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Assessment of Strategic Self-Regulation in Traumatic Brain Injury: Its Relationship to Injury Severity and Psychosocial Outcome

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Standard neuropsychological tests administered in a constrained and artificial laboratory environment are often insensitive to the real-life deficits faced by patients with traumatic brain injury (TBI). The Revised Strategy Application Test (R-SAT) creates an unstructured environment in the laboratory in which environmental cues and internal habits oppose the most efficient strategy, thus mimicking the real-life situations that are problematic for patients with TBI. In this study, R-SAT performance was related both to severity of TBI (i.e., depth of coma) sustained 2–3 years earlier and to quality of life outcome as assessed by the Sickness Impact Profile. This relationship held after accounting for variance attributable to TBI-related slowing and inattention. These findings support the validity of the R-SAT and suggest that behavioral correlates of quality of life outcome in TBI can be assessed in the laboratory with unstructured tasks.

In certain everyday situations, one's personal goals and expectations are consonant with the structured guidance provided by habits or the environment. Most people's morning routine, for example, is usually a highly structured and habitual sequence of events leading to a personal goal of going to work. In contrast, situations such as making a major purchase, disciplining children, or changing the direction of one's career are more ambiguous and unstructured. In these situations, environmental cues or internal habits cannot be relied on and may act in opposition to adaptive decision making; success depends on self-regulation of behavior according to internal goals, past experiences, and expectations for the future.

In spite of relatively preserved functioning in routine structured situations, many patients with brain injury are impaired in unstructured situations in which desired outcomes depend on self-regulation. Mirroring the behavioral distinctions, they often perform normally on standard neuropsychological tests, even those tests considered to be sensitive to frontal lobe dysfunction, most probably because these tests are highly structured and lack the essential elements of situations known to be associated with this syndrome.

This syndrome has been observed in patients with frontal lobe brain injury, perhaps best illustrated in case studies of dramatic personal and social upheaval (Eslinger & Damasio, 1985; Harlow, 1868). It can also be seen in association with traumatic brain injury (TBI), the effects of which are considered comparable with the effects of nontraumatic focal frontal brain injury (Alexander, 1982; Mattson & Levin, 1990; Stuss & Gow, 1992), with consequences for vocational, interpersonal, and leisure functioning (Dawson, Levine, Escobar, Schwartz, & Stuss, in press; Dikmen, Machamer, Savoie, & Temkin, 1996; Klonoff, Snow, & Costa, 1986).

Researchers have sought to assess this syndrome with novel tests that mimic the uncertainty inherent in unstructured real-life situations (Bechara, Damasio, Damasio, & Anderson, 1994; Goel, Grafman, Tajik, Gana, & Danto, 1997; Levine, Stuss, et al., 1998; Shallice & Burgess, 1991). In a study of 3 patients with traumatic brain injury, good neuropsychological test performance, and real-life dysfunction, Shallice and Burgess (1991) documented marked deficits on multiple subgoal tasks in which the patients had to

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determine the appropriate sequence of events, activate "markers" to treat a future activity as nonroutine, and respond appropriately to shifting and unpredictable circumstances. Goel and colleagues (Goel et al., 1997) found that patients with focal frontal lesions were disorganized in their overall problem-solving approach to an unstructured financial planning task (helping a fictional couple budget for long-term expenditures), even though, at the local level, the specific operations they used were comparable with the ones used by controls. On a gambling task studied by Bechara and colleagues (Bechara et al., 1994; Bechara, Damasio, Tranel, & Anderson, 1998), patients with ventral frontal lesions did not regulate their behavior in the face of competing response options, thus incurring high losses on the task.

In an earlier study, we assessed the presence of this behavioral syndrome across groups of patients with focal frontal lesions and TBI using a strategy application task (Levine, Stuss, et al., 1998). The task comprised simple paper-and-pencil items arbitrarily valued at 1 point or 15 points, with the 15-point items identified with a frame. Participants were told to get as many points as possible in 5 min and that they could not complete all the items within the 5-min time frame. Whereas healthy control participants selectively completed 15-point items to the exclusion of 1-point items, patients with frontal damage and with TBI tended to select items indiscriminately without respect to point value, in spite of preserved learning and retention of the task instructions.

In this study, we sought to extend the findings in TBI patients using the Revised Strategy Application Test (R-SAT). In the earlier study, patients with mild TBI were as likely to be impaired as those with moderate to severe TBI, suggesting limited specificity to the effects of significant TBI. We therefore attempted to increase the specificity of the task by more closely simulating real-life situations problematic for patients with TBI. This was accomplished by establishing a response pattern (completion of all items in a sequential manner) that was applicable as a strategy early in the test but became less applicable as the test progressed, forcing a shift in strategy (selective completion of certain items to the exclusion of other items) to maintain efficiency. In other words, efficient performance depended on inhibition of the response pattern reinforced at the beginning of the test.

Real-life functioning is the ultimate criterion against which the R-SAT must be validated. In this study, we concurrently administered the Sickness Impact Profile (SIP; Bergner, Bobbitt, Pollard, Martin, & Gilson, 1976), an established measure of health-related quality of life outcome in TBI (Dikmen, Ross, Machamer, & Temkin, 1995). We predicted that the validity of the R-SAT as a measure of deficits affecting real-life functioning would be supported by significant relationships with SIP scores.

Method

Participants

Participants were tested 3–4 years postinjury as part of a larger study on cognitive and behavioral outcomes from TBI. Initial participant contact took place in-hospital (at the time of injury) within a series of consecutive admissions to a major medical trauma center. After exclusions due to serious medical illness or death, psychiatric illness, substance abuse, refusals to participate, and loss of contact over the 3–4 years, 28 of the original sample of 94 were available for participation. These participants had also participated in our earlier TBI study at approximately 1.5 years postinjury (Levine, Stuss, et al., 1998). Injury and acute recovery characteristics, including Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) at 6-hr postinjury and the Injury Severity Score (ISS; Baker, O'Neill, Haddon, & Long, 1974) were documented in-hospital as part of separate research projects (M. L. Schwartz et al., 1998; Stuss et al., 1999; Stuss, Binns, et al., 2000).

Although the percentage of patients in comparison with the original sample is low (30%), we note that the original sample was unselected and drawn from consecutive hospital admissions; they were not recruited from chronic-phase treatment facilities. The participants in this study are demographically representative of the original sample, with no significant differences for age, sex, and years of education. Their dates of injury and ISSs were also not significantly different from the original sample. There was a significant difference in GCS: The present sample had more severe injury than the original sample, although the means for both fell in the moderate range (for the present sample: mean GCS = 10.45, SD = 4.15; for the other participants: M = 12.67, SD = 3.16), $t(93) = 2.84$, $p < .01$.

According to standard criteria (Teasdale & Jennett, 1974), 12 of the 28 participants in this study had mild TBI (GCS: 13–15), 6 had moderate TBI (GCS: 9–12), and 10 had severe TBI (GCS: 3–8). Because of the small n in the moderate group, these participants were combined with the severe TBI participants to form a moderate–severe group. Duration of loss of consciousness (LOC) and posttraumatic amnesia (PTA) in the moderate–severe group were assessed daily until discharge or recovery from PTA, whichever came first. Their LOC, defined as the number of hours during which GCS was 8 or less, ranged from 4 to 336 hr (Mdn = 72 hr). PTA, defined as number of days until Galveston Orientation and Amnesia Test (GOAT; Levin, O'Donnell, & Grossman, 1979) scores were 75 or greater for 2 consecutive days, ranged from 12–52 days (Mdn = 25 days). Mild TBI participants, by definition, had regained consciousness at 6 hr postinjury, and all but 1 of them attained scores of 75 or greater on the first GOAT administration.

Acute clinical computerized tomography (CT) scans were available for 27 of the 28 TBI participants. The scans were read by the attending neurosurgeon (Michael L. Schwartz) and classified according to a scheme modeled after Marshall et al. (1992). Focal parenchymal lesions (contusions, intracerebral hematomas, and multiple punctate hemorrhages) were identified on 13 of the 27 scans. Six participants had focal frontal lesions (1 bilateral, 2 left, and 3 right; 1 had an additional right temporal lesion), 5 had focal temporal lesions (1 left, 2 right, 2 bilateral; 1 had an additional right thalamic lesion and 1 had additional right basal ganglia and right occipital lesions), 1 had a focal right parietal lesion, and 1 had a right striatal lesion.

To control for potentially confounding effects of TBI patients' psychosocial cohort, we recruited age- and education-matched control participants from friends and family members of the TBI participants. As seen in Table 1, the three groups were well-matched, although there was a nonsignificant trend toward a larger proportion of women in the moderate–severe group.

Test Materials

The R-SAT comprised three paper-and-pencil activities, all of which were within the abilities of participants with intact basic visual, motor, and linguistic abilities: figure tracing, sentence

Table 1
Participant Characteristics

Characteristic	Mild	Moderate–Severe	Controls
Gender			
M	7	7	6
F	5	9	5
Age (years)			
M	32.3	31.0	31.5
SD	14.2	7.4	9.7
Education (years)			
M	13.3	12.8	15.0
SD	2.1	2.9	2.6
WAIS–R Vocabulary			
M	49.1	47.4	47.1
SD	13.3	8.6	11.0
GCS[a]			
M	14.58	7.3	
SD	0.07	2.6	
Time since injury[b]			
M	3.9	3.6	
SD	0.53	0.80	
ISS			
Mdn	17.0	32.0	
Minimum	14.0	10.0	
Maximum	29.0	50.0	

Note. M = male; F = female; WAIS–R = Wechsler Adult Intelligence Scale—Revised; GCS = Glasgow Coma Scale (Teasdale & Jennett, 1974); ISS = injury severity score (Baker, O'Neill, Haddon, & Long, 1974).
[a] At 6 hr postinjury. [b] Years from the date of injury to the date of testing.

copying, and object numbering (see Figure 1). Figure tracing was accomplished by drawing a line over all aspects of a printed figure. For sentence copying, printed sentences (drawn from newspapers or periodicals with a pre-high-school reading level) were copied on lines below the sentences. The object numbering items consisted of sets of printed objects of varying number. Objects within a set were numbered one-by-one by writing a number within each object.

Items were developed based on the time to completion per item, determined in pilot studies with healthy participants. Short items took 1–5 s to complete, medium items took 7–15 s, and long items took 20–30 s. Although the longer items were more time consuming, they did not demand more skill than the short items (e.g., copying a long sentence requires additional time, but not additional skill, over copying a short sentence). For each of the three activities, 225–285 items of different lengths were developed. These were printed on two stacks of ten 8½ × 14 in. pages (12 items scattered on each page), for a total of 60 pages (two stacks for each activity). Items were arranged such that the proportion of short items was high on the first pages of a stack and decreased progressively across subsequent pages within the stack, to the point where there were only one or two short items on the last page of the stack.

Across the three activities, there were 275 brief items available. Pilot work indicated that it would take a healthy young participant approximately 15 min to complete all the brief items without doing any of the lengthier items. With a 10-min time allotment for this task, therefore, there were always brief items available for participants to complete.

Participants also completed the SIP, a measure of the impact of TBI (or other illness) on quality of life across 12 categories. According to the standard technique for scoring this instrument (Bergner et al., 1976), items endorsed in each category were assigned a weighted value, summed, divided by the total possible score for that category, and multiplied by 100. The total SIP score, derived from all 12 categories, is considered a general measure of health-related quality of life. Summary scores for physical dysfunction and psychosocial dysfunction are also computed according to the standard scoring methods (Bergner et al., 1976).

Procedure

The six stacks of pages for the R-SAT were presented to the participant in two rows of three. After participants were oriented to the three activities, they were given the following instructions:

1) You will receive 100 points for each completed item.
2) You have 10 minutes to earn as many points as possible.
3) It is impossible to complete all the items in the six stacks in 10 minutes.
4) Do not work on stacks from the same activity one after another. [to ensure that all three activities are sampled]

Given the time constraints, the best strategy (not told to the participants) was to complete the short items to the exclusion of the lengthier items. On the first few pages of each stack, where nearly all items were brief, this strategy was consistent with both the structure of the task and a presumed internally driven habit to complete items sequentially on a page. As participants progressed through the pages of the task, however, these habitual and environmental factors opposed efficient performance as they would lead to completion of lengthy items.

The main dependent variable of interest was the number of brief items completed in 10 min. Because of variability in speed of information processing and motor execution, this variable is expressed as a proportion of the total number of items attempted (not including the first page of each stack, which contained only brief items). To ensure a minimum level exposure to lengthy items, we extended the 10-min time limit for slower participants until they reached the fourth page in one of the stacks.

Two other aspects of the task were designed to elicit errors in monitoring. For each activity, 55 items (7.3% of the total number of items) were enlarged to approximately 250% of the normal item size. One or two of these items were placed on 80% of the pages. Participants were instructed that no points would be awarded for completion of these items. Second, in each of the six stacks, the third, fourth, or fifth page had 10–12 simplistic hand-drawn faces scattered amongst the items. Participants were told that completion of an item on a page with faces (hereafter referred to as "face-page items") resulted in losing all points earned so far. Both the large items and the faces could be easily discriminated.

Several steps were taken to ensure that the task instructions were encoded and retained. First, they were limited to be within participants' mnemonic capacity. Prior to the start of the task, a selective reminding procedure was used to teach participants the instructions until they could be repeated from memory without error. A printed set of instructions was always available during the task. When the task was completed, the instructions were removed and participants were asked to freely recall the list of instructions. Instructions not freely recalled were prompted with a cue (e.g., "What did I say about the amount of time allowed?"). Participants were then asked to briefly describe their approach to the task.

Standard Neuropsychological Tests

The Trail Making Test, Parts A and B (Army Individual Test Battery, 1944), the Stroop interference procedure (Stroop, 1935), and the Digit Symbol subtest from the Wechsler Adult Intelligence Test—Revised (WAIS–R; Wechsler, 1985) were administered.

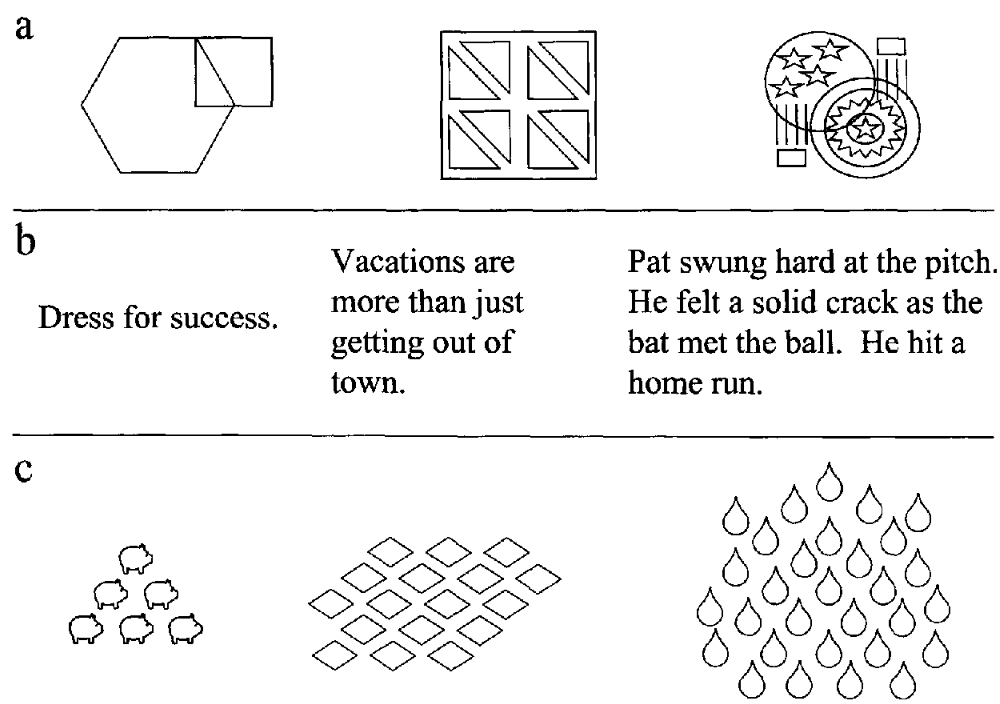

Figure 1. Sample items from the Revised Strategy Application Test (R-SAT). The tasks were to trace the figures (a), copy the sentences (b), and number the objects by writing numbers inside the objects (c). As the participant moved through the pages in the task, items increased in duration to completion but not in difficulty of completion. From "Ventral Frontal Contribution to Self-Regulation: Convergence of Episodic Memory and Inhibition," by B. Levine, M. Freedman, D. Dawson, S. E. Black, and D. T. Stuss, 1999, *Neurocase, 5,* p. 263. Copyright 1999 by Oxford University Press. Reprinted with permission.

These test data were unavailable for 2 of the TBI patients. Trail Making Test data were unavailable for 1 control participant.

Statistical Analyses

The effect of TBI severity on R-SAT performance (i.e., the proportion of items completed that were brief) was assessed with a one-way analysis of variance (ANOVA), with planned comparisons between the combined TBI groups and controls, each of the TBI groups and control participants, and the two TBI groups with each other. Nonparametric analyses (Fisher's exact test) were used to assess the frequency of lapses of intention (i.e., completing large items or items on pages with faces). Correlation and hierarchical regression were used to assess relationships between the R-SAT and SIP scores and to assess the amount of variance in the SIP uniquely attributable to the R-SAT.

Results

Injury Severity and R-SAT Performance

As seen in Figure 2, R-SAT performance was related to TBI severity. The reliability of this observation was confirmed by a significant effect of group, $F(2, 36) = 4.95$, $p < .05$. There was an overall effect of TBI, $t(37) = 2.04$, $p < .05$, but this was due to the moderate–severe group, which was significantly impaired relative to both the controls and the mild group, $t(25) = 2.69$, $p < .05$, and $t(26) = 2.11$, $p < .05$, respectively. The mild TBI and control groups did not significantly differ from each other, $t(21) = 0.84$.

Lapses of Intention

Completion of large or face-page items was infrequent, with median scores of zero for both types of items in all three groups. Contrary to expectation, control participants were more likely than patients to make at least one of these lapses. Ten of 11 control participants (91%) completed a large item or a face-page item, compared with 4 of 12 (67%) in the mild TBI group and 8 of 16 (50%) in the moderate–severe group, with the comparison between the controls and moderate–severe TBI participants statistically significant, $p = .042$ by Fisher's exact test (two-tailed).

Instruction Recall

Group differences in R-SAT performance could not be accounted for by failure to learn or to retain the instructions. Prior to the start of the task, all participants repeated the instructions without error. At the end of the task, all participants recalled all instructions either spontaneously (free recall) or with a cue. When asked to describe their strategy, 82% of the entire sample spontaneously mentioned the efficient strategy of focusing on brief items and 92% ac-

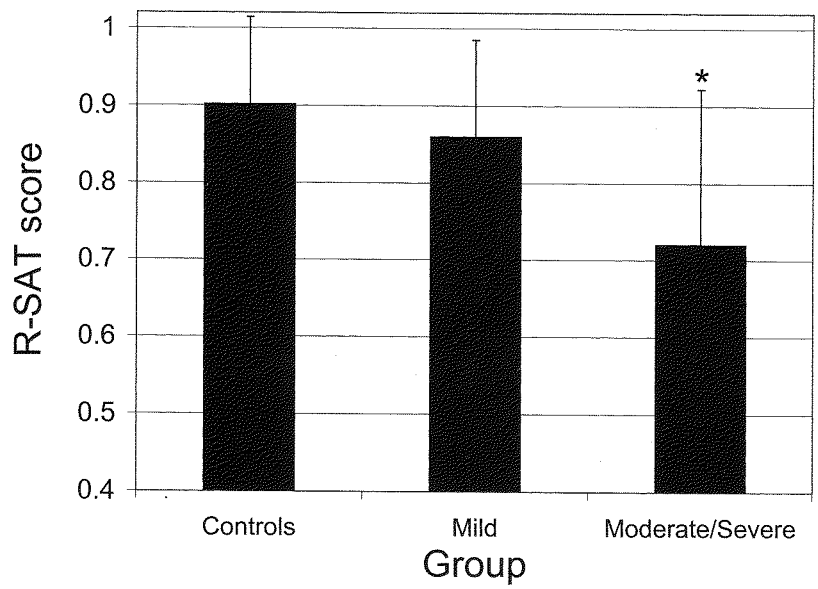

Figure 2. Revised Strategy Application Test (R-SAT) scores for traumatic brain injury and control groups. Error bars indicate standard deviations. Asterisk indicates significant difference from the other groups.

knowledged that this strategy could have been applied. Among the 10 participants with R-SAT scores in the lower quartile of the entire sample, 6 spontaneously mentioned the efficient strategy (which they did not apply). Of the remaining 4 participants, 2 acknowledged the strategy on direct query.

Relationship to Acute CT Findings

Neither the presence of a brain lesion on acute CT nor the location of lesion along the anterior–posterior axis was significantly related to R-SAT performance. There was evidence, however, for an effect of right-hemisphere lesions. The mean proportion of brief items for participants with right-hemisphere lesions was 0.69 (SD = 0.16), significantly lower than the control participants' mean of 0.90 (SD = 0.11), $t(16) = 3.31$, $p < .005$. Participants with no visible lesions (M = 0.81, SD = 0.20, n = 15) were not significantly different from controls. Participants with unilateral left-hemisphere and bilateral lesions had means of 0.86 (SD = 0.14) and 0.74 (SD = 0.15), respectively, but with an n of 3 in each group, there was not sufficient power to assess these lesion effects.

Psychosocial Outcome

R-SAT performance was significantly related to the SIP total score, $r(38) = -.40$, $p < .05$. As seen in Figure 3, this finding was accounted for by participants in the moderate–severe TBI group, $r(15) = -.50$, $p < .06$; correlations for the control and mild TBI groups were not significant.

To assess the unique variance in quality of life accounted for by the R-SAT relative to other neuropsychological tests, we conducted hierarchical regression analyses in which the standard neuropsychological tests, then the proportion of brief items, were regressed on the SIP total score. As seen in Table 2, the proportional score accounted for significant amounts of variance in the SIP total score over and above the Trail Making Part B, the Digit Symbol subtest, and the Stroop interference condition. Similar results obtained when all three of these tests were entered into the model first, followed by the proportional score, with adjusted R^2 increasing from .28 to .42, $t(31) = -2.98$, $p < .006$.

R-SAT performance was related to the SIP psychosocial summary score, $r(38) = -.34$, $p < .05$. There was also a significant relationship between the physical summary score and R-SAT performance, $r(38) = -.50$, $p < .002$. This pattern of relationships of these summary scores held when variance attributable to neuropsychological test performance was controlled (as in the above analyses with the SIP total score). For patients with significant physical consequences of severe TBI, physical and cognitive effects covary and are difficult to separate. For example, 6 patients in our sample had very high endorsement of physical symptoms on the SIP (i.e., physical summary scores ranging from 12.4 to 28.7 compared with scores below 7.0 for all other participants). With one exception, these patients had both very severe TBI (as indicated by GCS, very long PTA, or both) and impaired R-SAT performance.

Discussion

Many patients with brain injury are impaired in unstructured situations in which behavior would normally be determined by one's own personal goals and expectations. Although this syndrome is difficult to document in the laboratory, it can be revealed with tasks designed to mimic life's uncertainties (Bechara et al., 1994; Goel et al., 1997; Shallice & Burgess, 1991). In this study, deficits on a novel paper-and-pencil measure designed to assess self-regulation

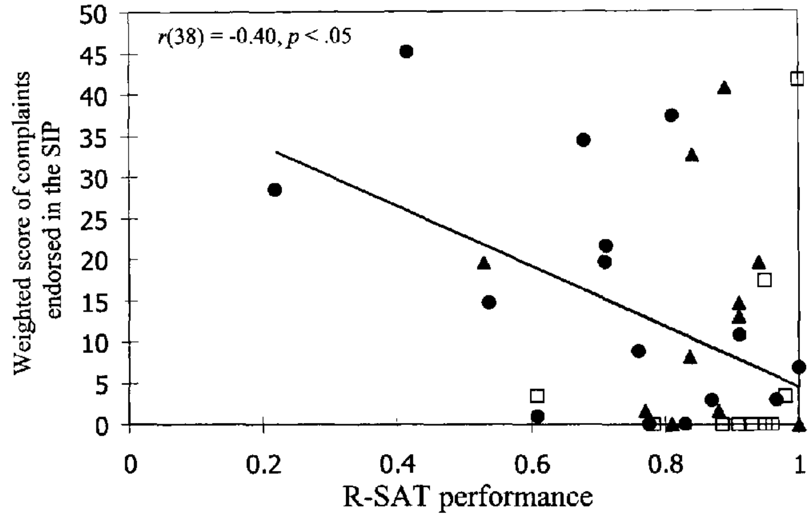

Figure 3. Relationship of Revised Strategy Application Test (R-SAT) performance to health-related quality of life as measured by the Sickness Impact Profile (SIP; Bergner et al., 1976). Closed circles = moderate–severe traumatic brain injury patients; closed triangles = mild traumatic brain injury patients; open squares = matched controls.

(R-SAT) were specific to patients with moderate to severe TBI. Additionally, R-SAT performance was significantly related to patients' real-life psychosocial outcome, suggesting a relationship between impaired self-regulation in the laboratory and handicapped life quality outcome.

Even though neuropsychological measures of global functioning and speeded information processing relate to injury severity indexes in patients with TBI (Dikmen, Machamer, Winn, & Temkin, 1995; Levin, 1992), similar dose-response relationships for measures of executive or supervisory processes have been elusive (Levin et al., 1990; Levine, Stuss, et al., 1998; Whyte, Polansky, Fleming, Coslett, & Cavallucci, 1995; for exceptions, see Levin, Mendelsohn, et al., 1994; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Accordingly, when the patients in this study were tested at 1.5 years postinjury, TBI severity effects were observed on measures of speeded information processing but not on standard executive tasks such as the Wisconsin Card Sorting Test (WCST; Levine, 1996).

The earlier version of the Strategy Application Test (Levine, Stuss, et al., 1998) demanded the formulation and application of a strategy to complete high-payoff items in

Table 2
Incremental Variance in Sickness Impact Profile Total Score Attributable to R-SAT Proportional Score Over and Above Standard Neuropsychological Tests

Variable	Adjusted R^2	t	p
Trail Making, Part B	0.29	3.94	.0005
R-SAT proportional score	0.42	−2.87	.008
Digit Symbol subtest	0.13	−2.50	.02
R-SAT proportional score	0.34	−3.48	.002
Stroop interference	0.14	2.62	.02
R-SAT proportional score	0.38	−3.84	.0006

Note. R-SAT = Revised Strategy Application Test.

the face of competing low-payoff items. In revising the test, we increased the environmentally driven opposition to efficient performance by fostering a response pattern (completing all items) that became progressively inappropriate as participants moved through the task. This feature made our task more similar to real-life situations in which self-regulation is required to overcome habitually or environmentally driven responses that are no longer adaptive. The effect of this manipulation was not to simply make the task harder (i.e., more sensitive), as there was now no difference between mild TBI participants and controls. Rather, the task is more specific in that only moderate to severe TBI patients were impaired.

The findings could not be accounted for by slowing, as the proportional score was corrected for overall number of items completed within the 10-min time frame. Indeed, slowing in more severely injured patients would work against our findings because slower participants encountered fewer lengthy items to select against than did faster participants. The findings could similarly not be accounted for by inability to encode or retain the instructions; all participants repeated the instructions without error prior to the start of the task, and posttask instruction recall was high even among participants who did poorly. Most of these same participants also mentioned the strategy of completing brief items in the posttest interview, even though they did not apply that strategy themselves, suggesting a dissociation between knowledge and behavior (Duncan, 1986; Kimberg & Farah, 1993).

Two proscriptions were included in the R-SAT that were expected to increase the sensitivity of the test to TBI: not to do large items or items on pages with faces. Contrary to our expectation and the results of previous research (Duncan, Johnson, Swales, & Freer, 1997), TBI patients were no more likely to lapse than their matched controls. The control participants were selected from age- and education-matched friends and family members of the TBI participants to control for socioeconomic cohort effects. To assess the possibility of increased lapses of intention in this control group, we compared them with a sample of 21 young university students administered the R-SAT for a separate study (Levine, 1999a). Whereas 91% of control participants committed one of the two lapses, only 38% of the students did so, $p = .008$ by Fisher's exact test (two-tailed).

Comparison of the proportional score and the lapses of intention suggests that these indexes may reflect dissociable processes. The TBI participants, perhaps sensitized to lapses of intention in their day-to-day life, avoided responses contravening the preannounced proscriptions. The socioeconomic-matched controls did not allocate sufficient attention to these task demands, perhaps due to poor motivation, yet they were superior to the TBI participants in strategically shifting their behavior in response to an unannounced change in reinforcement contingencies (i.e., the presence of lengthy items). This latter process, reflected by the R-SAT proportional score, appears to be more specifically affected by TBI.

Concurrent Validity of the R-SAT

The R-SAT was significantly related to quality of life as measured by the SIP; patients with low proportional scores endorsed SIP items reflecting impaired functioning in social and occupational situations. This relationship held after performance on other tests sensitive to TBI-related slowing and inattention was taken into consideration. It would be useful to know how the R-SAT's relationship to psychosocial outcome compares with nonspeeded tests of executive functioning. Although such tests were not administered in this session, we did administer the WCST (Grant & Berg, 1948) well into the chronic phase of recovery at 1.5 years postinjury (Levine, 1996; Levine, Stuss, et al., 1998). In exploratory post hoc analyses, WCST indexes did not account for significant amounts of variance in the SIP total score. Therefore, the R-SAT's relationship to life quality outcome is unique in comparison with other measures sensitive to nonspecific TBI-related slowing and attentional deficits as well as to the WCST administered 1.5 years earlier (see below for an analysis of the WCST's specificity).

Further validation of the R-SAT, and more generally the relationship of laboratory-assessed self-regulation to real-life functioning, requires concurrent administration of established measures of self-regulation (as in Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Robertson et al., 1997). The SIP, although containing items pertaining to the social and occupational consequences of impaired self-regulation, also includes assessment of physical complaints that were related to R-SAT performance. All but one of our patients with numerous physical complaints had very severe TBI. It is therefore impossible to disambiguate brain injury from physical injury to other body systems in our sample. In numerous other TBI patient samples, mental and psychological effects are considered more disabling than physical effects (Brooks, Campsie, Symington, Beattie, & McKinlay, 1986; Dikmen, Ross, et al., 1995; Jennett, Snoek, Bond, & Brooks, 1981). It is likely that the correlations between R-SAT performance and the physical complaints are due to the coincidence of physical injury with brain injury and do not reflect a causal association between physical injury and mental and behavioral effects.

Significant others' ratings provide an important adjunct to self-ratings, which can be compromised because of low insight (Jennett et al., 1981; Prigatano, 1991). As TBI patients rate physical symptoms more objectively than psychosocial symptoms (Prigatano, 1996; Sherer, Oden, Bergloff, Levin, & High, 1998), informants' ratings may be necessary to show a dissociation of higher correlations with psychosocial than with physical symptoms. In any case, underreporting of psychosocial deficits on the SIP most likely acted against our significant findings by reducing these ratings in patients with real-life deficits and low R-SAT scores.

The Effects of Focal and Diffuse Brain Injury on Self-Regulation

In both this study and a prior study (Levine, Stuss, et al., 1998), patients with right-hemisphere lesions were most impaired. Although we were not able to compare the effects of right- versus left-hemisphere lesions, right-lateralized effects have been reported for similar tasks (see M. F. Schwartz et al., 1998, 1999). Right-hemisphere damage affects sustained arousal, alertness, and monitoring (Posner & Petersen, 1990; Rueckert & Grafman, 1996; Stuss et al., 1994). TBI-related diffuse injury to ascending arousal systems has similar effects (Stuss et al., 1989). Such impairment in top-down control should affect performance on many neuropsychological tests, especially when testing occurs early in the recovery process (as in M. F. Schwartz et al., 1998).

The source of lesion information for this research has been acute CT. As acute CT underestimates cerebral pathology in TBI (Gentry, Godersky, Thompson, & Dunn, 1988; Jenkins, Teasdale, Hadley, Macpherson, & Rowan, 1986; Levin et al., 1993), other regions of cerebral damage cannot be ruled out. In a study of multitasking in a mixed-etiology sample of acutely hospitalized patients, Burgess and colleagues (Burgess, Veitch, de Lacy Costello, & Shallice, 2000) found that learning and memory of the task parameters were related to left anterior and posterior cingulate damage, planning was related to right dorsolateral prefrontal damage, and "intentionality" (i.e., following one's plan and task rules) was related to left prefrontal damage (mainly Brodmann Area 10). In comparing these results with the present findings, it is noted that the paradigm of Burgess and colleagues (Burgess et al., 2000) places a greater emphasis on learning, remembering, and following rules. We minimized the mnemonic contribution by reducing the number of instructions and ensuring their error-free recall prior to the start of the task. Our critical findings related to the proportional score, a measure of participants' strategic shift in response to an unannounced change in item properties. In the Six Element Test and its variants (Burgess et al., 1996; Burgess et al., 2000; Shallice & Burgess, 1991), shifts in item value, if included in the task, are announced to participants at the outset.

Taking this aspect of the R-SAT into consideration, we suggest that the ventral prefrontal cortex be included among the candidate critical areas for real-life tasks and laboratory analogues requiring self-regulation (Levine, 1999b). This region, which is particularly vulnerable to TBI (Courville, 1937; Gentry, Godersky, & Thompson, 1988), is involved in the inhibitory control of stimulus–reward associations (Dias, Robbins, & Roberts, 1996a; Mishkin, 1964; Rolls, 1996), which, in turn, has been related to psychosocial outcome in patients with ventral frontal lesions (Rolls, Hornak, Wade, & McGrath, 1994). TBI-related changes in this region can be quantified volumetrically on MRI even in the absence of focal lesions (Berryhill et al., 1995). This damage may contribute to TBI patients' impaired self-regulation on the R-SAT, just as it does on the Gambling Test (Bechara et al., 1998) and in patients with focal ventral frontal pathology due to strokes, tumors, or other nontraumatic etiologies (Alexander & Freedman, 1984; Eslinger & Damasio, 1985; Miller, Chang, Mena, Boone, & Lesser, 1993). Verification of this hypothesis would require high-resolution MRI concurrent with administration the R-SAT or other novel measures sensitive to impaired self-regulation; such studies are ongoing in our laboratory. Preliminary support for this hypothesis is garnered from TBI patient M.L., who had a severe TBI with right ventrolateral frontal damage and severe impairment on measures of psychosocial outcome as well as on both versions of the SAT and the Gambling Test (Levine, Black, et al., 1998; Levine, Freedman, Dawson, Black, & Stuss, 1999).[1] He was additionally impaired on object alternation, a measure of inhibition with documented sensitivity to ventral frontal dysfunction (particularly Area 47) in monkeys (Mishkin, 1964) and humans (Freedman, Black, Ebert, & Binns, 1998). M.L. performed normally on measures sensitive to dorsolateral prefrontal cortical function (for similar findings in patients with TBI, see Gansler, Covall, McGrath, & Oscar-Berman, 1996; but see also Levin, Culhane, et al., 1994).

Our findings suggest that the assessment of patients with TBI and other patients with ventral frontal pathology should include unstructured measures of self-regulation with features that act in opposition to efficient performance, such as tasks involving reversal of previous stimulus–reward associations. Such measures are not present in most neuropsychological test batteries. In particular, the WCST (Milner, 1963), although it is relatively unstructured, assesses shifting across perceptual dimensions (e.g., from color to form) rather than reversal of prior stimulus–reward associations (Dias, Robbins, & Roberts, 1996b; Mishkin, 1964). The former is considered attentional and is sensitive to dorsolateral frontal lesions in the monkey, whereas the latter is considered affective and is sensitive to ventral frontal lesions in the monkey (Dias et al., 1996a). Accordingly, patients with ventral frontal lesions are preserved on the WCST relative to patients with dorsolateral frontal lesions (Stuss, Levine, et al., 2000). We have noted a similar pattern on other executive tests considered sensitive to frontal damage (Levine, Stuss, & Milberg, 1997; Stuss et al., 1998).

Conclusions

Assessment of real-life impaired self-regulation in patients with TBI can be accomplished by creating a situation in the laboratory in which habit or environmental cues oppose the most efficient response. The R-SAT creates such a situation by establishing a response pattern that becomes less adaptive as one progresses through the task. Performance on the R-SAT was sensitive to TBI severity. It was also related to real-life functioning as documented on a measure of psychosocial outcome even after TBI-related slowing and inattention on standardized tests was taken into consideration. TBI is heterogeneous, with multiple neuropathologies and behavioral effects. Ventral frontal, diffuse, and right-hemisphere damage should all be taken into consideration when interpreting TBI-related executive control deficits.

[1] M.L.'s data were included in the sample of TBI patients reported in this study.

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