NEUROPSYCHOLOGICAL OUTCOME IN RELATION TO HEAD INJURY SEVERITY

Contributions of Coma Length and Focal Abnormalities[1]

Barbara L. Ross, PhD, Nancy R. Temkin, PhD, David Newell, MD and Sureyya S. Dikmen, PhD[2]

ABSTRACT **Ross BL, Temkin NR, Newell D, Dikmen SS: Neuropsychological outcome in relation to head injury severity: contributions of coma length and focal abnormalities.** ***Am J Phys Med Rehabil*** **1994;73:341–347**

Neuropsychological test performances of 102 consecutive head-injured patients were evaluated at 1 mo and 1 yr after injury. The results of the study indicated that both coma length and the presence of focal abnormalities on computed tomography (CT) scans contribute independently to neuropsychological outcome. The effects of coma length are stronger than the effects of focal abnormalities evident on CT scans and continue to exert a stronger influence on neuropsychological outcome over the year postinjury. These results suggest that the extent of diffuse pathology may be a more important determinant of long-term behavioral outcome than the presence of focal lesions.

Key Words: Head trauma, Head injury severity, Neuropsychological functioning, Outcome

Previous studies of head-injured patients have indicated that head injury severity is associated with the extent, course, and rate of neuropsychological recovery.[1–4] The majority of studies that have assessed the relationship between head injury severity and outcome have used the degree of impaired consciousness as the measure of severity (e.g., length of coma, post-traumatic amnesia (PTA) or initial Glasgow Coma Score (GCS)), most commonly depth of coma.[5,6] For the most part, these studies indicate that deeper and longer coma is associated with poorer general outcome[7] as well as more severe short- and long-term deficits in attention, memory and problem solving.[1,8]

Another measure of head injury severity that has been associated with neuropsychological outcome is the presence of mass lesions.[7,9,10] Studies have indicated that mortality and morbidity after traumatic head injury have varied as a function of the type of lesion (e.g., contusion, subdural hematoma, epidural hematoma, etc.) and the depth of lesion. In general, intracerebral hematomas have been associated with poorer intellectual functioning and general outcome than other types of mass lesions (e.g., extradural hematomas).[7,11] In addition, other studies have indicated that deeper lesions are associated with poorer outcome than more superficial lesions.[11,12]

Although many studies have found a significant relationship between a number of head injury severity measures and subsequent neuropsychological functioning, very few studies have assessed how different indices of severity interact and relate to neuropsychological outcome. For instance, both longer coma and the presence of mass lesions have been associated with poorer outcome. However, little attempt has been made to assess whether individuals with similar length of coma experience a similar clinical outcome despite different types of lesions.[7,9]

An exception is the work of Gennarelli and colleagues.[7] The results of their study indicated that coma severity and type of lesion contributed independently to mortality and morbidity (i.e., Glasgow Outcome Scale (GOS) ratings). For instance, although mortality rates were higher for individuals with deeper coma, the rates varied greatly according to the nature of the lesion found among patients with the same depth of coma. Also, mortality rates were highest for individuals with subdural hematomas regardless of their depth of coma. Similarly, ratings of morbidity varied by depth of coma and type of lesion. Although Gennarelli et al.'s study indicated that both severity indices were related to global outcome, the contribution of these severity measures to more specific aspects of long-term neuropsychological functioning (e.g., memory, attention, problem solving) in head injury survivors has not been addressed.

In a more recent study, Williams et al.[13] evaluated the effects of focal lesions on the outcome of indi-

0894-9115/94/7305-0341$03.00/0
American Journal of Physical Medicine & Rehabilitation

This study was supported by Grant HS06497 from the Agency for Health Care Policy and Research.
[1] From the Department of Rehabilitation Medicine (B.L.R., S.S.D.), Neurological Surgery (N.R.T., D.N., S.S.D.), Biostatistics (N.R.T.) and Psychiatry and Behavioral Sciences (S.S.D.), University of Washington, Seattle, Washington.

[2] All correspondence and requests for reprints should be addressed to: Department of Rehabilitation Medicine (RJ-30), University of Washington, 1959 NE Pacific Street, Seattle, WA 98195

viduals with otherwise mild head injuries (GCS, 13–15). The results of their study indicated that early neuropsychological outcome (i.e., soon after the resolution of PTA) of individuals with mild head injuries complicated by intracranial lesions was more similar to the outcome of moderately injured subjects than mildly injured subjects with no associated lesions. In addition, as with moderately injured subjects, subjects with complicated mild head injuries were more likely to experience persisting disabilities 6 mo after the injury (i.e., on GOS ratings) than those with uncomplicated mild head injuries. The results of the Williams et al. study support the need to jointly consider coma severity and the presence of focal lesions in evaluating the relationship between head injury severity and long-term outcome for individuals with a wide range of head injury severity.

The purpose of this study was to assess the impact of two different measures of neurologic severity on neuropsychological outcome in head injury survivors over a 1-yr period. The indices of severity used in this study were coma length and focal abnormalities as indicated on CT. More specifically, the goals were to evaluate how each severity measure was related to cognitive functioning as well as to assess the extent to which these severity variables interacted in relation to neuropsychological outcome. It was hypothesized that the two indices of severity would be interrelated but also would provide independent contributions to neuropsychological outcome.

METHOD

Subjects

The subjects included in this study were patients admitted to Harborview Medical Center, a level I trauma center, for acute head injuries. The 102 subjects constituting the sample of this study represent consecutive patients who were admitted over a 17-mo period and who met the following criteria: (1) loss of consciousness for any length of time, the presence of PTA for at least 1 hr or evidence of cerebral trauma (e.g., positive neurologic signs, hematoma) even if loss of consciousness or PTA was not present; (2) head injury serious enough to require hospitalization; (3) survival for at least 1 mo; (4) residence that would allow availability for 1- and 12-mo follow-ups; (5) no history of previous significant head injury, alcoholism, cerebral disease, mental retardation or psychiatric disorder (e.g., schizophrenia, manic-depressive illness, etc.); (6) age range between 15 and 60 yr at the time of injury; (7) English-speaking; (8) willingness to participate in the study. Subjects were examined at 1 and 12 months postinjury. Neuropsychological outcome 1 mo postinjury on these subjects and a friend control group has been reported elsewhere.[8]

The group consisted of a broad spectrum of head injury severity, with mild and moderate cases constituting the majority of the group. The GCS soon after the injury was 3–8 in 29 cases, 9–11 in 13 cases, and 12+ in 60 cases. Thirteen subjects were neurologically too impaired (e.g., in coma) to be tested at 1 mo. Two subjects were untestable at 1 yr.

Measures

Neurologic Severity Measures

Time from injury to consistently following simple commands was used as an index of length of coma. The operational definition of following commands is the same as that specified in the motor response category of the GCS.[14]

CT findings were also used as a measure of neurologic severity. CT scans performed within 1 wk postinjury were selected for review. If more than one CT was performed during that week, the one indicating the most serious finding was used. Although CT scans were not formally done as a part of the study, they were performed on 70 of the subjects in this study as a part of their clinical assessment. On the basis of their CT findings, individuals were placed into two categories, focal abnormalities and nonfocal. The following lesions were specified as focal: cerebral contusions, intracranial hematomas including intracerebral, subdural, epidural and intraventricular. Those who had CT abnormalities, other than those specified above as focal, those with normal CTs or those on whom no CTs were performed were placed in the nonfocal group. Contusions were often low-density lesions with small, scattered hemorrhages and were determined by consecutive scans, in most cases. Coalesced hemorrhages with edema were considered intracerebral hematomas. The presence of layered intraventricular blood was not considered hematoma. Only high-density lesions that formed a cast of the ventricular system were considered intraventricular hematomas. Subdural and epidural hematomas were classified by standard radiologic criteria. Individuals with focal lesions on CT were included in a single group because of the small number of cases in each lesion category.

Neuropsychological Measures

An expanded Halstead-Reitan Neuropsychological test battery was used to evaluate patients at 1 and 12 mo postinjury. Only certain measures were analyzed for the purposes of the present study. The measures used in the present study were: Wechsler Adult Intelligence Scale (WAIS), Verbal (VIQ) and Performance (PIQ) intelligence quotient scores[15]; the Selective Reminding Test, the sum of the recall score and the sum of consistent long-term recall[16]; the Trail Making Test, number of seconds to complete; the Stroop Test (parts 1 and 2)[17]; the Category

Test, number of errors; Tactual Performance Test, time per block (TPT-T); the Impairment Index (II).[18] The measures were chosen to assess general intellectual functioning (WAIS-VIQ, PIQ), attention, flexibility and quickness (Trail Making Test, Stroop), memory and learning (Selective Reminding Test), motor and psychomotor functioning (TPT-T) and reasoning (Category Test). In addition, the impairment index is a composite score that reflects the number of Halstead-Reitan tests that are in the impaired range. The abilities assessed by these measures range from relatively simple to quite complex. These measures have been used extensively in previous research, including in the area of traumatic head injury. Tests scores were converted into ranks for data analysis (see "Data Analysis Section" for additional information on this procedure).

Data Analysis

The data were analyzed to answer the following questions. (1) What are the effects of coma length on neuropsychological functioning before and after controlling for the effects of focal abnormalities evident on CT scans? (2) What are the effects of focal abnormalities evident on CT scans on neuropsychological functioning before and after controlling for the effects of coma length? (3) Is there evidence to suggest differential impact of focal abnormalities on CT scans as a function of coma length?

To address the relationship between head injury severity and neuropsychological functioning, two sets of hierarchical analyses of variance were performed, using coma length (≤24 hr *v* >24 hr) and focal CT abnormalities (negative *v* positive) as the independent variables and neuropsychological test performance as the dependent variables. Raw scores on the neuropsychological measures were transformed into ranks for two reasons. First, by using ranked data, individuals that were neurologically too impaired to be tested could be included in the analyses as receiving the poorest score. Although test scores could not be obtained for untestable patients, we were confident that they would have performed worse than any of the individuals that were tested. Second, ranking the data eliminated skewness in the distribution of scores.

The effect of coma length was assessed by entering coma length into the analysis after the effect of the focal CT abnormalities factor was partialled out. Corresponding analyses were performed evaluating focal CT abnormalities. The question of the differential impact of focal CT abnormalities as a function of coma length was evaluated by examining the significance of the interaction terms in the analyses.

RESULTS

The demographic features and injury characteristics of the four groups formed on the basis of coma length (≤24 hr and >24 hr) and presence of focal abnormalities evident on CT (focal abnormalities and no focal abnormalities) are presented in Table 1. In summary, a majority of the subjects were men in their early to mid-twenties with a high school education. Within the two coma length categories, no significant differences existed between the length of time required to follow commands for individuals with focal *v* nonfocal abnormalities on CT.

Table 2 presents the median scores for the neuropsychological measures at 1 mo postinjury for the four groups formed on the basis of coma length (≤24 hr and >24 hr) and the presence of focal CT abnormalities (focal abnormalities and no focal abnormalities). Medians are presented in this summarization of data in order that neither outliers nor the particular score assigned to the untestable patients would bias the scores. However, *mean ranks* were used in the data analysis. This table also shows the results of the 2-factor hierarchical analysis of vari-

TABLE 1
Demographic and injury characteristics

	Coma ≤ 24 hr		Coma > 24 hr	
	No focal abnormalities	Focal abnormalities	No focal abnormalities	Focal abnormalities
	n = 55	*n* = 18	*n* = 18	*n* = 11
Demographics				
Age M (SD)	27.33 (9.78)	25.84 (7.13)	22.25 (5.72)	27.46 (7.39)
Education M (SD)	12.18 (2.33)	12.17 (2.09)	10.88 (1.89)	12.73 (1.74)
Gender *n* (%) Male	35 (64)	13 (72)	15 (83)	8 (73)
Glasgow Coma Scale M (SD)	13.12 (2.75)	12.85 (1.43)	8.61 (2.92)	7.00 (3.37)
Range	3–15	9–15	3–14	3–14
Activity at Time of Injury *n* (%)				
MVA	41 (74)	14 (78)	16 (88)	8 (73)
Falls	5 (9)	3 (17)	1 (6)	1 (9)
Fights	1 (2)	0 (0)	0 (0)	2 (18)
Other	8 (14)	1 (6)	1 (6)	0 (0)

TABLE 2

Neuropsychological outcome at 1-mo after head injury

Measure	Medians				Significance levels				
	Coma ≤ 24 hr		Coma > 24 hr						
	No focal abnormalities	Focal abnormalities	No focal abnormalities	Focal abnormalities	Coma length	Focal Abnormalities	Coma length controlling focal abnormalities	Focal abnormalities controlling coma length	Interaction
	n = 46	*n* = 17	*n* = 15	*n* = 11					
VIQ	106	100	79	42	0.001	0.01	0.001	0.13	0.69
PIQ	106	99	76	63	0.001	0.001	0.001	0.03	0.37
Trials A	23	25	56	101	0.001	0.06	0.001	0.41	0.87
Trials B	59	67	160	301	0.001	0.07	0.001	0.52	0.57
Stroop, 1	43	46	115	Unt.[a]	0.001	0.03	0.001	0.30	0.81
Stroop, 2	105	114	244	Unt.[a]	0.001	0.003	0.001	0.06	0.90
Sum of recall	86	79	45	Unt.[a]	0.001	0.001	0.001	0.06	0.46
Consistent long-term recall	76	57	0	Unt.[a]	0.001	0.002	0.001	0.08	0.41
Category	29	34	90	137	0.001	0.16	0.001	0.64	0.46
TPT-time	0.39	0.49	1.19	Unt.[a]	0.001	0.003	0.001	0.03	0.36
Impairment index	0.30	0.40	1.0	Unt.[a]	0.001	0.006	0.001	0.04	0.12

[a] Unt, untestable.

ance. At 1 mo postinjury, the effect of coma length was highly significant for all measures of neuropsychological functioning ($P < 0.001$), indicating that individuals with longer coma length performed more poorly on measures of neuropsychological outcome. The effect of coma length remained highly significant ($P < 0.001$) even when the effects of focal CT abnormalities were controlled. At 1 mo, individuals with focal CT abnormalities performed significantly worse than individuals without focal CT abnormalities on all measures of neuropsychological functioning, except Trails A and B, which were marginally significant, and the Category test. The effect of focal CT abnormalities, controlling for coma length, was significant only for PIQ, TPT-T and II (see Table 2).

The results at 1 mo do not provide statistical support for the differential impact of focal CT abnormalities as a function of coma length as there was no significant interaction between the effects of coma length and focal CT abnormalities. Inspection of the medians for the four groups suggests that at 1 mo, there were larger differences between the focal *v* nonfocal CT groups for the longer coma condition than for the shorter coma condition. However, these differences or the sample sizes were not large enough to reach significance. Approximately one-half of the patients with longer coma in addition to focal abnormalities visible on CT were untestable at 1 mo postinjury, whereas approximately one-third of those with longer coma but no focal abnormalities visible on CT were untestable at 1 mo.

The effect of coma length was also significant for all neuropsychological measures 1 yr postinjury (see Table 3). This effect held after controlling for focal lesions on CT as well. Individuals with focal lesions on CT performed significantly more poorly than individuals with no focal lesion on CT only on Sum of Recall, Trails A, and the time component of TPT at 1 yr, with only the latter remaining significant after controlling for coma length. Again, at 1 yr, there is no evidence to support a differential impact of focal CT abnormalities as a function of coma length.

Despite the relatively small number of individuals in each of the focal CT categories, a descriptive examination of impairment index by CT findings was performed to explore how outcome varied by coma length and specific CT findings (e.g., contusion, subdural hematoma, etc.) (see Fig. 1). At 1 mo, coma length appeared to be related to level of impairment for all individuals, regardless of CT finding, with a substantial overlap among the various groups. Focal lesions evident on CT also appeared to be an important factor in influencing outcome, because none of the individuals in the three hematoma categories had an impairment index of less than 0.3 at 1 mo, whereas many of the individuals in the nonfocal CT categories had an impairment index of less than 0.3. At 1 yr, coma length remains

TABLE 3

Neuropsychological outcome at 1-yr after head injury

Measure	Medians				Significance levels				
	Coma ≤ 24 hr		Coma > 24 hr						
	No focal abnormalities	Focal abnormalities	No focal abnormalities	Focal abnormalities	Coma length	Focal abnormalities	Coma length controlling focal abnormalities	Focal abnormalities controlling coma length	Inter-action
	n = 52	*n* = 18	*n* = 15	*n* = 10					
VIQ	108	107	98	97	0.003	0.14	0.006	0.30	0.32
PIQ	112	111	99	93	0.001	0.06	0.001	0.43	0.59
Trials A	20	24	30	34	0.001	0.01	0.001	0.06	0.45
Trials B	51	54	72	64	0.001	0.99	0.001	0.63	0.61
Stroop, 1	40	42	55	50	0.001	0.70	0.001	0.79	0.15
Stroop, 2	94	106	106	134	0.013	0.12	0.02	0.22	0.28
Sum of recall	89	85	71	74	0.001	0.05	0.001	0.22	0.30
Consistent long-term recall	80	72	41	44	0.001	0.09	0.001	0.31	0.27
Category	17	16	34	32	0.001	0.87	0.001	0.55	0.74
TPT-time	0.33	0.39	0.61	0.91	0.001	0.005	0.001	0.03	0.66
Impairment index	0.10	0.30	0.60	0.60	0.001	0.11	0.001	0.38	0.32

related to level of impairment. However, at 1 yr, individuals with focal CT lesions did not appear to differ on the impairment index from those without focal injuries on CT, because there was a similar range of scores for individuals with and without focal CT abnormalities.

At both 1 mo and 1 yr, there was considerable overlap among the impairment levels of individuals in the different focal CT groups, suggesting that, in this data, no particular focal lesion on CT led to a substantially poorer outcome than other focal lesion types on CT. However, the few subjects with epidural hematomas showed relatively better performances than those with other focal CT lesions. Furthermore, there was no consistent relationship between outcome and focal lesions on CT that were surgically removed *v* those that were not surgically removed. There were too few cases in each category to reliably interpret these results.

DISCUSSION

The goal of this study was to examine the effects of length of coma and the presence of focal CT abnormalities on neuropsychological outcome after traumatic head injury. The present study provides evidence to suggest that both indices of head injury severity make independent contributions to neuropsychological outcome. The findings of this study are consistent with previous research, which found that individuals with longer coma[1, 8, 19, 20] and individuals with focal lesions[9, 21] perform more poorly on neuropsychological evaluations than individuals with less severe injuries. Furthermore, this study provides additional information regarding the relative importance of different severity indices and their contribution to neuropsychological outcome and how these relationships change over time.

In this study, there was a significant relationship between coma length and neuropsychological outcome at 1 mo and 1 yr postinjury, an effect that was essentially undiminished by controlling for the effects of focal CT abnormalities at both time periods. Because coma length is generally used as a clinical indicator of diffuse axonal injury,[22, 23] the strong relationship between coma length and outcome supports the notion that more severe diffuse axonal injury is an important contributor to neuropsychological deficits following head injury for at least 1 yr after the injury.

The presence of focal CT abnormalities was also significantly related to neuropsychological outcome, particularly at 1 mo. This effect was, however, diminished when the effect of coma length was removed. These findings are consistent with that of Williams et al.,[4] who found that coma level was more predictive of cognitive outcome than other head injury severity measures (e.g., the presence of mass lesions), despite the fact that other severity measures provided an independent contri-

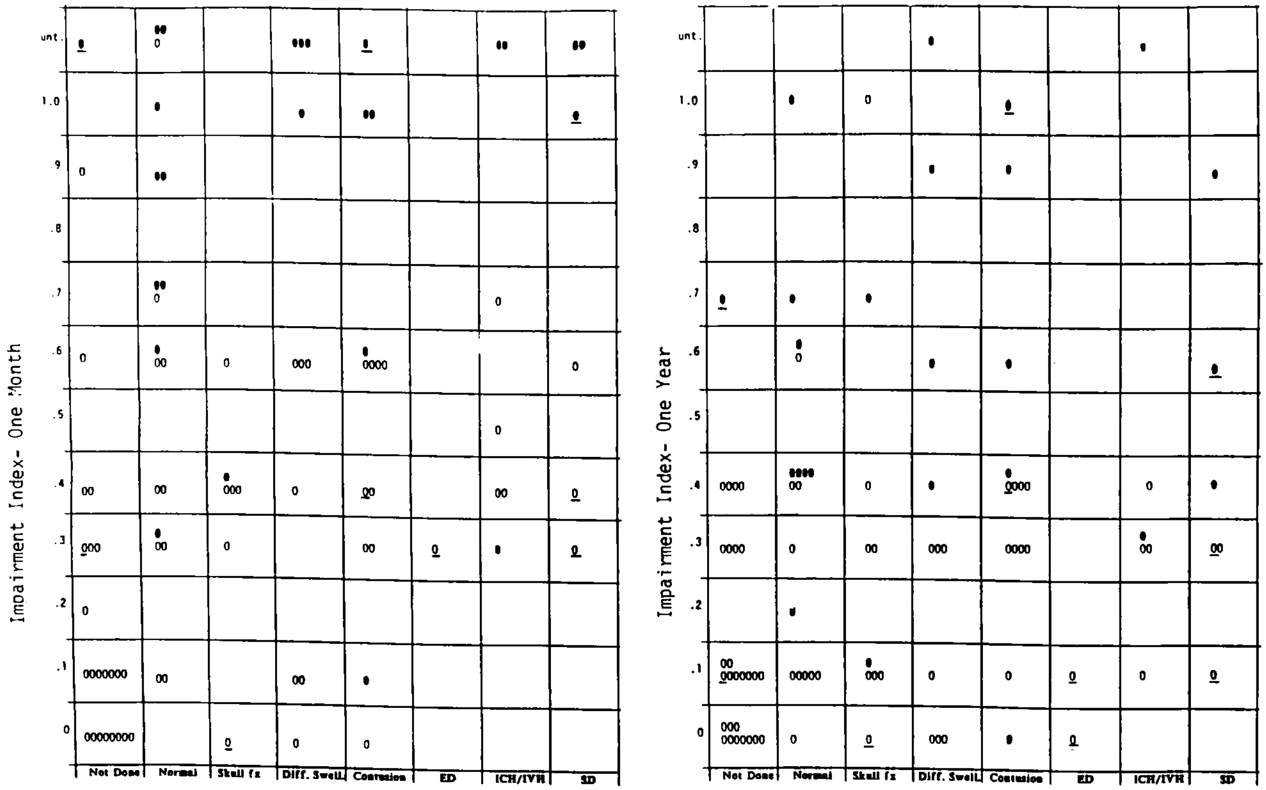

Figure 1. Impairment index by coma length and CT findings. O, coma ≤ 24 hr, no surgery; O̲, coma ≤ 24 hr, surgery; ●, coma > 24 hr, no surgery; ●̲, coma > 24 hr, surgery. Unequal numbers of subjects in a CT group from 1 mo to 1 yr reflect incomplete testing so that it was not possible to calculate an II. ED, epidural; ICH, intracerebral; IVH, intraventricular; SD, subdural.

bution to the prediction of outcome. Luerssen and colleagues[24] reasoned that the particularly poor outcome often associated with [subdural] hematomas may not be specifically caused by the presence of hematoma but rather because the hematoma often is an indicator of significant diffuse brain injury. The explanation provided by Luerssen et al. may account for the relatively stronger and more persistent relationship between outcome and length of coma compared with focal CT abnormalities found in this study.

Another important contribution of this study is that the relationship between head injury severity and outcome at two points in time postinjury was evaluated. Many previous studies, including the studies of Gennarelli et al.[7] and Williams et al.,[4] report data from a single follow-up. As a result, based upon the results of previous studies, it is difficult to determine how the relationship between severity and outcome varies over time in the same individuals. In this study, there is some evidence to suggest that the detrimental effects of mass lesions on neuropsychological functioning decrease over time, perhaps as lesions resolve.[10] Another factor that may contribute to the reduced effect of focal CT abnormalities at 1 yr involves the timing of the CT scans, which were conducted closer to the 1-mo testing.[12] The effect of coma length, however, remains strong over the course of the year postinjury. The persistent effect of coma length on neuropsychological functioning suggests that the extent of diffuse pathology related to head trauma may be a more important determinant of long-term outcome than the extent of secondary injuries (i.e., focal lesions).

In this study, no interaction was found between coma length and focal CT abnormalities on neuropsychological outcome. Based on the available literature in this area, it is not clear whether one would expect a more detrimental effect of focal CT abnormalities on the outcome of individuals with short *v* long coma. Because of the small sample size of this study, these results cannot be used reliably to evaluate a potential interaction between coma length and focal abnormalities evident on CT.

Previous studies have indicated that outcome varies as a function of type of lesion, with some lesions being associated with greater damage to the brain and thus greater cognitive impairments than others.[7, 21, 25] For example, several studies found higher mortality rates[24, 26] and poorer ratings of outcome[7] in head injury survivors with subdural hematomas as compared with those with epidural hematomas. Our focal CT abnormality group consisted of individuals with different types of lesions. Therefore, it may be argued that a potential relationship between focal CT abnormality and neuropsychological outcome may appear less robust, because a diverse group of lesions was considered together rather than if certain lesion types (e.g., subdural hematomas) had been considered independently. To assess whether outcome varied by focal CT abnormality, data from the current study were examined by lesion type.

The results depicted in Figure 1 do not suggest that the relationship between focal CT abnormalities and outcome is weakened by considering focal lesions as a single group. Despite the small number of subjects in each group, the data in Figure 1 illustrate a large overlap in the performance of individuals with different focal CT abnormalities 1 mo and 1 yr postinjury. These data do not provide evidence to suggest that outcome associated with any one abnormality is substantially worse than another. Consistent with the literature,[7] however, individuals with epidural hematomas seem to perform better than individuals with other focal lesions. However, because this study has only a few cases with each type of focal CT abnormality, these data cannot adequately address the relative effect of specific lesion type. The extent of variability in outcome across different categories of focal CT abnormalities is consistent with previous research.[26] Regardless of the type of focal CT abnormality, the effect of coma is strongly related to impairment index. This strong relationship between coma length and outcome for individuals with hematomas is consistent with the findings of Luerssen et al.[24] described earlier.

In conclusion, this study demonstrates that coma length and focal abnormalities visible on CT contribute independently to neuropsychological outcome soon after the injury. The effects of coma length are stronger than the effects of focal CT abnormalities and continue to exert a stronger influence on neuropsychological outcome over the year postinjury. We found no evidence of an interaction between the effects of coma length and CT findings. The primary contributions of this study were to evaluate the manner in which two different measures of head injury severity interact and relate to many facets of long-term neuropsychological outcome as well as to examine the nature of this relationship at two points in time over the course of the first year after the injury. Future research should be aimed at evaluating the interrelationship among various measures of severity in relation to neurobehavioral outcome for improved understanding of the pathophysiology of impairments and recovery from these impairments and for improved prediction of outcome.

REFERENCES

1. Dikmen S, Machamer J, Temkin N, McLean A: Neuropsychological recovery in patients with moderate to severe head injury: 2 year follow-up. *J Clin Exp Neuropsychol* 1990; 12(4):507–519.

2. Dikmen S, Reitan R, Temkin N: Neuropsychological recovery in head injury. *Arch Neurol* 1983;40:333–338.

3. Stuss D, Buckle L: Traumatic brain injury: Neuropsychological deficits and evaluation at different stages of recovery and in different pathologic subtypes. *J Head Trauma Rehabil* 1992;7(2): 40–49.

4. Williams JM, Gomes F, Drudge O, Kessler M: Predicting outcome from closed head injury by early assessment of trauma severity. *J Neurosurg* 1984;61:581–585.

5. Marshall L, Gautille T, Klauber M, Eisenberg H, Jane J, Luerssen T, Marmarou A, Foulkes M: The outcome of severe closed head injury, *J Neurosurg* 1991;75:S28–S36.

6. Vollmer D, Torner J, Jane J, Sadovnic B, Charlebois D, Eisenberg H, Foulkes M, Marmarou A, Marshall L: Age and outcome following traumatic coma: Why do older patients fare worse? *J Neurosurg* 1991;75:S37–S48.

7. Gennarelli T, Spielman G, Langfitt T, Gildenberg P, Harrington T, Jane J, Marshall L, Miller D, Pitts L: Influence of the type of intracranial lesion on outcome from severe head injury: A multicenter study using a new classification system. *J Neurosurg* 1982;56:26–32.

8. Dikmen S, McLean A, Temkin N, Wyler A: Neuropsychological outcome at one-month post injury. *Arch Phys Med Rehabil* 1986;67:507–513.

9. Katz D: Neuropathology and neurobehavioral recovery from closed head injury. *J Head Trauma Rehabil* 1992;7(2):1–15.

10. Levin H, Williams D, Eisenberg H, High W, Guinto F: Serial MRI and neurobehavioral findings after mild to moderate closed head injury. *J Neurol Neurosurg Psychiatry* 1992;55:255–262.

11. Alexandre A, Colombo F, Nertempi P, Benedetti A: Cognitive outcome and early indices of severity of head injury. *J Neurosurg* 1983;59:751–761.

12. Wilson J, Weidmann K, Hadley D, Condon B, Teasdale G, Brooks D: Early and late magnetic resonance imaging and neuropsychological outcome after head injury. *J Neurol Neurosurg Psychiatry* 1988;51:391–396.

13. Williams D, Levin H, Eisenberg H: Mild head injury classification. *Neurosurg* 1990;27(3):422–428.

14. Teasdale G, Jennett B: Assessment of coma and impaired consciousness: A practical scale. *Lancet* 1974;2:81–84.

15. Wechsler D: *Wechsler Adult Intelligence Scale*. New York, The Psychological Corporation, 1955.

16. Buschke H: Selective reminding for analysis of memory and learning. *J Verbal Learning and Verbal Behav* 1973;12:543–550.

17. Stroop J: Studies of interference in serial verbal reactions. *J Exp Psychol* 1935;18:643–662.

18. Reitan R, Wolfson D: *The Halstead-Reitan Neuropsychological Test Battery: Theory and clinical interpretation*. Tucson, Neuropsychology Press, 1985.

19. Bricolo A, Turazzi S, Feriotti G: Prolonged post-traumatic unconsciousness. *J Neurosurg* 1980;52:625–634.

20. Dikmen S, Temkin N, McLean A, Wyler A, Machamer J: Memory and head injury severity. *J Neurol Neurosurg Psychiatry* 1987;50:1613–1618.

21. Cooper PR (ed): *Head Injury*. Baltimore, Maryland, Williams & Wilkins, 1987.

22. Gennarelli T: Cerebral concussion and diffuse brain injuries, in Cooper R (ed): *Head injury*. Baltimore, Maryland, Williams & Wilkins, 1987, pp 100–120.

23. Levin L, Guilburd J, Lemberger A, Soustiel J, Feinsod M: Diffuse axonal injury: Analysis of 100 patients with radiological signs. *Neurosurg* 1990;27(3):429–432.

24. Luerssen T, Klauber M, Marshall L: Outcome from head injury related to patient's age: A longitudinal prospective study of adult and pediatric head injury. *J Neurosurg* 1988;68:408–416.

25. Eisenberg H: Outcome after head injury: General considerations and neurobehavioral recovery, in Becker D, Povlishock J (eds): *Cent Nervous System Trauma Status Report*. Bethesda, Maryland, National Institute of Neurological and Communicative Disorders and Stroke, 1985, pp 271–280.

26. Waxman K, Sundine M, Young R: Is early prediction of outcome in severe head injury possible? *Arch Surg* 1991;126: 1237–1242.