
<td></td>
<td>18</td>
<td>17</td>
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<td>Assoc. Learn. Hard</td>
<td>9*</td>
<td>10</td>
<td></td>
<td></td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
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<tr>
<td>MQ</td>
<td>95*</td>
<td>106*</td>
<td></td>
<td></td>
<td>118</td>
<td>119</td>
<td></td>
<td></td>
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<tr>
<td>Selective Reminding</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum RCL</td>
<td>80*</td>
<td>86*</td>
<td></td>
<td></td>
<td>90</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum LTS</td>
<td>76*</td>
<td>83*</td>
<td></td>
<td></td>
<td>90</td>
<td>89</td>
<td></td>
<td></td>
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<tr>
<td>Sum LTR</td>
<td>70*</td>
<td>80*</td>
<td></td>
<td></td>
<td>87</td>
<td>87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum CLTR</td>
<td>56*</td>
<td>72*</td>
<td></td>
<td></td>
<td>83</td>
<td>83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay RCL-30 min</td>
<td>7*</td>
<td>8‡</td>
<td></td>
<td></td>
<td>9</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay RCL-4 h</td>
<td>6*</td>
<td>8†</td>
<td></td>
<td></td>
<td>9</td>
<td>9</td>
<td></td>
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<tr>
<td>Delay Recog.-30 min</td>
<td>10*</td>
<td>10</td>
<td></td>
<td></td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day Recog.-4 h</td>
<td>10*</td>
<td>10</td>
<td></td>
<td></td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significance levels refer to comparisons between HI and friend controls at 1 month and at 12 months.

*p < 0.001.

†p < 0.01.

‡p < 0.05.

( ) sample size.
subgroups on the basis of TFC: (1) 7 days or greater; (2) 1–6 days; (3) 1–24 hours; (4) none or less than 1 hour. The median subtest values and the results of the comparisons among the head injury subgroups are not presented in order to save space. This information is available from the authors upon request. At 1 month after injury, the subgroups with more severe head injury are significantly impaired on more subtests on both the WMS and SRP than the uninjured subjects. For instance, those with TFC equal to or greater than 7 days were significantly impaired on all subtests of both the WMS and the SRP (p < 0.001). In fact, 11 of the 18 cases that were in coma for 7 or more days were neurologically too impaired to be tested at 1 month post injury. Those with coma length of 1 to 6 days are not impaired on as many subtests as those with 7+ days of coma but are impaired on more subtests than the two milder groups. The same trend is to be noted at 1 year after injury as a function of length of coma. However, it should also be noted that the subgroups are impaired on fewer measures reflecting recovery of memory over time. These results also suggest the persistence to at least 1 year, of memory problems for those more severely injured, that is, in coma for greater than 1 day, and particularly for those in coma for more than 7 days. In contrast, the two milder groups appear comparable and are not significantly different from the group of uninjured subjects.

Finally, there also seems to be an effect due to the nature and difficulty level of the task. In general, the SRP appears to be a little more sensitive than the WMS to the severity level of head injury. Proportionally speaking, the head injury subgroups are significantly impaired on more of its components than on the components of the WMS (for example see the results for the 1–24 hours of coma group on the two measures at 1 month or for the 25 hour-6 day group at 12 months). With respect to the WMS, those components that are more robust or less affected are measures of orientation, concentration (i.e. mental control), and short term memory (i.e. digit span forward) while those more sensitive are those that are difficult and require storage into long-term memory (for example logical memory, delayed recall, hard pairs of associate learning). With regard to the SRP, indices of short-term memory and recognition recall are the most robust while those requiring consistent retrieval from long-term memory are the more vulnerable.

(2) The relationship between memory impairment and different indices of impaired consciousness. Table 5 shows median performances on the sum of consistent long term retrieval of the SRP at 1 and 12 months after injury for the head injury group classified on the basis of TFC, PTA, and GCS obtained within 24 hours of injury. The results of these analyses suggest that impaired consciousness, irrespective of the index used, has an impact on memory. In terms of the specifics: (a) There is a systematic ordering of memory performance as a function of severity of impaired consciousness at 1 month. This relationship is much weaker at 1 year; (b) There is a substantial improvement in memory from 1 month to 1 year in all subgroups classified on the basis of the three indices of impaired consciousness. The greater the degree of impairment the greater is the room to improve and the greater is the magnitude of change; (c) By one

<table>
<thead>
<tr>
<th>Time to Following Commands</th>
<th>1 month</th>
<th>1 Year</th>
</tr>
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<tbody>
<tr>
<td>WMS 25 hr-6 d</td>
<td>72</td>
<td>18</td>
</tr>
<tr>
<td>SR 1-24 h</td>
<td>90</td>
<td>25</td>
</tr>
<tr>
<td>1-6 d</td>
<td>90</td>
<td>25</td>
</tr>
<tr>
<td>&lt; 1 hr</td>
<td>90</td>
<td>25</td>
</tr>
<tr>
<td>postal ommision</td>
<td>90</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 5 Impaired consciousness sum of consistent longterm retrieval medians

<table>
<thead>
<tr>
<th>Severity indices</th>
<th>1 month</th>
<th>1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to Follow Commands</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 7 d</td>
<td>39*</td>
<td>45*</td>
</tr>
<tr>
<td>25 hr-6 d</td>
<td>67*</td>
<td></td>
</tr>
<tr>
<td>1-24 h</td>
<td>80</td>
<td></td>
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<tr>
<td>&lt; 1 hr</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Controls</td>
<td>83</td>
<td>83</td>
</tr>
<tr>
<td>Glaston Coma Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-8</td>
<td>45*</td>
<td></td>
</tr>
<tr>
<td>9-11</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>12+</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>Controls</td>
<td>83</td>
<td>83</td>
</tr>
</tbody>
</table>

Significance levels refer to comparisons between head injured and friend controls at 1 and 12 months.

* p < 0.001.
† p < 0.01.
‡ p < 0.05.
year, with the exception of the most severe sub-
group(s) within each of the classifications, the head
injury subgroups are performing at or near the level
of the comparison subjects. At 1 year roughly one
third of the group within each of the classifications is
significantly impaired in memory functioning.

Discussion

The results, consistent with reports in the literature
and the common complaints of head injured patients,
suggest that head injuries are associated with memory
problems. However, the effect is not an all-or-none
phenomenon. Many factors and their interactions
influence the nature and severity of the problems
observed. Time from injury to when the assessment is
performed, the nature of the memory task, and the
severity of the injury are all influential. Time reflects
recovery. The longer the time since injury, the greater
the amount of recovery and the less the magnitude
of impairment. Head injured patients performed better
at 1 year than they did at 1 month, the two time points
selected for this study. The nature of the task, reflec-
ting the demands placed on the individual, is also
important in observing an impairment. Head
injured patients were not equally impaired on various
components of the measures used. Even though this
was not the primary focus of the study, easy mea-
sures, and measures assessing certain processes, such
as orientation, or short term memory, were less likely
to identify a deficit than more complex measures and
those involving storage of new information into long
term memory. These observations are consistent with
those previously reported in the literature.\(^\text{12-13}\) The
influence of time or the nature of the task depend on
the severity of the head injury.

Keeping time and the tasks constant, several severity
indices were used to explore the degree to which they
are associated with memory performance and
whether or not they may provide reliable estimates of
memory impairment. All three indices of impaired
consciousness used, namely, time to following com-
mands, PTA, and GCS within 24 hours of injury, are
closely associated with memory outcome. The degree
of this relationship, however, changes with time. The
results in table 5 clearly show the increasing levels of
memory impairment with increasing levels of impaired
consciousness at 1 month after injury, ir-
respective of how impaired consciousness is defined.
The relationship is a little more systematic for TFC
and GCS than retrospectively assessed PTA. Even
though the medians of all head injury subgroups
classified on the basis of PTA were lower than for the
comparison subjects, only the group with 14 or more
days was reliably more impaired. With the other indi-
ces, each of the three subgroups with greater than 1
hour of coma and each subgroup based on GCS were
performing reliably worse than the comparison
group. This close association, however, disappears at
1 year so that only the subgroup(s) representing
approximately one third of the total group and the
most severely injured are reliably impaired. The
ranges for this impairment are: TFC > 1 day,
PTA \(\geq 14\) days, and GCS \(\leq 8\). For the rest of the
subgroups, recovery and factors affecting recovery
seem to take over. A familiar pattern, consistent with
our earlier findings, is the magnitude of change as a
function of head injury severity.\(^\text{14}\) The greater the
degree of impairment, the greater the room for
improvement, and the greater the amount of change.
However, in spite of the magnitude of change, those
who are initially most severely injured are also the
ones who remain the most impaired. In other words,
very severe cases improve a lot, but do not recover
fully by 1 year.

A closer association between degree of impaired
consciousness and behavioural outcome soon after
injury as compared to later is an important obser-
vation which has also been previously reported by
others. Klove and Cleeland\(^\text{15}\) reported a significant
relationship between PTA and Halstead's
Impairment Index within 3 months of injury but not
later. Mandelberg\(^\text{16}\) found Wechsler Adult Intel-
legence IQ values to be related to PTA at 3 months
and 6 months after injury but found no such
relationship later. Disassociation of relationships
seems to apply also to indices other than impaired
consciousness. Levin \(\text{et al}\)\(^\text{2}\) found focal lesions
involving the left temporal lobe to be associated with
verbal memory difficulties within 6 months after
injury but not at 1 year. Such disassociation,
unfortunately, does not seem to occur for the more
severe diffuse injuries as reflected in the groups with
deep or prolonged impaired consciousness, a finding
consistent with those of Levin \(\text{et al}\)\(^\text{2}\) and Van Zom-
eren and Van Den Burg.\(^\text{17}\)

The results of the present study indicate that the
time from injury to when the assessment is made,
the nature of the task, the severity of the injury, and
the interaction of these variables influence memory
performance. Therefore, these variables need to be
considered, controlled, or accounted for in studies of
cognitive functioning, as well as, in the evaluation of
the individual head injured case. Differences in the
distribution of ranges of these variables in different
studies need to be examined as potential causes for
the inconsistencies in the literature regarding the
relationship between severity and outcome or the
relationship of time from injury to the testing of out-
come.

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