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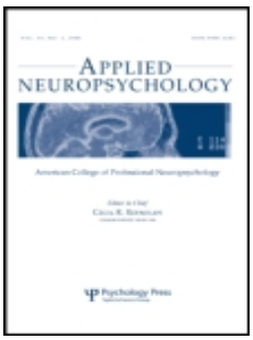

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Neuropsychological functioning following a spinal cord injury

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Key words spinal cord injury, cognition disorders, neuropsychological deficits, traumatic brain injury, head injury

Abstract Studies indicate that 10–60% of the spinal cord injury (SCI) population retains residual cognitive deficits following the injury However, previous studies have not used a comprehensive neuropsychological battery and/or a well-matched control group In addition, no study has determined if cognitive deficits continue more than one year after injury The present study addressed these limitations by comparing the performance of a chronic SCI group (Mean=17 years post-injury) and a well-matched control group in four cognitive areas Memory, visuospatial skills, attention/executive functioning, and processing speed were assessed Results from a discriminant function analysis indicated that information processing speed best differentiated between the SCI and control groups Twenty-nine percent of the SCI group performed 1 to 2 standard deviations below the control group mean These results could not be attributed to psychological status or history of alcohol consumption The findings emphasize the importance of neuropsychological evaluation after SCI

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ACCORDING to the National Spinal Cord Injury Statistical Center, 68% of spinal cord injury (SCI) result from a rapid acceleration-deceleration event, such as a motor vehicle accident or fall (Stover et al 1986) Often, in addition to a spinal cord injury, a concomitant head injury is sustained and may be overlooked in the acute care setting (Narayan et al 1990) or more chronically due to the focus upon problems directly associated with the SCI One study of SCI patients (Davidoff et al 1984) in acute care settings showed that loss of consciousness and post-traumatic amnesia frequently went unassessed In the emergency room, only 22% of SCI patients were assessed routinely for post traumatic amnesia, not to mention other cognitive deficits, when 91% actually incurred post traumatic amnesia of at least 24 h

Although cognitive deficits after mild head injury typically recover within the first year, subtle deficits may still be present even when the head injured group is compared to a well-matched trauma control group one year after injury (Dikmen et al 1995) No study has examined the incidence of cognitive deficits in SCI patients who are more than one year post-injury which is the purpose of the present study This is an important issue because the cognitive deficits seen after mild head injury (e g , attention, rapid processing speed, memory and learning, Gronwall 1987, Dikmen et al 1995, Levin et al 1987) are crucial in learning new self-care skills and in coping with the significant life-style and vocational changes which are often necessary immediately after SCI and for years to come

Vocational rehabilitation is likely to be particularly influenced by cognitive deficits associated with head injury (Dikmen et al 1994) For example, the speed of name writing which partially reflects processing speed, was the best predictor of vocational success in head injured patients Moreover, SCI patients with cognitive deficits have a greater frequency of impaired psychosocial adjustment and adaptation than SCI patients without cognitive deficits (Davidoff et al 1992) These findings underscore the necessity of comprehensively assessing the prevalence of continuing cognitive deficits in SCI patients beyond one year post injury The results from this study should also be helpful to the clinician in determining the areas of cognitive function that should be emphasized in the neuropsychological evaluation, and would have implications for the SCI patient and their families in terms of vocational rehabilitation, social adjustment, and long-term management of their health care

The incidence of cognitive deficits soon after SCI

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varies (Davidoff et al 1992), partially because of differences across studies in the demographic characteristics and coexisting conditions of individuals with SCI (e g , age, educational level, time since injury, alcohol history, previous head injuries, psychiatric history and concomitant emotional factors, Roth et al 1989, Frank et al 1985) Most studies also frequently rely upon published normative data rather than incorporating a control group which is matched on extraneous variables that could potentially confound the interpretation of the neuropsychological results In addition, different neuropsychological tests have been used to evaluate cognitive function and importantly, a comprehensive non-manual battery has not been developed (Richards et al 1988) The assessment of cognitive deficits in SCI needs to incorporate non-manual tests that are sensitive to the deficits most common after head injury (e g , attention, memory, executive functioning, processing speed, emotional status) An estimate of premorbid ability should also be included to obtain a more accurate clinical judgment of spared and impaired cognitive function

The main objectives of the present study were to determine if SCI patients, at least one year post injury, showed cognitive deficits on a non-manual neuropsychological battery when compared to a normal control group which was matched on critical demographic factors We were particularly interested in whether chronic SCI patients would show evidence of impairment in some, but not all, areas of cognitive function, perhaps because some cognitive deficits are more amenable to recovery and/or there is a propensity for head injury to have a greater affect on certain neural systems

Method

Subjects

Seventy-five patients with a spinal cord injury (SCI) and sixty-four healthy control subjects without a spinal cord injury volunteered for this study The SCI subjects were recruited from the Albuquerque Veterans Administration Medical Center (VAMC) and a private rehabilitation hospital Control subjects were friends or relatives of the SCI group or were recruited from the general medical clinic at the VAMC SCI patients were included only if they had incurred their injury through a traumatic event such as a motor vehicle accident or a fall, which could produce a concomitant head injury All subjects were excluded who had a history of central or peripheral neurological problems *prior* to the SCI Subjects were also excluded if they had been admitted to an inpatient alcohol treatment program or a psychiatric unit prior to the SCI A total of four subjects were dropped from the study due to incomplete data, fatigue, failure to return for completion of testing, or color blindness The SCI patients participated with the understanding that their results were available to aid medical management, and the control subjects were paid a nominal fee to cover travel expenses

All SCI subjects were at least one year post-injury with a mean of seventeen years post-injury (SD= 11 61, range=1 to 57 years) In the SCI sample, 87 7% were paraplegic and 12 3% were quadriplegic As can be seen in Table 1, the two groups were matched on age, gender, handedness, education, and estimated premorbid intellectual ability (reading recognition from the Wide Range Achievement Test, Jastak et al 1984, Vocabulary subtest of the Wechsler Adult Intelligence Scale-Revised, Wechsler, 1981) There also was no difference between the two groups in alcohol consumption (Short Michigan Alcohol Screening Test, Selzer et al 1975) Hence, history of alcohol consumption did not covary with group membership and could not explain the results

Procedures

Both groups were given a comprehensive neuropsychological battery which had no manual requirements If the patients were quadriplegic and could not press the key required for some tests, the examiner pushed the key based on the patient's verbal response The four areas of cognitive function that were evaluated included processing speed, memory, attention/executive functioning, and visuospatial skills

Processing speed was tested with the Symbol Digit Modalities Test (SDMT, Smith 1973) and the color nam-

TABLE 1 Characteristics of spinal cord injury and control subjects

Variables	SCI group (n=75)	Control group (n=64)
Age	45 8	47 6
	(12 7)	(15 1)
Gender (% male)	89 3	93 8
Handedness (% right)	92 0	91 5
Education	13 9	14 2
	(2 2)	(2 3)
WAIS-R vocabulary[2]	51 0	53 6
	(10 3)	(10 6)
WRAT-R reading[2]	71 7	74 0
	(11 8)	(12 8)
SMAST	2 9	2 8
	(3 3)	(4 2)

[1] Tabled values reflect means with standard deviations in parentheses, except where otherwise specified

[2] Vocabulary scale score equivalents are 10 and 11 for the SCI and control groups, respectively WRAT-R standard score equivalents are 108 and 110 for the SCI and control groups, respectively

ing measure of the Stroop Test (Stroop 1935) *Memory* was assessed using the immediate and delayed logical memory subtest of the Wechsler Memory Scale (Russell 1988), the fifth trial and long delay trial of the California Verbal Learning Test (Delis et al 1987), and the Warrington Recognition Memory Test (Warrington 1984) *Attention/Executive Functioning* was assessed using the WAIS-R Digit Span, the sum of four trials of the Paced Auditory Serial Addition Test (PASAT, Gronwall 1987), the Controlled Oral Word Association test (Benton et al 1983), the category measure of the Wisconsin Card Sort Test (Heaton 1981), the WAIS-R Similarities test and an interference measure from the Stroop Test which consisted of the color naming trial minus the color/word trial *Visuospatial skills* were tested using the Hooper Visual Organization Test (HVOT, Hooper 1983), the Judgment of Line Orientation, and the Facial Recognition Tests (Benton et al 1983) *Emotional status* was measured by the Minnesota Multiphasic Personality Inventory (MMPI) (Dahlstrom et al 1975) The order of the neuropsychological tests was counterbalanced across subjects

TABLE 2 Mean raw scores (standard deviations) on the neuropsychological tests

	SCI group (n=75)	Control group (n=64)
Processing speed		
SDMT*	44 4	53 2
	(11 1)	(12 4)
Stroop* (color naming)	61 6	69 5
	(15 2)	(14 6)
Memory		
Logical memory I	26 0	26 3
	(7 2)	(7 2)
Logical memory II	22 2	23 2
	(6 5)	(7 7)
CVLT trial 5	11 9	12 6
	(3 0)	(2 7)
CVLT long delay	10 4	10 6
	(3 2)	(3 7)
Warrington word	45 8	46 6
	(4 1)	(4 5)
Warrington face	39 8	40 1
	(5 2)	(5 9)
Executive function/attention		
WCST categories	3 8	4 3
	(2 2)	(2 2)
Verbal fluency (CFL)	41 0	43 2
	(14 1)	(13 1)
PASAT	105 4	117 9
	(40 9)	(39 1)
WAIS-R similarities	21 1	21 6
	(4 2)	(4 4)
Stroop*	27 8	32 8
(color naming minus interference)	(11 0)	(12 2)
WAIS-R digit span*	14 1	15 7
	(4 1)	(3 7)
Visuospatial skills		
Hooper	26 1	27 0
	(3 0)	(4 1)
Line orientation*	24 9	27 0
	(4 3)	(5 6)
Facial recognition	44 4	44 6
	(3 6)	(4 6)

*p<0 05 for univariate F tests between the SCI and the healthy control group

Overview of statistical analysis

Composite scores for each area of cognitive functioning were computed by converting the raw scores from the individual tests into z-scores, using the means and standard deviations of the control group The z-scores for each neuropsychological test in a particular domain were then summed and averaged to calculate a mean z-score for each composite The composite scores were used as the dependent measures in a discriminant function analysis to determine which cognitive function(s) best differentiated the SCI and the control groups A separate discriminant function analysis was performed on the MMPI scores to determine which measure(s) of psychopathology differentiated the groups The distinguishing MMPI scales that emerged from these analyses were then controlled in a hierarchical multiple regression analysis to determine if the group differences that were found in neuropsychological performance could be attributed to differences in psychological status

Results

Table 2 displays the mean raw scores for the two groups on each of the neuropsychological tests Table 3 and Fig 1 display the mean z-scores for the groups on each of the composite measures

To identify which composites *uniquely* differentiated the two groups, a stepwise discriminant function analysis was conducted using the Rao method The analysis showed that of the four areas of cognitive

TABLE 3 Mean (standard deviation) Z-scores on the neuropsychological composites

Composites	SCI group (n=75)	Control group (n=64)
Processing speed*	−0 63	0 00
	(0 90)	(0 83)
Memory	−0 12	0 00
	(0 71)	(0 68)
Attention/executive function	−0 27	0 00
	(0 70)	(0 58)
Visuospatial	−0 21	0 00
	(0 57)	(0 70)

* Significantly different (p<0 001) using stepwise discriminant function analysis

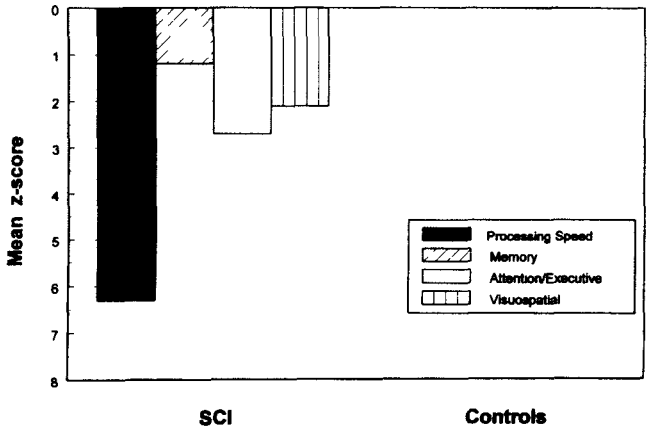

Fig 1 Mean Z-scores of neuropsychological composites for the SCI group The control group values are equal to 0 for all composites

function, only processing speed was uniquely impaired in the SCI relative to the control group (Rao's V=18 29, p<0 001) Memory, attention/executive function, and visuospatial skills did not significantly increase Rao's V Though processing speed was impaired in the SCI group relative to the control group, the group differences were small, accounting for only 11 8% of the variability Moreover, an examination of the raw scores on the SDMT and color naming of the Stroop Test (Table 2) which comprised this composite, shows that the SCI group's mean performance was less than 1 standard deviation below the control group's mean Thus, while processing speed was diminished in the SCI group, on the average it still was within the low normal range However, 29%, 9 3%, and 2 7% of the SCI group performed 1 to 2, 2 to 3, and 3 or more standard deviations below the control group mean respectively Therefore, 41% of the SCI patients demonstrated potentially significant processing speed deficits

One question that arises is whether the slower information processing speed in the SCI group could be attributed to group differences in psychological status (e g , depression, anxiety) which could influence cognitive functioning To address this issue, the two groups were compared on the 10 MMPI subscales An examination of the L,F, and K scales for each subject indicated that all MMPI profiles were valid Table 4 shows the means and standard deviations for each MMPI scale An inspection of the group means in this table suggests that the SCI group had elevated scores on several of the scales To determine which of these scales best differentiated between the two groups, a stepwise discriminant function analysis was conducted using the 10 MMPI subscales as the dependent measures This analysis revealed that scales 1, 8, and 7 each significantly increased Rao's V (Rao's V=38 61, p<0 001 for scale 1, Rao's V=5 70, p<0 05 for scale 8, Rao's V=7 30, p<0 01 for scale 7), indicating that the SCI group's scores were significantly elevated on all three scales Scale 1, which reflects somatic complaints, accounted for the largest portion of the variance Scale 8 which reflects psychotic symptoms, is often elevated with unusual symptoms such as those seen with SCI, and scale 7 which reflects anxiety, accounted for somewhat less unique variance

To test whether processing speed was still diminished in the SCI group after controlling for differences between the two groups in psychological status, scales 1, 8, and 7 of the MMPI were used as covariates in an analysis of covariance (ANCOVA) The ANCOVA showed that higher scores on these three MMPI scales were associated with poorer processing speed (F(3,134)=3 66, p<0 025) This finding, however, was due entirely to the relationship between Scale 1 and processing speed (F(1,134)=7 01, p<0 01) Most importantly, the ANCOVA showed that when the effects of the three MMPI scales were controlled, significant group differences still emerged in processing speed (F(3,134)=5 28, p<0 025)

Discussion

The present study demonstrated that processing speed deficits existed in an SCI group which was evaluated a mean of seventeen years post injury In

TABLE 4 Means (standard deviations) of T-scores on the MMPI

Scales	SCI group (n=75)	Control group (n=64)
MMPI 1*	73 15 (16 21)	57 83 (12 15)
MMPI 2	70 36 (16 19)	62 45 (11 91)
MMPI 3	67 47 (11 95)	58 22 (8 67)
MMPI 4	66 43 (10 03)	61 58 (11 92)
MMPI 5	58 40 (8 94)	59 62 (9 90)
MMPI 6	59 51 (8 47)	55 45 (9 97)
MMPI 7*	63 23 (13 85)	58 33 (11 08)
MMPI 8*	70 72 (14 74)	60 78 (12 21)
MMPI 9	59 93 (9 74)	57 36 (12 92)
MMPI 10	54 51 (11 73)	53 34 (11 73)

* Significant differences between the SCI and control groups in a stepwise discriminant function analysis

contrast, the SCI group demonstrated no significant deficits in memory, visuospatial and attention/executive functioning skills Though Table 2 suggests the deficits in processing speed in the SCI group were subtle, closer examination of the data suggests otherwise Specifically, twenty-nine percent of the SCI group performed one to two standard deviations below the control group mean in processing speed, 9 3% performed two to three standard deviations below, and 2 7% performed three or more standard deviations below the control group mean Thus, 41% of our chronic SCI sample showed processing speed deficits that were clinically significant This is likely to have an important impact upon vocational potential, especially as the life expectancy after SCI increases and there is an increasing need for vocational productivity and knowledge about cognitive deficits This issue is becoming increasingly important due to the increased life expectancy with SCI (Geisler et al 1983) In addition, the relevance of the cognitive impairments that were identified in our sample cannot be overstated when one considers that health care needs often increase due to problems secondary to SCI and, hence, present greater cognitive challenges to the SCI patient

Alcohol history and critical demographic factors were matched across the two groups and therefore could not explain the poorer performance in the SCI group The SCI group also demonstrated elevations on scales 1, 8, and 7 of the MMPI when compared to the control group, but the ANCOVA demonstrated that these differences could not account for the SCI group's deficits in processing speed The discriminant function analysis showed that processing speed was the only variable that significantly differentiated between the SCI and the control groups in a model that compared the groups on four cognitive abilities Previous research in the area of SCI and neuropsychological functioning has not attempted to determine if the deficits are unique to one area of cognitive functioning, which is important because there is considerable overlap in these neuropsychological functions For example, attention can influence all other functions and speed of processing influences several of the measures included in the attention/executive function composites (e g , verbal fluency, PASAT, Stroop) Our results show that when the intercorrelations among the different composites are controlled, processing speed is the only unique predictor of group differences Previous research has relied upon multiple individual comparisons which does not control for these intercorrelations

These findings are likely due to concomitant head injury, though medications frequently used in SCI patients (e g , for spasticity, pain) could impact This study did not obtain data to document the possibility of closed head injury (e g , duration of loss of consciousness, retrograde and anterograde amnesia) due to the long time period between injury and evaluation, but this information is difficult to obtain reliably, especially long after injury (Richards et al 1991) However, concomitant head injury is likely as post-traumatic amnesia greater than 24 h occurs in 91% of SCI patients (Davidoff et al 1984) In addition, although processing speed deficits are not specific to closed head injury, they are frequently reported (Gronwall 1987) Given the high incidence of post traumatic amnesia after SCI, it is likely that mild and moderate concomitant head injuries were incurred Moderate head injuries typically produce continuing cognitive deficits one year later (Dikmen et al 1995) However, if the injury is mild, deficits one year after injury are minimal (Dikmen et al 1995), and patients in the present study were evaluated a mean of 17 years post-injury Hence, the influence of head injury would be expected to be subtle, which is consistent with the small mean group differences in processing speed found in our study

A longitudinal prospective study is necessary at this point to definitely determine the relationship between concomitant head injury and SCI, but our results emphasize the importance of neuropsychological evaluation after spinal cord injury

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