

The Influence of Motivation on Neurocognitive Performance Long after Mild Traumatic Brain Injury

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Motivation and the presence of mild traumatic brain injury (MTBI) were crossed to determine whether individuals with MTBI could overcome attention deficits many years after injury. Contrary to prediction, university students with self-reported MTBI (average time since injury = 6.4 years) performed no differently from controls on a short but demanding set of neurocognitive tasks. As predicted, however, motivation differentially affected these groups by elevating controls' performance while leaving the MTBI group's performance unaffected. This finding was mainly due to individuals with more than one MTBI. These results suggest that university students who have sustained more than one MTBI may demonstrate subtle, long-term neurocognitive impairment. Additionally, motivation may be an important variable to consider in MTBI research. © 2000 Academic Press

Introduction

Although it is well known that mild traumatic brain injury (MTBI) produces neurocognitive impairment shortly after injury, there are inconsistent results regarding long-term sequelae (e.g., Dikmen et al., 1995, vs Klein, Houx, & Jolles, 1996). Previously, Bernstein and colleagues (Bernstein et al., 1999; Bernstein, Lawson, & Segalowitz, 1996) reported performance decrements associated with MTBI up to 8 years postinjury on attentionally demanding tasks when participants were subjected to long testing procedures (3 h). It is unclear whether these results were due to MTBI per se or rather to a reduction in motivation and/or attention in the MTBI group. Gronwall & Wrightson (1977) have suggested that the neurocognitive impairment associated with MTBI might be related to reduced attentional capacity. If this is true, then individuals with MTBI might be unable to overcome subtle deficits in information processing, even when motivated to do so. The present study addresses this hypothesis by simultaneously manipulating motivation and the presence of MTBI.

Method

Participants. Seventy-one introductory psychology students signed up for course credit for a study involving general health and attention. Participants were divided into two groups (MTBI and control), based on their responses to a general health questionnaire. MTBI was defined as any blow to the head forcing one to stop whatever one was doing due to dizziness, pain, disorientation, or unconsciousness.

Initially, there were 39 controls and 32 students with MTBI; however, during a postexperimental interview, eight controls recalled having had a MTBI. When analyzed, these participants did not differ from the original 32 participants with MTBI. They were, therefore, added to the MTBI group. After regrouping, 56% of the total sample reported MTBI. Forty students with MTBI (27 female) (mean age = 19.8, range = 17–42) were matched for age, sex, and cognitive and emotional complaint to 31 controls (18 female) (mean age = 20.0, range = 17–34). Eight of the 40 individuals with MTBI reported unconsciousness (6/8 people reported fewer than five minutes). Average length of time since injury was 6.4 years (range = 2 months to 37 years). Ten participants received medical attention for their injuries and two participants were hospitalized overnight. Eight participants reported more than one MTBI.

Materials and procedure. A double blind procedure was employed. Participants completed three questionnaires assessing general health, head injury, and a wide variety of cognitive, emotional, and physical complaints, and then returned later that week to do the behavioral measures. The questionnaires and behavioral tasks required 15 and 45 minutes to complete, respectively.

Both the control and MTBI groups were subdivided into two groups each: those receiving a psychological manipulation aimed at increasing motivation level (Motivated) and those receiving no such manipulation (Non-Motivated). Motivated participants were told that their performance was a decent indicator of how well they could expect to do in university.

Behavioral measures included the Digit Symbol from the WAIS-R, the 2- and 1.2-s trials of the Paced Auditory Serial Attention Task (PASAT), and three computerized auditory and visual discrimination tasks described below. The PASAT involves an auditory series of single digit numbers that must be consecutively added. All tasks but the PASAT were used previously by Bernstein and colleagues (Bernstein et al., 1999; Bernstein et al., 1996); however, target probability on the auditory and visual discrimination tasks was raised in the present study to increase task difficulty.

In the first computerized task (Duration), participants responded to a 150-ms 400 Hz target tone (40% probability) while ignoring a 100-ms 400 Hz nontarget tone. In the second task (Hard Distract), participants performed the Duration task simultaneously with a visual working memory task: single

digit numbers flashed every 2 to 2.25 s. Participants responded by pressing a button with their left hand whenever three odd numbers appeared consecutively (e.g., 3, 1, 9) or when three consecutive ascending or descending numbers appeared (e.g., 1, 2, 3 or 7, 6, 5) (30% probability). Meanwhile, participants responded with their right hand whenever a long target tone sounded. In the third task (Easy Distract), participants responded with one hand to the number counting task just described while responding with the other hand whenever a double tone was preceded by a single, high warning tone (50% probability). At the end of the study, participants rated their motivation level on a 1–10 scale.

Results

Questionnaires. The MTBI and control groups reported a similar incidence of cognitive and emotional complaints. Conversely, relative to controls, the MTBI group reported more diagnosed problems (e.g., reading disability, depression, migraines), $t(69) = 2.31, p < .05$. Moreover, the MTBI group tended to report more physical symptoms such as fatigue, sleep problems, and nausea over the past six months, $t(69) = 1.69, p < .1$. Finally, collapsing across head injury, there was a trend for the motivated group to report a higher motivation level than the nonmotivated group, $t(69) = 1.78, p < .1$.

Behavioral measures. There were no performance differences between the control and MTBI groups overall; however, interactions between head injury and motivation were observed on two of the five measures: 1.2-s PASAT, $F(1, 69) = 5.76, p < .05$ and Duration task accuracy, $F(1, 69) = 3.01, p < .1$. On the 1.2-s PASAT, motivation improved controls' accuracy, $t(28) = 2.36, p < .05$, but it had no effect on the MTBI group's accuracy, $t(38) < 1$ (see Table 5). On the Duration task, when motivated, controls improved while the MTBI group worsened. Neither difference within group was significant, however. Also on the Duration task, controls tended to exhibit a higher threshold to respond (Beta), $Z = 1.87, p < .1$, Mann–Whitney U corrected for ties. Further analyses were performed to determine the effects

TABLE 5
PASAT Accuracy (%) as a Function of MTBI
and Motivation

	Nonmotivated	Motivated
CONTROLS		
PASAT 2 s	.394	.530
PASAT 1.2 s	.307	.435
MTBI		
PASAT 2 s	.421	.427
PASAT 1.2 s	.321	.287

of number of MTBIs reported and loss of consciousness. Individuals who reported more than one MTBI performed worse on the 1.2-s PASAT than did either the controls, $t(36) = 1.83, p < .1$, or the individuals who reported only one MTBI, $t(28) = 2.29, p < .05$. In fact, when those participants with more than one MTBI are removed from the MTBI group, there is no longer a significant interaction between head injury and motivation on the 1.2-s PASAT, $F(1, 61) = 1.54, p > .1$). Unlike the number of MTBIs sustained, unconsciousness did not discriminate between or among the groups. A final set of analyses revealed that diagnosed problems, self-reported sleep complaints, and other physical problems accounted for no significant variance in the head injury by motivation interaction.

Discussion

More than one-half of the university undergraduates who signed up for what was described as a general health and attention study reported a MTBI (average time since injury = 6.4 years). Participants with MTBI performed no worse than matched controls on a set of highly demanding neurocognitive measures. However, when motivated to do their best, controls' performance improved on two out of five measures (PASAT and a tone discrimination task) while the MTBI group's performance was either unaffected or hindered. Simply telling participants that their performance indicated how well they could expect to do in university was sufficient to obtain these results. The difference in response to motivation was mainly due to those individuals who reported more than one MTBI. These individuals' PASAT performance was worse than that of either the controls or that of the MTBI group reporting only one MTBI.

These findings are inconsistent with previous work on high functioning university students with self-reported MTBI long after injury (Bernstein et al., 1999; Bernstein et al., 1996). Perhaps one reason for the difference in findings is the length of testing used. In the prior studies, participants underwent 3 h of testing. Therefore, fatigue may have influenced their performance. In the present study, participants completed all performance measures within 40 minutes. A second reason for the discrepant findings might be the number of MTBIs sustained. In the previous studies, 50 to 70% of the participants with MTBI reported more than one MTBI.

In the present study, only 20% of the MTBI group reported multiple MTBIs, and these individuals accounted for most of the variance. Thus, some of the disparity in findings may be due to fatigue and the number of MTBIs reported. Despite these differences, in the present study, motivation differentially affected controls and individuals with MTBI. As predicted, motivation boosted controls' performance without affecting the MTBI group's performance. This effect was largely due to those individuals who reported multiple MTBIs. It is unclear why this pattern of performance did not occur on

all of the tasks. Perhaps when task demands approach or exceed one's information processing capacity, a heightened motivation level is insufficient to raise one's performance. This speculation is supported in part by the subjective difficulty of the PASAT reported by many participants. Whatever the reason for these findings, our data suggest that motivation and multiple MTBIs may moderate performance on a demanding neurocognitive task like the PASAT many years after injury. Further work on the effects of motivation on performance may help clarify the path of recovery after MTBI.

REFERENCES

- Bernstein, D. M., Flynn, E., Wong, M., & Weinberg, H. 1999. *Residual neurocognitive impairment 8 years after mild head injury*. Paper presented at the 27th meeting of the International Neuropsychological Society, Boston, MA, February.
- Bernstein, D. M., Lawson, S., & Segalowitz, S. J. 1996. Subtle changes in cognitive performance following mild head injury. *Journal of the International Neuropsychological Society*, **2**, 18 (abstract).
- Dikmen, S. S., Machamer, J. E., Winn, H. R. et al. 1995. Neuropsychological outcome at 1-year post head injury. *Neuropsychology*, **9**, 80–90.
- Gronwall, D., & Wrightson, P. 1977. Cumulative effects of concussion. *Lancet*, **2**, 995–997.
- Klein, M., Houx, P. J., & Jolles, J. 1996. Long-term persisting cognitive sequelae of traumatic brain injury and the effect of age. *Journal of Nervous and Mental Disease*, **184**, 459–467.

Profound Amnesia Does Not Impair Performance on 36-Item Digit Memory Test: A Test of Malingered Memory

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Global amnesia spares immediate span of attention while compromising retrieval after a delay filled with distractions. Accordingly, we hypothesized that the Digit Memory Test (DMT) would classify persons with severe, disabling amnesia as “nonmalingerers” better than malingering tests utilizing interference or recall paradigms. Fourteen cases with profound amnesia, including 2 persons with global amnesia, obtained scores of 100% correct on the 36-item DMT. However, the Rey 15-item Test of malingering and a multiple choice delayed recognition memory test yielded false positive outcomes. We conclude that the DMT has excellent specificity with respect to correctly identifying persons with severe memory disorders due to neurological lesions by correctly classifying all as “nonmalingerers.” © 2000

Introduction

The 72-item Digit Memory Test (DMT) relies on immediate span of attention and a forced choice procedure to detect suspected malingering (Prigatano et al., 1997). A 36-item version has been shown to yield fewer false positives than the Rey 15-item Test (Guilmette et al., 1994). That is, patients with head injuries, probable dementia, anoxic encephalopathy, basilar artery aneurysms, alcoholism, aphasia, frontal and temporal lobe lesions obtained near perfect scores on the DMT (i.e., > 90% correct). Such patients have been selected on the basis of their unequivocal cerebral disorder/disease or because the anatomic brain lesion was localized.

Implicit in these studies of malingering is the assumption that brain damage resulted in serious memory impairment. However, the severity of these impairments has not been well established. For example, Prigatano and Amin (1993; cited by Prigatano et al., 1997) reported amnesia in 5 cases on the basis of higher Wechsler Full Scale IQ than General Memory Index (GMI), the latter measuring immediate recall. However, closer inspection of their delayed memory scores revealed levels of functioning at or above the 25th percentile (i.e., Average range). Whereas, the study by Guilmette et al. (1994) selectively reported low delayed memory scores only for verbal material in a sample of brain injured persons. Accordingly, one might argue that the specificity of DMT to brain injuries has been established, but its specificity to profound and pervasive amnesia, per se, remains unknown. The objective of the current study was to address this problem. We hypothesized that even patients with the most severe memory problems would perform well on the DMT, a test designed to identify feigned memory problems.

Methods

Participants. Fourteen English speaking persons with chronic amnesia (4 females and 10 males) were recruited from two Canadian and two British neuropsychological laboratories. They had volunteered in a prior study (McGlone et al., 1999). All had documented amnesia that was neurologically based, such as severe head injury (6), anoxia (1), encephalitis (2), cerebrovascular accidents (3), cyst (1), or status epilepticus (1). The participants' mean age was 41.4 years ($SD = 8.2$, range = 28–60), and their mean level of education was 12.6 years ($SD = 2.7$). Mean duration of the amnesic disorders was 7.3 years ($SD = 4.3$, range = 1–15). At the time of their initial neuropsychological assessment, there was a mean discrepancy of > 40 points between the Wechsler Full Scale IQ and GMI (McGlone et al., 1999). All of the individuals were right-handed, with one exception. The protocol was granted ethical approval, and each participant provided informed consent.

The participants were subdivided into 3 groups: (1) those with "global" amnesia, who were incapable of sustaining ongoing conscious memories

($n = 2$). Such patients did not recognize the examiner when reintroduced to her after a five-minute distraction; (2) those with “pure” amnesia who had severe, disabling memory impairments with an otherwise normal cognitive profile ($n = 8$); and (3) those with “amnesia-plus” syndromes, who showed evidence of severe memory loss along with cognitive decline on other neuropsychological measures ($n = 4$). At the time of testing, 2 participants were employed part-time, 5 individuals did volunteer work and received disability insurance, and the remaining 7 received disability insurance, except a homemaker with spousal income. Thus, the amnesic sample comprised persons whose lives were significantly disrupted by severe memory impairments. However, none of the participants had any known financial incentive to perform poorly (i.e., they were not in litigation at the time of testing).

Procedures. Each test session lasted approximately 2 h, with a 10-min break midway. Recognition memory testing (McGlone et al., 1999) was followed by the DMT, Rey 15-item Test and neuropsychological screening measures.

Tests of malingering. Participants were given a short form of the DMT, which consists of 3 sets of white cards (3 by 5 inches). Each set had 24 cards: 12 cards with a single 5-digit number were interleaved with 12 cards containing 2, vertically aligned, 5-digit numbers, 1 of which matched the 5-digit number on the preceding card. Participants were told that this was a memory test that required concentration and that some persons found it to be difficult. The target number was exposed for 3 s. In Set A, there was a 5-s delay with no distraction between presentation and forced choice selection. In Set B, the time interval was extended to 10 s. In Set C, the time interval was 15 s. Feedback was given after every response. At the end of Sets A, B, and C, participants were told routinely that they had done well.

The Rey 15-item Test has also been used to detect feigned or exaggerated memory impairments (Guilmette et al., 1994). Participants were given 10 s to memorize 15 different letters, numbers, or geometric shapes printed on a 3 by 5 matrix. Immediately following this, they had to reproduce as many items as possible. The total number of correct items recalled was calculated. Although recalling 15 items appears difficult, redundancy of the stimuli makes the task easy (e.g., A, B, C; a, b, c). Guilmette et al. (1994) suggested a cutoff score of 7 or below as being suggestive of factitious memory complaints.

Neuropsychological screening measures. The neuropsychological screening measures (see Spreen and Strauss, 1991) consisted of the following: (1) Digit Span Forward. The maximum number of digits that could be repeated in the correct order was recorded; (2) Paired-Associate Learning. The 10 Paired-Associates were from the Wechsler Memory Scale—Form I. In the acquisition phase, 6 easy and 4 hard pairs were presented with feedback over 3 trials, and each correct item was assigned a point (i.e., maximum score = 30). After 30 min, delayed recall of the 6 easy and 4 hard pairs was requested (i.e., maximum score = 10); (3) Rey–Osterrieth Figure. For the Copy com-

ponent, participants drew the figure within 5 min and the result was scored using a standardized 36-point system. After a 5-min delay interval, and without warning, the individual was required to draw the figure from memory (36 points maximum); (4) Pre-Morbid Estimate of Intelligence. This is a regression equation which used factors of age, sex, education, occupation, and region to estimate premorbid Full Scale IQ (FSIQ). The results are reported in standard scores with a mean of 100; (5) Wide Range Achievement Test—Revised (WRAT-R). The reading subtest is a single word articulation measure that yields standard scores with a mean of 100; and (6) Mini-Mental Status Exam (MMSE). Maximum score on the MMSE was 30.

Results

Tests of malingering. The participants made no errors whatsoever on the 36-item DMT, including the 2 persons with global amnesia. By contrast, the mean number of items recalled on the Rey 15-item Test was 10.9 for the entire group (*SD* = 3.2, range = 6–15). The mean score for the global amnesia group was 9.0 (*SD* = 4.3, scores = 6 and 12), for the pure amnesia group the score was 11.3 (*SD* = 3.2, range = 6–15), and for the amnesia-plus group the score was 11.3 (*SD* = 3.3, range 8–15). Two of the 14 persons (i.e., 14.3%) with neurologically based amnesic disorders fell below the cut-off score of 7 on the Rey 15-item Test, but all obtained scores of 100% correct on the 36-item short form of the DMT.

Neuropsychological screening measures. Table 6 contains the means and standard deviations for the neuropsychological screening measures. As expected, Digit Span Forward fell within normal range except for the amnesia-

TABLE 6
Neuropsychological Screening Measures

Test/Group <i>M(SD)</i>	Global amnesia <i>n</i> = 2	Pure amnesia <i>n</i> = 8	Amnesia-plus <i>n</i> = 4	Overall sample <i>N</i> = 14
(1) Digit Span	6.5 (0.7)	6.5 (1.1)	4.8 (1.0)	6.0 (1.2)
(2) Paired-associate				
Acquisition	9.5 (<i>n</i> = 1)	9.6 (4.0)	7.4 (1.6)	8.9 (3.4)**
Delay	2.0 (<i>n</i> = 1)	4.5 (1.4)	3.8 (1.7)	4.1 (1.6)**
(3) Rey-Osterrieth				
Copy	18.8 (18.7)	30.3 (4.7)	24.5 (2.4)	27.0 (7.7)
Delay	6.3 (3.1)	5.9 (5.4)	6.6 (3.6)	6.1 (4.5)*
(4) Pre-Morbid				
Estimate of FSIQ	110.1 (4.7)	107.2 (8.7)	100.5 (7.0)	105.7 (8.2)
(5) WRAT-R	105.5 (3.5)	102.1 (10.5)	79.5 (14.5)	96.1 (15.1)
(6) MMSE	27.5 (2.1)	27.4 (1.8)	24.3 (2.9)	26.5 (2.5)

* Two standard deviations below norms in Spreen and Strauss (1991) or <5th percentile.

** Three standard deviations below norms in Spreen and Strauss (1991) or <1st percentile.

plus group. By contrast, tests of learning and delayed memory (i.e., the Rey Figure and Paired Associates) fell 2 or more standard deviations below average according to norms published in Spreen and Strauss (1991).

Summary and Discussion

We have demonstrated that patients with severe, pervasive, disabling, and chronic amnesia due to brain lesions nevertheless obtained perfect scores on the 36-item DMT. For the first time, it was shown that two persons with global amnesia who forget everything after a distraction also performed perfectly on the DMT. Indeed, McGlone et al. (1999) demonstrated that these same persons consistently obtained chance or lower than chance scores on a 4-item multiple choice delayed recognition memory test (with a 7-min delay filled with distractions).

Consistent with Rogers (1997), we agree that tests of malingering should be specific rather than general, hence the need to validate tests of malingered memory impairment, rather than malingered "brain injury." Our data suggest that the DMT has better specificity for correctly classifying memory disordered individuals as "nonmalingerers" than the Rey 15-item Test or a simple forced choice recognition format (McGlone et al., 1999). We suggest that performance on the DMT was not compromised in organic amnesia because immediate span of attention was spared. In contrast, retrieval protocols like the Rey 15-item Test may produce false-positive outcomes.

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REFERENCES

- Guilmette, T. J., Hart, K. J., Giuliano, A. J., & Leininger, B. E. 1994. Detecting simulated memory impairment: Comparisons of the Rey fifteen-item test and the Hiscock forced-choice procedure. *The Clinical Neuropsychologist*, *8*(3), 283-294.
- McGlone, J., Black, S. E., Evans, J., Parkin, A., Sadler, M., Sita, A., Squires, E., Stuss, D., & Wilson, B. A. (1999). Criterion based validity of an intracarotid amobarbital recognition memory protocol. *Epilepsia*, *40*(4), 430-438.
- Prigatano, G. P., Samson, I., Lamb, D. G., & Bortz, J. J. 1997. Suspected malingering and the digit memory test: A replication and extension. *Archives of Clinical Neuropsychology*, *12*(7), 609-619.
- Rogers, R. (Ed.). 1997. *Clinical assessment of malingering and deception*. New York: Guilford Press.
- Spreen, O., & Strauss, E. 1991. *A compendium of neuropsychological tests. Administration, norms and commentary*. New York: Oxford University Press.

Performance of Children with Traumatic Brain Injury on a 4-Disk Version of the Tower of London and the Porteus Maze

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The aim of this study was to assess planning ability in children with traumatic brain injury (TBI) using a 4-disk Tower of London (TOL) and the Porteus Maze. Participants were 10, 6–10 years old, and 12, 11–16 years old, children with moderate to severe TBI and 15, 6–10 years old and 15, 11–16 years old controls. On both tests, children in the older age group performed significantly better than children in the younger age group. On the TOL, children with TBI performed significantly more poorly than the controls on the 5 complex problems but not on the 5 simple problems. There was no effect for TBI on Porteus Maze performance. Results confirm the adverse impact of TBI on planning ability in children but point to subtleties in assessing it. © 2000 Academic Press

Impairment of executive functions is a significant symptom following traumatic brain injury (TBI) in children, because the area responsible for executive functions, the frontal lobe, is a common site of TBI. Impairment of planning ability, a component of executive functioning, following TBI is of particular consequence because planning ability is required in a wide range of activities at home and in school. Little research, however, has been conducted to clarify the effects of TBI on planning in children.

Levin and his colleagues (e.g., Levin et al., 1993, 1994) used a 3-disk Tower of London (TOL) to study planning ability in children with TBI. The TOL is a nonroutine, look-ahead puzzle adapted from the artificial intelligence literature by Shallice (1982) to assess planning. The task requires arranging in a set number of moves three colored rings (red, green, and blue) on three rods of different heights to match a given arrangement of the rings. The TOL involves (a) formulating an overall schema, (b) identifying the subgoals required for the overall schema and organizing them into a sequence of moves, and (c) holding the subgoals and overall schema in spatial working memory. The version of TOL employed by Levin et al. had 12 problems and the required number of moves for solution ranged from two to five. Although they found that young children (6–10 years old) with TBI performed significantly more poorly than controls, this impairment was not consistent in older children and adolescents (11–16 years old) with TBI, a result they attributed to a ceiling effect on the TOL for the older age group.

The present study examined whether children with TBI are impaired in

their planning ability using a 4-disk version of the TOL to overcome any possible ceiling effect. The Porteus Maze, a maze-tracing task sensitive to frontal-lobe damage in adults (Lezak, 1995), was also employed. According to Porteus (1959, p. 7), this test measures the "process of choosing, trying, and rejecting or adopting alternative courses of conduct or thought."

Two groups of participants took part in the study, TBI and control. In the TBI group, 10 participants (6 males and 4 females) were 6–10 years old and 12 participants (9 males and 3 females) were 11–16 years old. In the control group, 15 participants (5 males and 10 females) were 6–10 years old and 15 (7 males and 8 females) were 11–16 years old. Participants from the TBI group were recruited from two metropolitan children's hospitals. The severity of the TBI participants were either moderate ($n = 5$) or severe ($n = 17$). At the time of the study, all were at least six months postinjury and were not suffering from any severe perceptual, linguistic, or motor impairment that could prevent them from undertaking the two tests. None of the TBI participants had any previous history of neurological or psychiatric disorder. The controls were recruited from the general community and none had a history of neurological or psychiatric disorder. All participants were paid \$5.00 for taking part in the study.

The version of the TOL used in the study has four wooden colored rings (blue, yellow, white, and black) and three wooden rods, one that can accommodate 2 rings, one 3, and one 4. The task of the participants was to rearrange the colored rings within a specified number of moves to match a particular configuration shown in a diagram. There were one 2-move, one 3-move, one 4-move, two 5-move, two 6-move, one 7-move, and two 9-move problems. The five problems requiring two to five moves were considered "simple" and the five problems requiring six to nine moves were considered "complex." Measures obtained were: (a) percentage of problems correctly solved within three attempts and (b) initial planning time for each problem (i.e., the time between the target position being shown and the first ring being picked up and released for the first attempt). Although initial planning time was recorded, the instructions of the test emphasized accuracy rather than speed of performance.

The Vineland Revision of the Porteus Maze requires participants to complete a series of 12 printed mazes of increasing level of difficulty within a specified number of trails. The test was not timed. The measure obtained was test age calculated by subtracting half a year for every unsuccessful trial within the specified number of trials from the ceiling score of 17.

Performances of participants on the TOL and the Porteus Maze are summarized in Table 7. An alpha level of .05 was used for all statistical analyses. A $2 \times 2 \times 2$ (age \times injury \times complexity) mixed ANOVA was conducted to analyze the percentage correct within three attempts for the TOL. The main effects of age, $F(1, 48) = 12.996$, $p < .05$, injury, $F(1, 48) = 12.264$, $p < .05$, and complexity, $F(1, 48) = 328.26$, $p < .05$, were all significant.

TABLE 7

Performance of Children with TBI and Controls on the 4-Disk Tower of London (TOL) and the Porteus Maze

Variable	6–10 years old				11–16 years old			
	TBI		Controls		TBI		Controls	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
% correct TOL (simple)	88.00	19.32	98.67	5.16	100.00	0.00	98.67	5.16
% correct TOL (complex)	26.00	18.97	44.00	20.28	43.33	16.70	61.33	22.00
Initial planning time TOL (s) (simple)	14.72	11.50	8.14	3.80	6.25	1.84	4.48	1.57
Initial planning time TOL (s) (complex)	12.61	11.45	9.72	4.23	9.33	3.87	6.12	2.66
Porteus Maze (test age)	12.45	2.53	12.70	2.04	14.54	1.57	14.33	1.57

The only interaction that was significant was that between injury and complexity, $F(1, 48) = 5.26, p < .05$. Simple main effects analyses were conducted to determine the source of this interaction. Results indicated that children with TBI performed significantly more poorly than the controls on the complex but not on the simple problems of the TOL. Planned comparisons between children with TBI and controls conducted separately for the two age groups also indicated significant differences for the complex but not the simple problems.

A $2 \times 2 \times 2$ (age \times injury \times complexity) mixed ANOVA was conducted to analyze initial planning time for the TOL. The main effects of age, $F(1, 48) = 11.429, p < .05$, and injury, $F(1, 48) = 6.609, p < .05$, were significant, but the main effect for complexity was not, $F(1, 48) = 2.105, p > .05$. None of the interactions was significant.

A 2×2 (age \times injury) ANOVA was conducted to analyze the test age for the Porteus Maze. The main effect of age was significant, $F(1, 48) = 10.078, p < .05$, but the main effect for injury was not, $F(1, 48) = 0.001, p > .05$. The interaction between age and injury was also not significant, $F(1, 48) = 0.153, p > .05$.

On the 4-disk TOL, children in the old age group performed significantly better than children in the young group. This suggests that the ability to plan, as measured by this test, develops with age. The significant two-way interaction between injury and complexity indicated that children with TBI performed significantly more poorly than the controls on the complex but not the simple problems. This result could be due to the different amount

of working memory required for problems in the simple and complex conditions. Children with TBI showed difficulties in solving complex rather than simple problems because in the complex problems more subgoals were involved and needed to be stored in working memory. Unlike the results reported by Levin et al. (1993, 1994), the impaired performance on the TOL was found for both the young and old TBI groups in the present study. These results suggest that the ceiling effect of the 3-disk TOL can be overcome by adding an extra colored ring and increasing correspondingly the length of the wooden rods. More importantly, results of this study showed that the ability to plan is affected by TBI in both young and old children.

Results for initial planning time on the TOL indicated that children in the young age group took significantly longer to plan than children in the old age group and that children with TBI were significantly slower than controls in planning to solve the puzzle. These results suggest that the time taken to plan shortens with age and that the longer planning time taken by children with TBI could be due to a general slowness in information processing after TBI. Overall, children in the old age group performed significantly better on the Porteus Maze than children in the young age group. This suggests that the ability to plan as measured by this test also develops with age. Children with TBI, however, were not found to perform significantly more poorly than the controls on the Porteus Maze. This result suggests that the ability to plan as measured by this test is not affected by TBI in children.

The difference in results between the Porteus Maze and the 4-disk TOL could again be due to the different amount of working memory required in the two tests. Another possible reason for the difference in results between the Porteus Maze and the 4-disk TOL is the different nature of the two tests. While the former uses a relatively familiar task (viz., maze tracing) to assess the planning ability, the latter employs an unfamiliar, nonroutine task to assess the same ability. Children with TBI might have more difficulty with tasks that they have not encountered before than tasks that they are familiar with. Further research is needed to test the validity of these two explanations.

REFERENCES

- Levin, H. S., Culhane, K., Mendelsohn, D., Lilly, M. A., Bruce, D., Fletcher, J. M., Chapman, S. B., Harward, H., & Eisenberg, H. M. 1993. Cognition in relation to magnetic resonance imaging in head-injured children and adolescents. *Archives of Neurology*, **50**, 897–905.
- Levin, H. S., Mendelsohn, D., Lilly, M. A., Fletcher, J. M., Culhane, K. A., Chapman, S. B., Harward, H., Kusnerik, L., Bruce, D., & Eisenberg, H. 1994. Tower of London performance in relation to magnetic resonance imaging following closed head injury in children. *Neuropsychology*, **8**, 171–179.
- Lezak, M. D. 1995. *Neuropsychological assessment*. New York: Oxford University Press.
- Porteus, S. D. 1965. *Porteus Maze Test: Fifty years' application*. New York: Psychological Corporation.
- Shallice, T. 1982. Specific impairments of planning. *Philosophical Transactions of the Royal Society of London*, **298**, 199–209.

Alterations of the Task-Set Reconfiguration Process in Closed Head Injury Adolescents

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The cost of shifting tasks across consecutive trials was examined as a function of the time interval between a task-cue and a subsequent target (cue-to-target interval, CTI). Task-shift costs are assumed to index a process by which subjects reconfigure their task-set when they must perform different tasks across consecutive trials. In neurologically intact teenagers, increased CTI causes reduced task-shift costs since subjects have more time to reconfigure their task-set prior to target onset. Some closed head injury adolescents however, show no reduction of task-shift costs with increased CTI. This indicates that subjects are incapable of reconfiguring their task-set from the cue alone, they also require the target before they are able to initiate this reconfiguration. © 2000 Academic Press

Introduction

Several of the behavioral problems observed in closed head injury (CHI) victims with frontal brain lesions (Levin et al., 1991; Van Zomeran & Brouwer, 1990) suggest an impairment of the Supervisory Attentional System (SAS; Norman & Shallice, 1986). The SAS is conceived as the general source of control for mental processes. Investigation of this system has often been said to be problematic because it is difficult to isolate its effects from the more elementary behaviors involved in task execution. Here, the SAS is investigated in neurologically intact and CHI adolescents in the context of a task-shift paradigm, where the cost of changing tasks across consecutive trials served as an index of its function.

On each trial, subjects were shown a task-cue indicating whether they should identify the shape of the subsequent target (circle or triangle) or provide its location (up or down). On half the trials, subjects performed the same task as in the previous trial, and a different task on the other half of trials. Variations in the cue-to-target temporal intervals (CTI) manipulated the time subjects had to appropriately configure their task-set prior to target onset.

Method

Subjects. Two CHI teenagers (P.O.B. and P.L.D.) participated in the experiment. Both CHI subjects were examined two month posttrauma. Respectively aged 12 and 14 years, each of these subjects was compared to its own age-matched neurological control group. Control group 1 comprised 10 subjects aged 11 or 12 years, whereas control group 2 was made of 11 subjects aged 13 or 14 years.

Stimuli. The fixation point was an asterisk (2×2 mm) appearing in the center of the screen. The target was either a circle or a triangle (2×2 cm), which was displayed either above or below (distance of 5 cm) the fixation point. The task-cues were: (1) a triangle drawn inside a circle (2×2 cm), indicating that the subject should report the shape of the target, or (2) a bidirectional vertical arrow, with one end pointing upward and the other downward, indicating that the subject should report the location of the target. All stimuli were shown in black over a white background. Subjects sat approximately 45 cm from the computer screen. The height of the screen was adjusted for each subject so that the fixation point was at eye level.

Procedure. Subjects were first administered two training blocks of 65 trials each. In each of these blocks, the task (identify the target shape—circle vs triangle—or localize the target—up vs down) to be performed on the target remained constant throughout. Then, five experimental blocks of 65 trials each were administered, with a 5-min pause between each block. In the experimental blocks, the task to be performed (shape or localization) varied randomly from trial to trial with the constraint that it remained the same as that on the previous trial on half the trials. Subjects were instructed to respond as rapidly and as accurately as possible. Responses were produced verbally (“circle,” “triangle,” “up,” or “down”) and were registered by means of a voice-key. In both the training and the experimental blocks, trials began by a 750-ms fixation point, followed then by the task-cue. Either 150, 450, 850, or 1550 ms later (cue-to-target interval, CTI), the target was displayed and remained visible until response production.

The factors examined were CTI (150, 450, 850, or 1550 ms) and whether the task to be performed on a particular trial was the same or different from that on the previous trial (task-shift factor: hold vs shift). Conditions were distributed randomly and in equal numbers of trials within each block. The first trial of each block was not included in the data analyses since the task-set factor was irrelevant for that particular trial. For the same reason, all trials on which an error occurred as well as all the trials that immediately followed were also rejected from the analysis.

Results

Correlations between RTs and error rates were nonsignificant and positive, thus showing no speed–accuracy trade-off. Correct response times (RTs) were analyzed with an ANOVA including the factors of task-shift (hold vs shift) and CTI (150, 450, 850, or 1550 ms).

In both control groups, the main effects of task-shift [group 1: $F(1, 9) = 17.9$; $p < .01$; group 2: $F(1, 10) = 59.3$; $p < .01$] and of CTI [group 1: $F(3, 27) = 75.4$; $p < .01$; group 2: $F(3, 30) = 89.3$; $p < .01$] were significant. These main effects indicate longer RTs in the shift than the hold condition and decreasing RTs with increased CTI. Both control groups also show a

significant task-shift \times CTI interaction [group 1: $F(3, 27) = 4.4$; $p < .05$; group 2: $F(3, 30) = 16.3$; $p < .01$]. This latter result indicates a progressive decrease of the task-shift cost with increasing CTI. In other words, both groups benefit from an increased CTI with respect to their task-shift costs.

Both patients showed significant main effects of task-shift [P.O.B.: $F(1, 283) = 9.8$; $p < .01$; P.L.D.: $F(1, 229) = 56.7$; $p < .01$] and of CTI [P.O.B.: $F(3, 283) = 21.8$; $p < .01$; P.L.D.: $F(3, 229) = 14.0$; $p < .01$] similar to those found in normal controls.

In striking contrast to normal controls however, P.O.B. and P.L.D. showed no task-shift \times CTI interaction [P.O.B.: $F(3, 283) < 1$; P.L.D.: $F(3, 229) < 1$]. This result indicates that the CHI subjects do not benefit from an increased CTI to reconfigure their task-set when tasks change across consecutive trials.

Importantly, the absence of the task-shift \times CTI interaction in P.O.B. and P.L.D. appears not to be a function of the magnitude of their task-shift costs. Indeed, P.O.B. showed task-shift costs that are within the range of those shown by his matched controls, none of them exceeding ± 1.2 standard deviations away from the normal mean. Notably however, P.L.D. exhibited abnormally large task-shift costs at all CTI's (z scores of 5.44, 6.05, 4.19, and 4.39 for CTI's of 150, 450, 850, and 1550 ms, respectively).

Discussion

The results of the control groups show reduced task-shift costs with an increased time interval between the onset of the task-cue and the subsequent target. This observation suggests that, when they must shift tasks across consecutive trials, neurologically intact subjects begin to reconfigure their task-set rapidly after the onset of the cue. This reconfiguration proceeds through time so that, with an increased interval between the task-cue and the target, the subject's task-set is brought closer to that required to appropriately process the target. These results and interpretations are in agreement with those previously reported by Meiran (1996).

On this basis, the lack of a task-shift \times CTI interaction in P.O.B. and P.L.D. observed here should be considered a crucial anomaly. Indeed, it means that subjects are entirely incapable of reconfiguring their task-set based on the presentation of the task-cue alone. Rather, they appear to remain passive with respect to their task-set until the target is presented. Only at that time do they seem to deploy any of the task-set reconfiguration activity that is required to properly process the target in the shift condition. As indicated above, this deficit is not dependent upon the occurrence of abnormally large task-shift costs. This means that the apparent inertia shown by P.O.B. and P.L.D. with respect to task-set reconfiguration does not imply that the reconfiguration process is affected in itself. Rather, it appears that the spontaneous initiation of task-set reconfiguration and the act of reconfiguration should be conceived as separate. Whereas P.L.D. appears to have both processes impaired, only the former is affected in P.O.B.

REFERENCES

- Levin, H. S., Eisenberg, H. M., Benton, A. L. 1991. In *Frontal lobe function and dysfunction* (Chap. 17, pp. 318–338). Oxford: Oxford University Press.
- Meiran, N. 1996. Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory and Cognition*, **22**(6), 1423–1442.
- Norman, D. A., & Shallice, T. 1986. Attention to action: Willed and automatic controlled of behavior. In R. J. Davidson, G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self regulation*, **4**, 1–18.
- Van Zomeran, A. H., & Brouwer, W. H. 1990. In Swets & Zeitlinger (Eds.), *Traumatic brain injury: Clinical, social and rehabilitation aspects*. Amsterdam.