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The effects of focal and diffuse brain damage on strategy application: Evidence from focal lesions, traumatic brain injury and normal aging

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Abstract

A new test of strategy application was designed to be relatively free of the constraints that limit the standard neuropsychological assessment of supervisory abilities. The validity of the test was assessed in 3 samples of participants with varying degrees of supervisory deficits and frontal systems dysfunction: focal frontal lesions, traumatic brain injury (TBI), and normal aging. Inefficient strategy application varied systematically across the 3 groups and was not due to extraneous factors such as forgetting the test instructions. Previous case studies have emphasized strategy application deficits in the face of normal neuropsychological test performance. In this study, it was shown that strategically impaired participants from a consecutive series can include those both with and without deficient neuropsychological test performance. When neuropsychological impairment was present, it was greatest on executive functioning tasks. Among participants with nonstrategic performance, there was evidence for a dissociation of knowledge from action. This finding was not specific to focal frontal lesions. A number of supervisory processes contributing to strategy application were identified. Exploratory analyses indicated differential effects of lesion location on these processes, especially inferior medial frontal and right hemisphere lesions. Overall, the results supported the use of unstructured tasks in the assessment of supervisory abilities. (*JINS*, 1998, *4*, 247–264.)

Keywords: Executive functioning, Strategy application, Frontal lobe, Traumatic brain injury, Aging

INTRODUCTION

According to Norman and Shallice's (1986) theory, unstructured, nonroutine situations call upon different cognitive processes than structured, routine situations. In structured situations, behavioral schemas are automatically triggered by environmental cues; a "contention scheduler" selects the schema that is most strongly activated. In unstructured situations, environmental cues are not sufficient; contention scheduling needs to be strategically modulated by a supervisory system according to internally represented goals and intentions. This supervisory control supports planning, error correction, and inhibition of strong habitual responses. Without supervisory control, inappropriately triggered schemas produce perseverative or distractible behavior.

Deficits in day-to-day functioning following brain disease have been attributed to lack of supervisory control (Shallice & Burgess, 1993). These deficits may not be observed on standard neuropsychological tests, which are rich in environmental cues and examiner-provided structure. Therefore, many individuals with brain damage earn normal test scores in spite of supervisory deficits that affect everyday functioning (Eslinger & Damasio, 1985; Mesulam, 1986; Stuss & Benson, 1986).

Testing for Supervisory Deficits

Shallice and Burgess (1991a) addressed this problem by designing unstructured but quantifiable multiple subgoal tasks

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to assess supervisory skills. The tasks, which were administered to 3 people with frontal lesions, required running errands in a shopping district and completing open-ended desktop activities. The individual components of the tasks were within the abilities of the participants, but the coordination and efficient execution of these components required the formulation, application, and monitoring of strategies for maximizing efficiency. In other words, the tasks drew upon strategy application skills that are needed in many real-life situations. In spite of normal performance on neuropsychological tests, including standardized tests of executive functioning, the participants had marked strategic problems on the multiple subgoal tasks compared to neurologically normal controls.

In this study, we administered an adaptation of one of Shallice and Burgess's (1991a) tasks to neurologically normal participants and participants with brain disease of different etiologies. Briefly, this strategy application task consisted of pictures to name, arithmetic problems to solve, and designs to copy. All of the items were within the abilities of participants with intact basic linguistic, perceptual, and motor skills, but there were more items than could be completed in the 5-minute time allotment. Half of the items were randomly selected to be 15-point items and were clearly designated with a dotted line frame (see Figure 1); the remaining items were worth 1 point each. Participants learned the instructions and were given the goal of maximizing points, but were not told how to achieve this goal. To achieve it, they had to formulate and apply a strategy of selective completion of framed items. At the same time, they had to inhibit a habitual response to complete the other (unframed) items that were equal in simplicity to and spatially interspersed among the framed items.

Our goals were to establish the task's validity as a measure of strategy application and to examine the effects of cerebral dysfunction on performance. Three methods were used to assess validity: (1) administration of the test to groups of participants with different types of frontal systems dysfunction (i.e., neuroanatomical or neurophysiological changes in the frontal cortex or its supporting structures), (2) evaluation of the contribution of processes secondary to strategy application, and (3) correlation of performance on the test with performance on a concurrently administered battery of neuropsychological tests.

The Effects of Frontal Systems Dysfunction on Strategy Application: Frontal Lesions, Traumatic Brain Injury, and Normal Aging

The three groups of participants included those with focal frontal lesions, traumatic brain injury (TBI), and neurologically normal elderly. Based on prior research, we expected strategy application deficits to be related to the relative degree of frontal systems dysfunction in each group.

Historically, focal frontal lesions have had a definitive role in neuropsychological research on strategic disorders. This role is supported by case studies in which frontal disease is accompanied by dramatic disruption in everyday strategic behavior (e.g., Harlow, 1848; Luria, 1981; Penfield & Evans, 1935) and controlled group studies on the syndrome of deficits following frontal lesions (see Stuss et al., 1994b; Tranel et al., 1994 for reviews). There is reason, however, to question the specificity of this behavioral–anatomical correlation. Studies comparing individuals with frontal and nonfrontal lesions on a test specifically designed to measure supervisory processes, the Tower of London (TOL; Shallice, 1982) have yielded inconsistent results (Glosser & Goodglass, 1990; Karnath et al., 1991; Owen et al., 1990; Shallice & Burgess, 1991b). Accordingly, functional neuroimaging suggests a distributed system mediating TOL performance that involves the frontal lobes as well as other cortical and subcortical regions (Baker et al., 1996). This research leads to the prediction that the degree of deficit on our strategy application task should be highest in the group of participants with focal frontal lesions, but that this deficit may not be specific to frontal lesions. To assess the specificity of deficits to focal frontal pathology, we compared the performance of participants with focal frontal lesions to that of participants with focal posterior lesions. Furthermore, based on the heterogeneity of frontal structure and function (Stuss et al., 1995), lesion analyses should reveal differential involvement of specific frontal regions.

TBI causes both focal and diffuse cerebral dysfunction affecting the frontal cortex and frontal–subcortical pathways (Adams et al., 1977, 1982; Courville, 1937; Gentry et al., 1988). This pattern of dysfunction has been related to deficits in strategic processes that figure prominently in the postacute cognitive profile of TBI (Mattson & Levin, 1990; Stuss & Gow, 1992). A unique feature of TBI is involvement of orbitofrontal regions. These areas, with their extensive interconnections to both limbic and sensory regions, are considered important to anticipation of future consequences and strategic decision making (Bechara et al., 1994; Damasio et al., 1991; Nauta, 1971). Indeed, TBI patients with damage in these regions were used for the study on which our measure is based (Shallice & Burgess, 1991a). To encompass the full range of TBI outcomes, we tested a consecutive series of individuals with TBI; we did not select participants based on injury type, severity, lesion location, or behavior. For the entire TBI sample, we expected a significant effect of TBI on strategy application, but we predicted it would be less consistent than in the focal frontal group. We then sought to identify strategically impaired TBI participants based on injury characteristics and lesion information. TBI participants were compared to a set of carefully matched control participants.

The neurologically normal participants provided a comparison for the other groups and allowed for the investigation of the effects of normal aging on performance. Although normal aging should not cause deficits as severe as focal frontal lesions and TBI, there is evidence for age-related decline in frontal systems (Coffey et al., 1992; Creasey & Rapoport, 1985; Flood & Coleman, 1988; Gur et al., 1987;

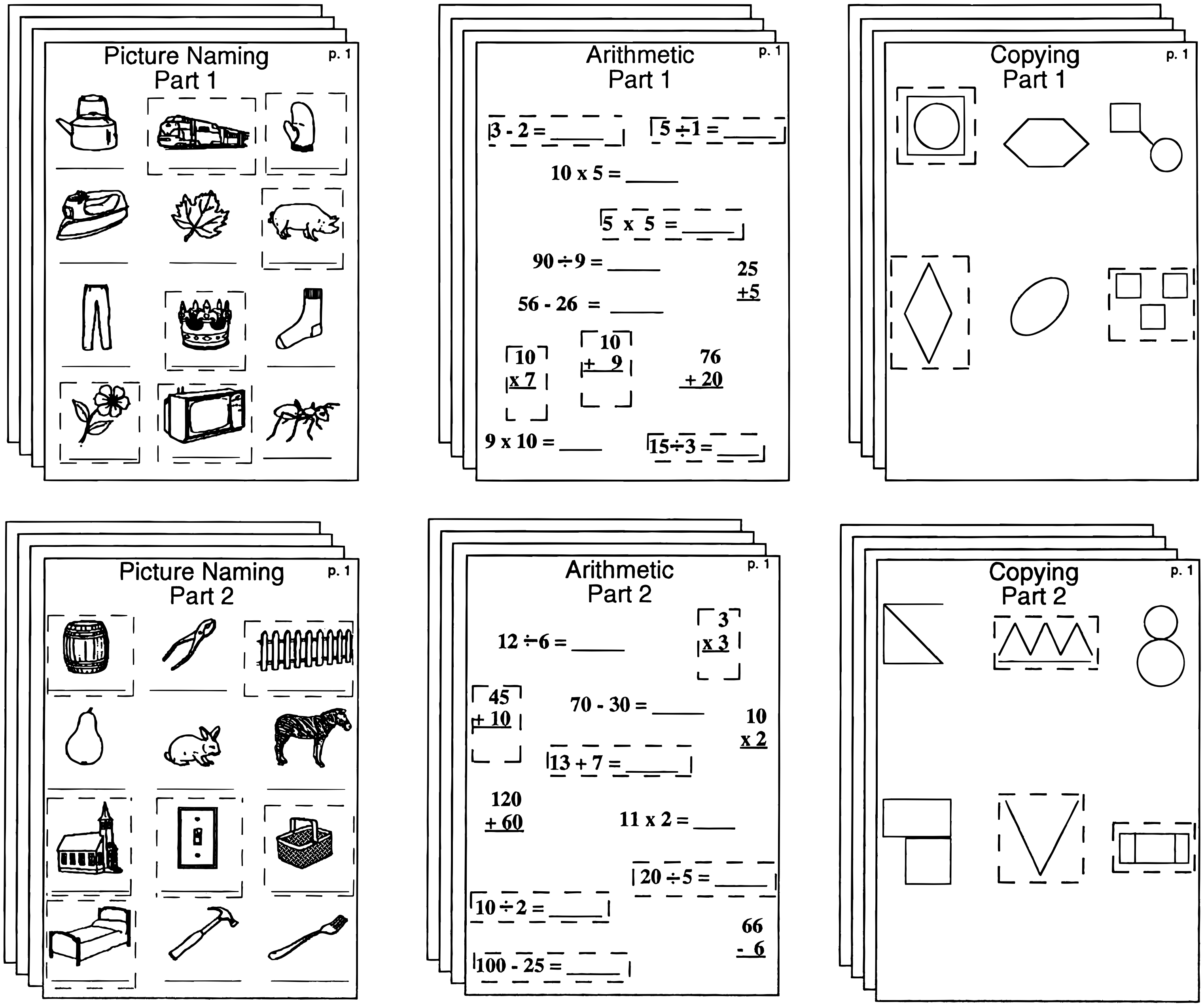

Fig. 1. Schematic representation of the strategy application task.

Raz et al., 1997) and on unstructured tasks reliant on supervisory processes (Albert et al., 1990; Craik et al., 1987; Levine et al., 1995). Furthermore, three recent functional neuroimaging studies documented age-related differences in frontal regional cerebral blood flow (rCBF) activations that were attributable to inefficient strategic operations during encoding or retrieval (Cabeza et al., 1997; Grady et al., 1995; Schacter et al., 1996). We predicted a significant effect of age (i.e., younger *vs.* older participants) on strategy application performance. In relation to the TBI and focal frontal groups, however, this effect should be modest.

Process Specificity in Strategy Application Assessment

As a second method for assessing test validity, we evaluated the contribution of processes subordinate to strategy application. Encoding and retention of instructions concerning the task's goals and constraints were assessed both before and after the task. Once intact encoding and retention of the instructions was established, a structured interview was conducted to assess participants' understanding of the task demands. We also analyzed item difficulty to document that the complexity of the task's subcomponents did not interfere with their coordination.

The concurrently administered battery of neuropsychological tests included measures of general intellectual functioning, naming, memory, attention, and executive functioning. Traditional executive functioning tests are limited as measures of strategy application in unstructured situations, but they are more reliant on the self-initiated processes critical to strategy application than are other neuropsychological tests. In the absence of a gold standard strategy application measure, we predicted a differential pattern in which performance on our test would be more related to executive functioning tests than to other neuropsychological tests.

Summary

We have developed a paper-and-pencil test of supervisory abilities in which the steps towards efficient performance were not structured for the participants, requiring them to formulate and apply a strategy. The main goal of this study was to establish the validity of this test in three groups of participants prone to different degrees of strategy application deficits. Validity was also established through assessment of the contribution of more basic, lower-level abilities (e.g., learning and retention of instructions) to performance and the relation between our test and established neuropsychological tests. Within-group variability and the complexity of the neuroanatomical systems hypothesized to mediate strategy application motivated additional analyses of the effects of lesion type and location on performance.

METHODS

Research Participants

Focal lesion

The focal lesion participants were medically stable with focal frontal ($N = 10$) or focal nonfrontal brain damage ($N = 6$) due to an acute event (e.g., infarction, hemorrhage, resection) occurring at least 3 months prior to testing (with the exception of 1 frontal resection participant tested 1 month postsurgery; see Tables 1 and 2). Lesion localization was determined by a neurologist (M.A.) from CT or MRI that had been obtained for clinical purposes. We did not have the scan for 1 participant (#2101) whose lesion localization was obtained from the radiologist's report. For the remaining 9 participants, lesion diagrams were constructed on standardized templates (Damasio & Damasio, 1989, see Figure 2). In addition to lobar classification, frontal lesions were classified as dorsolateral or medial. Medial frontal lesions could be inferior (Brodman's areas 10, 11, 12, 25, and

Table 1. Participant characteristics

Group	Sex		Handedness		Age (years)		Education (years)		Estimated IQ		WAIS–R Vocabulary	
	Male	Female	Right	Left	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Focal lesion												
Frontal	3	7	10	0	50.2	14.8	12.5	3.2	104.5	6.5	46.7	10.6
Posterior	2	4	6	0	44.9	8.9	13.4	3.3	111.8	8.1	48.2	8.9
Traumatic brain injury												
TBI	24	18	19	5	29.4	10.4	13.0	2.3	102.2	8.1	47.1	9.0
Controls	11	9	17	3	29.0	9.4	14.9[a]	2.4	107.4[a]	8.8	52.1	11.0
Normal aging												
Older	12	8	18	2	71.8	4.7	13.9	3.0	114.5	6.4	N/A	N/A
Younger	9	11	18	2	29.7	7.6	15.8[a]	2.8	109.4	8.2	N/A	N/A

[a]Significantly different from comparison group.

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Table 2. Focal lesion participant characteristics[a]

Participant #	Sex	Age (years)	Education (years)	Estimated IQ	WAIS–R Vocabulary	Etiology	Time postonset	Lesion location	Efficiency score
Right frontal									
2024	F	70	13	114	60	Stroke	3 M	DL, striatal	0.24
2044	F	37	12	96	28	Tumor	4 M	SM	0.21
2107	F	27	12	98	48	Resection	1 M	DL	0.38
Left frontal									
2056	F	45	14	91	N/A	Tumor	11 M	DL	0.85
2058	F	70	11	107	52	Tumor	6 Y	IM, SM, DL	0.21
2100	M	54	17	ESL	ESL	Stroke	10 M	IM, SM, septal	0.32
2120	M	68	16	100	44	Stroke	14 Y	SM, DL	0.51
Bilateral frontal									
2039	M	43	13	106	N/A	Stroke	3 M	IM, SM, DL, septal	0.23
2101	M	46	5	ESL	ESL	Tumor	1 Y	IM	0.24
2122	F	41	12	N/A	N/A	Stroke	8 M	IM, striatal, septal	0.23
Right posterior									
2040	F	38	12	107	44	Resection	7 Y	Temporal	0.46
2057	M	36	17	118	58	Resection	11 Y	Temporal	0.29
2103	F	50	8	105	44	Stroke	3 Y	Inf. parietal	0.21
2108	M	50	17	122	59	Stroke	2 Y	Temporal	1.00
Left posterior									
2032	F	59	15	117	48	Resection	4 Y	Temporal	0.87
2036	F	38	14	102	36	Resection	8 Y	Temporal	0.44

[a]Abbreviations: ESL = English as a second language; IM = inferior medial; SM = superior medial; DL = dorsolateral prefrontal, L = left, R = right.

32 on the medial surface), superior (areas 6, 8, 9, and 24 on the medial surface), or both.

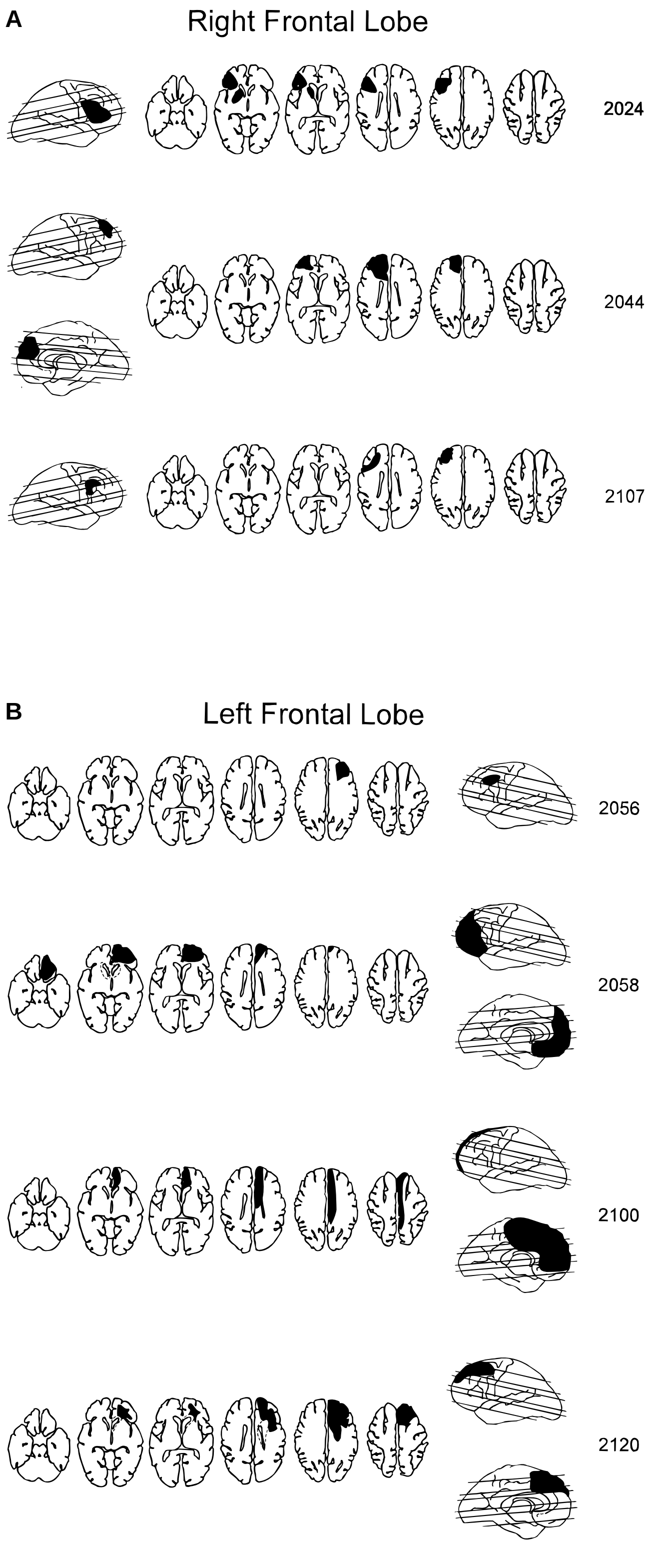
Four of the 6 posterior participants had temporal lobectomies for the relief of epilepsy and therefore had highly consistent lesions (with the exception of one of these 4 who had an additional small medial thalamic lacune); the other 2 had strokes with inferior right parietal and anterior temporal lesions, respectively.

Traumatic brain injury

The traumatic brain injury participants were drawn from a pool of 94 participants in a previous study on posttraumatic amnesia (PTA) who had been recruited from consecutive admissions to a major metropolitan trauma center due to a blow to the head followed by an alteration in consciousness. For the current study, 4 were excluded due to ongoing alcohol problems, 30 refused to participate, and 18 were lost to follow-up. The resulting 42 participants were tested an average of 1.8 years after the injury (SD = .48; range = 1.0–2.5; see Table 1). In terms of injury characteristics and background characteristics, these 42 participants were representative of the original sample of 94.

The Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) taken at 6 hours postinjury was used to characterize severity (M = 11.8, SD = 3.9, median = 14, range: 3–15). In cases of intubation or pharmacologic immobilization for treatment of intracranial pressure, the GCS score was extrapolated from available data. Based on standard criteria (Teasdale & Jennett, 1974), 25 participants were classified as *mild* ($13 \leq$ GCS ≤ 15), 7 as *moderate* ($9 \leq$ GCS ≤ 12), and 10 as *severe* ($3 \leq$ GCS ≤ 8). Other severity indices included PTA duration, defined as the number of days postinjury at which participants twice consecutively achieved a score of 75 or greater on the Galveston Orientation and Amnesia Test (GOAT; Levin et al., 1979), and length of loss of consciousness (LOC) determined from participants' reports and medical records. Incomplete GOAT data (only 1 day of testing) were dropped for 5 TBI participants. LOC could not be determined for 8 participants.

Acute clinical CT scans were available for 37 (88%) of the 42 TBI participants. A CT scan was not clinically indicated for the other 5 participants, all with mild TBI. The scans were read by the attending neurosurgeon (M.S.) and classified according to a scheme modeled after Marshall et al. (1992). Focal parenchymal lesions (contusions, intracerebral hematomas, and multiple punctate hemorrhages) were identified in 11 of the scans. Eight TBI participants had focal frontal lesions (3 right, 3 left, 2 bilateral; 1 had an additional basal ganglia lesion, and 1 had additional basal ganglia, temporal, and occipital lesions), 2 had focal temporal lesions (1 left, 1 right), and 1 had a focal right parietal lesion. Several participants received subsequent scans for clinical purposes. New focal parenchymal lesions in 3 participants were identified on these scans and included in the analyses: 1 right inferior frontal hemorrhagic contusion, 1 small right basal ganglia hemorrhagic contusion, and 1 large right temporal intracerebral hematoma.



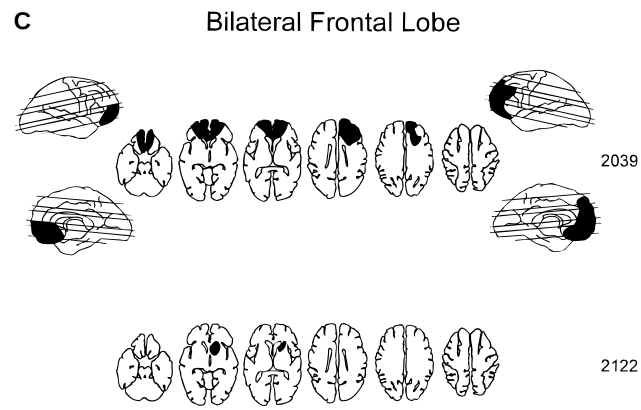


Fig. 2. Schematic diagrams of lesion locations drawn on standardized templates (Damasio & Damasio, 1989). The left side of the template corresponds to the participants' right side. For 1 bilateral frontal lobe participant (#2101), the scan was not available; his lesion localization was obtained from radiologists' reports. The drawing for participant #2122 depicts the left side of the lesion, but the lesion is bilateral on a slice not selected for these diagrams (i.e., the second slice on p. 189 of Damasio & Damasio's text).

In order to control for socioeconomic and cultural factors specific to the TBI participants, 20 friends and family members of these participants, individually matched on age and education, served as TBI controls (see Table 1).

Neurologically normal

The neurologically normal young and old participants, recruited from the Rotman Research Institute's volunteer database, consisted of 20 younger (age 18–39 years) and 20 older (age 63–79 years) participants (see Table 1). These participants, as well as all other participants in this study, were screened for preexisting head injuries or other neurological conditions, serious medical problems that could impact cognition, extensive drug or alcohol abuse or substance abuse treatment, past inpatient psychiatric treatment, use of psychoactive medication within 30 days prior to the study (except for some of the focal lesion participants who were stabilized on antiseizure medication), history of learning problems (i.e., a childhood diagnosis of learning disability or being held back in school), or, in the older participants, dementia as evidenced by test performance or Mini-Mental State Exam score (Folstein et al., 1975).

All participants in this study were proficient English speakers. Those who spoke English as a second language (ESL) were functioning in English-speaking occupational or educational settings.

Materials

The strategy application test consisted of three activities: picture naming (96 items), arithmetic (96 items), and figure copying (48 items). The items were designed to be within the abilities of participants with intact basic language, arithmetic, and visuoperceptual–visuoconstructive skills. Each activity was divided into two equal-sized sections (called Part 1 and Part 2) consisting of items printed on four sheets of paper (see Figure 1). For the purposes of this paper, analyses were restricted to performance on the first two sheets of each section, in which half of the items were randomly selected to be worth 15 points each and the remaining half

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were worth 1 point each. The third and fourth sheets of each section contained only one 15-point item. Fifteen-point items were distinguished from 1-point items by a dotted frame. All pages were clearly labeled at the top (e.g., "Picture Naming, Part 1") and numbered in the upper right corner ("p. 1"–"p. 4").

Procedure

All timing devices, including participants' watches, were removed from view. The sections were arranged in front of participants as depicted in Figure 1. The following instructions were given:

> "In the next 5 minutes I would like you to do three different tasks for me, each of which is in two parts. The tasks are to write the names of these pictures, work out these arithmetic problems, and copy these drawings. Notice that each part of each task is made up of four sheets. How you do the tasks is up to you, but there are a number of important rules you must follow:
>
> 1. Do not do the two parts of the same task one after the other. For example, if you do items on Arithmetic, Part 1, do not do items on Arithmetic, Part 2 next. You should go to either Picture Naming or Copying next.
> 2. Some of the items have boxes around them. Those items are worth 15 points. Items without boxes are worth 1 point.
> 3. You only have 5 minutes. It is *impossible* to finish all of the items in that amount of time.
> 4. You must try to get as *many points* as you can.
> 5. None of the three tasks is more important than the other. You receive the same amount of credit for Picture Naming, Arithmetic, and Copying.
> 6. Work as quickly as you can without making any mistakes."

Before the task began, a selective reminding technique 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 5-min task was completed, the printed set of instructions was removed and participants' free recall of the rules was tested again.

Next, a brief, structured interview was administered to determine the extent to which participants were aware of the most efficient strategy (i.e., selective completion of the 15-point items before doing any 1-point items). The interview consisted of the following questions: "How did you go about completing the task?" "Did you do anything to get as many points as possible?" and "Would it have made sense to do the 15-point items first?" If participants spontaneously acknowledged the most efficient strategy after the first or second question, the interview was terminated. Participants who did not acknowledge the most efficient strategy were asked the third question to determine if they would agree that selective completion of the 15-point items was sensible or allowed within the constraints of the task.

Measures

Efficiency score

In order to maximize points in the limited time period, the most strategic approach was to selectively complete 15-point items to the exclusion of 1-point items. This required inhibition of a tendency to approach items in order according to their spatial arrangement on the page (without respect to point value) or to do 1-point items because they could be completed effortlessly and were readily available. Therefore, selective completion of 15-point items was assumed to reflect supervisory processes, whereas completion of 1-point items was assumed to reflect unmodulated contention scheduling.

To quantify strategy application performance, an efficiency score was calculated by summing the number of consecutive 15-point items and dividing this sum by the total number of items completed (minus 1 as the first 15-point item could not enter into the numerator). Participants who completed all of the 15-point items, then did 1-point items received a score of 1.0. High scores (i.e., .90–1.0) could only be achieved through intentional selection of 15-point items and were considered to reflect consistently strategic performance. Participants who did not apply such a strategy, however, could still complete consecutive 15-point items by chance. The most typical nonstrategic approach was to follow the spatial arrangement of the items (i.e., right-to-left, top-to-bottom) without regard to point value. This approach resulted in an efficiency score in the low .20s. Therefore, any score of .30 or below was viewed as reflecting nonstrategic performance. Participants with scores ranging from .30 to .90 showed varying degrees of inconsistency in their approach to 15-point items. These included selective completion of 15-point items for one activity (e.g., picture naming), but not others; completing groups of 15-point items followed by groups of 1-point items; or general selection of 15-point items with occasional slips to 1-point items. To compare participants with unambiguously strategic or nonstrategic performance, some of the analyses were conducted on groups of participants defined by efficiency scores of .90 to 1.0, and .30 or below.

Neuropsychological measures

The North American Reading Test–Revised (NART–R; Blair & Spreen, 1989) and/or the vocabulary subtest from the WAIS–R (Wechsler, 1985) were used to obtain an estimate of general intellectual functioning. Participants in the TBI and focal lesion groups also received the paired associate learning subtest from the Wechsler Memory Scale–Revised (WMS–R; Wechsler, 1987), the Boston Naming Test (BNT; Kaplan et al., 1983), and semantic word list generation (naming as many animals or grocery items as possible in 60 s; SWLG). Because the WAIS–R Vocabulary subtest, NART–R, and BNT assume a lifetime of exposure to English, these data were discarded for ESL participants. Handedness was assessed by interview.

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All participants received phonemic word list generation (PWLG; naming as many words as possible in 60 s beginning with the letters F, A, and S; Spreen & Strauss, 1991) and the Wisconsin Card Sorting Test (WCST). The WCST was administered according to the criteria of Grant and Berg (1948; Milner, 1963) with the following exceptions. All 128 cards were administered to all participants, even if all six categories had been achieved with fewer cards. Perseverative errors were scored beginning with the second category. For patients who failed to complete a single category, perseverative errors were scored according to the Heaton system (Heaton et al., 1993). Errors that matched the same dimension as the previous response were tallied and designated prior response repetitions (Nelson, 1976). The WCST was not administered to 2 young participants because of color blindness or because of prior exposure to the test. Participants in the TBI and focal lesion groups also received the Trail Making Test, Parts A and B (Army Individual Test Battery, 1944) and the Stroop interference procedure (Stroop, 1935).

Analyses

Within each main group of participants, subgroup differences were assessed with analysis of variance (ANOVA) or *t* test. That is, the focal frontal subgroup was compared to the focal posterior, the TBI subgroups were compared to the TBI controls, and the older adult subgroup was compared to the young. *Post-hoc* pairwise comparisons were evaluated with the Tukey honestly significant difference comparison (or the Tukey–Kramer modification for unequal cell sizes). Because the efficiency scores were not distributed normally, group differences in efficiency scores were assessed nonparametrically (Wilcoxon rank-sum tests, or rank order correlations) or transformed to a more normal distribution (Blom, 1958), then analyzed parametrically.

RESULTS

General Intellectual Ability and Education

There were no differences in estimates of general intellectual ability or education for the focal lesion participants. Although every attempt was made to obtain matched controls to the TBI participants, the TBI controls had more years of education [$t(60) = 3.00$, $p < .005$] and lower estimated IQ [$t(52) = 2.20$, $p < .05$] than the participants with TBI (see Table 1). WAIS–R vocabulary scores did not significantly differ. The neurologically normal older participants had a significantly higher estimated IQ and marginally significantly fewer years of education than their younger counterparts [estimated IQ: $t(38) = 2.13$, $p < .05$; education: $t(38) = 2.02$, $p < .06$; see Table 1]. To statistically control for the effects of estimated IQ and education, these variables were entered as covariates in between-group comparisons.

Test Validity

Subgroup differences

The focal frontal subgroup's efficiency score distribution was strongly skewed in the direction of nonstrategic performance (see Figure 3, top). Six of 10 (60%) focal frontal participants earned efficiency scores below .30, more than any other subgroup. The difference between the distributions of focal frontal and focal posterior subgroups is reflected in their skewness values (2.11 *vs.* 0.66), but nonparametric comparison of the distributions was not significant [Wilcoxon two-sample $Z(N = 16) = 1.25$, $p < .22$].

TBI participants earned significantly lower efficiency scores than matched controls (see Figure 3, middle) [Wilcoxon two-sample $Z(N = 62) = 2.39$, $p < .05$]. This effect was unchanged after submitting the transformed efficiency scores to an analysis of covariance with education as a covariate. There was no effect of severity when mild, moderate, and severe TBI participants (as defined by GCS) were compared, nor was there a significant correlation between GCS and performance. A relation between TBI severity indices and performance was further probed by comparing TBI participants with nonstrategic (efficiency scores of .30 or less, $N = 14$) and strategic (efficiency scores of .90 or greater, $N = 16$) groups. There were no differences in severity indices between these groups: For nonstrategic participants, GCS = 12.0, percentile ranking of GOAT recovery = 50.4, percentile ranking of LOC = 51.2; for strategic participants, GCS = 11.2, percentile ranking of GOAT recovery = 55.1, percentile ranking of LOC = 58.6. TBI, then, was significantly associated with nonstrategic performance. There was heterogeneity of performance within the TBI participants, but this heterogeneity could not be accounted for on the basis of TBI severity.

The normal aging subgroups had similarly shaped distributions that did not significantly differ, although the younger subgroup's distribution tended to be more negatively skewed than the older subgroup's (skewness values of −1.1 and −0.45, respectively), corresponding to a larger percentage of high efficiency scores and smaller percentage of low efficiency scores in the younger subgroup (see Figure 3, bottom). To adjust for the differences in estimated IQ and education (see Table 1), transformed efficiency scores were submitted to an analysis of covariance with estimated IQ and education as covariates. After adjusting for estimated IQ and education, the age subgroup effect was significant [$F(1,35) = 5.11$, $p < .05$], corresponding to a mild age-related tendency toward nonstrategic performance.

Processes unrelated to strategy application

The influence of extraneous factors was assessed through analysis of item difficulty, participants' recall of the instructions, and participants' understanding of the task demands.

By designing simple test items, we reduced the possibility that attentional capacity would be directed away from strategy application and toward the test content. The over-

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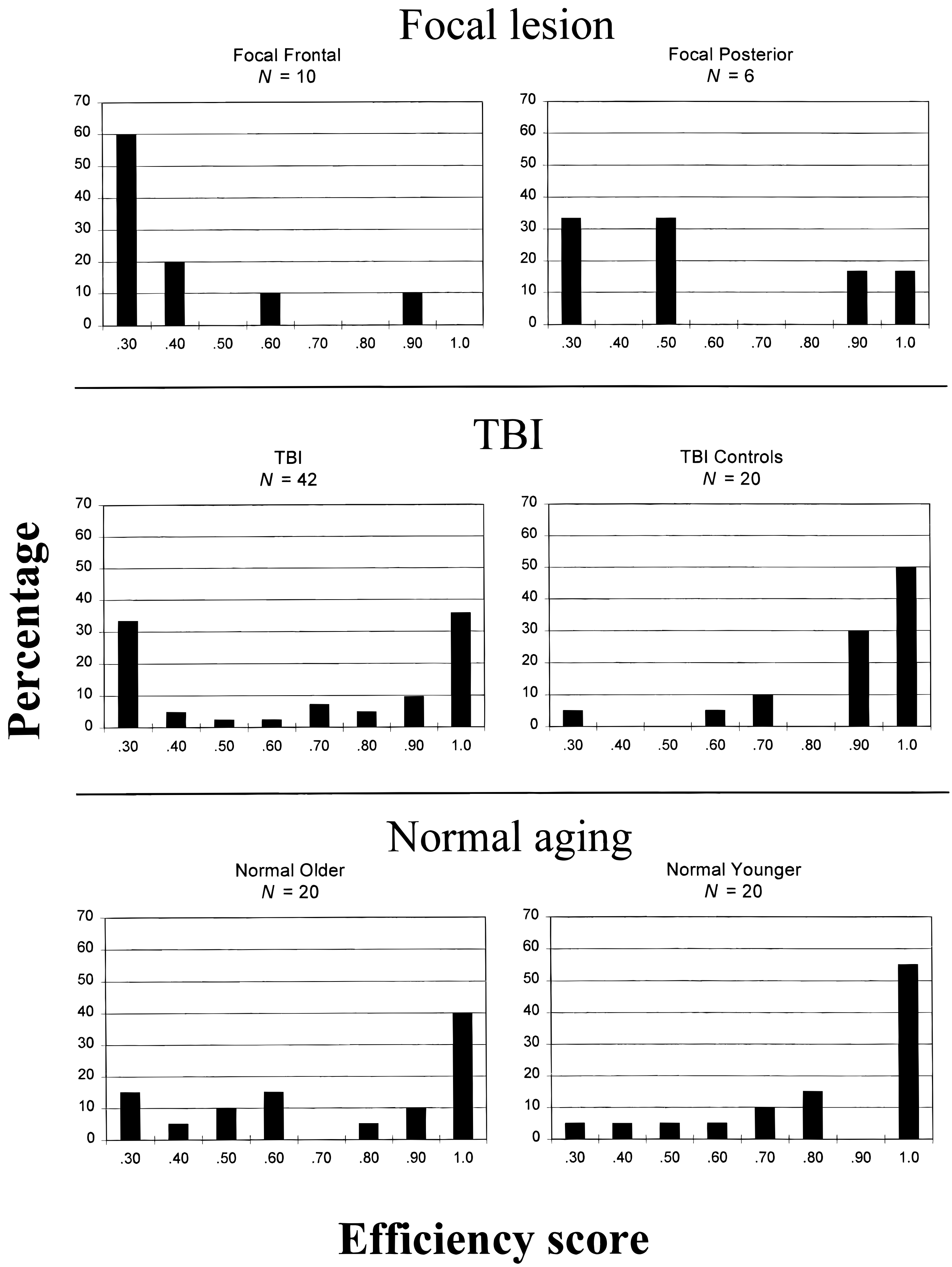

Fig. 3. Distributions of efficiency scores in six subgroups. Each chart shows the percentage of participants in each subgroup with different efficiency scores.

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all error rate for the entire sample was 2.8% (*SD* = 3.3, range = 0–16) and not significantly correlated with efficiency scores. Error rates were nearly identical for 1-point and 15-point items. There were no significant differences in error rates when subgroups were compared within each main group of participants, or when they were grouped according to lesion lateralization.

Low efficiency scores could be due to deficits in memory processes subordinate to strategy application, such as simple encoding and retention of the instructions. Encoding problems were dealt with by ensuring error-free recall of the instructions before beginning the test. When the test was completed, retention was assessed by asking the participants to repeat the instructions again. The relationship between retention of the instructions and efficiency was assessed by comparing participants with nonstrategic performance (i.e., efficiency scores of .30 or less, $N = 27$) to those with strategic performance (i.e., efficiency scores of .90 or greater, $N = 47$) on the posttest free recall of instructions.

Overall, nonstrategic performance was not strongly related to recall of instructions. Both strategic and nonstrategic participants recalled the instruction that framed items were worth 15 points at similar rates (92 and 96%, respectively). Recall of the instruction to get as many points as possible was relatively low: 36% for the nonstrategic participants and 58% for the strategic participants (not significantly different, $p > .05$). A significant difference was observed for the instruction concerning the time limitations, which was recalled by 65% of the nonstrategic participants and 91% of the strategic participants [$\chi^2(1, N = 71) = 7.29$, $p < .01$].

Even when adequately encoded and retained, the instructions may have inadvertently suggested an approach other than a strategic one. For example, the belief that doing the 15-point items to the exclusion of the 1-point items was against the rules would result in a low efficiency score independent of strategy application.

The strongest test of participants' understanding of the task parameters would be acknowledgment of the most efficient strategy in response to the questions "How did you go about completing the task?" and "Did you do anything to get as many points as possible?" Not surprisingly, all of the participants in the strategic group affirmed the strategic approach that they had taken. More importantly, 13 of 27 (46%) of nonstrategic participants acknowledged the most efficient strategy by saying that they should have selectively completed 15-point items or that they did selectively complete 15-point items (in contrast to their actual performance). These included 1 of 6 focal frontal, 1 of 1 focal posterior, 8 of 14 TBI, 1 of 1 TBI control, and 2 of 3 normal older participants.

As a test of unawareness or frank misinterpretation of the task demands, we asked 10 of the 14 nonstrategic participants who did not acknowledge the strategic approach if it would have been sensible to skip the 1-point items and do the 15-point items exclusively (4 were not asked due to oversight). Three of these 10 (2 TBI and 1 right frontal) unambiguously said that skipping the 1-point items was not allowed within the constraints of the task. Seven of the 10 agreed that skipping the 1-point items was not precluded by the instructions.

Relation to other measures

Rank-order correlations between efficiency scores and other measures revealed modest relationships with general intellectual level, digits forward, confrontation naming, WCST measures, Trail Making, and Stroop (ranging from .25 to .35, *p*s < .01). Of more interest was whether nonstrategic participants could be differentiated from the strategic participants in terms of their pattern of scores on these measures. As seen in Table 3, nonstrategic participants were significantly less educated [$t(72) = 3.8$, $p < .0005$] and had a lower estimated IQ [$t(67) = 2.3$, $p < .05$]. After statistically adjusting for these variables, significant differences between the two groups were present for WCST perseverative errors and prior response repetitions [$F(1,65) = 13.5$, $p < .0005$, and $F(1,65) = 11.7$, $p < .01$, respectively], Trail Making, Part B [$F(1,41) = 5.8$, $p < .05$], Stroop word read-

Table 3. Comparison of participants with strategic and nonstrategic performance on background variables and neuropsychological tests

	Strategy Group[a]			
	Strategic		Nonstrategic	
Measure	*M*	*SD*	*M*	*SD*
Age	36	18	42	17
Years of education	14.5[b]	2.4	12.1	2.7
Estimated IQ	109[b]	8.1	104	10.1
WAIS–R Vocabulary	51	7.3	45	12.3
Digits Forward	7.2	1.3	6.1	1.4
Digits Backward	5.3	1.4	5.3	1.5
WMS–R Paired Associates–immediate recall	21	2.1	19	4.3
WMS–R Paired Associates–delayed recall	8.0	0.2	7.4	1.2
Boston Naming Test	55	2.9	52	7.7
Semantic word list generation	27	6.7	23	7.2
Phonemic word list generation	43	10	35	9
WCST categories	8.5	2.5	6.2	3.3
WCST perseverative errors	14[c]	5.4	25	12.5
WCST prior response repetitions	2.5[c]	3.1	9.2	8.1
Trail Making, Part A	24	12	32	13
Trail Making, Part B	59[c]	24	88	48
Stroop word reading	44[c]	7.1	55	11.1
Stroop color naming	59[c]	9.9	71	16.3
Stroop inference	104[c]	20	129	37

[a]Strategic group: efficiency scores of .90 to 1.0; Nonstrategic group: efficiency scores of .30 or less. [b]Significantly different than nonstrategic group. [c] Significantly different than nonstrategic group after statistically adjusting for education and estimated IQ.

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ing, color naming, and interference [$F(1,42) = 14.2$, $p = .001$; $F(1,42) = 8.3$, $p < .01$; and $F(1,42) = 4.5$, $p < .05$, respectively]; and WMS–R delayed paired associate recall [$F(1,41) = 5.43$, $p < .05$]. Overall, this pattern of results indicated a relation between nonstrategic performance and deficits on traditional tests of executive functioning, generalized slowing, and inefficient delayed recall.

Lesion Analyses

Exploratory analyses of lesion type and location were conducted in an attempt to account for the heterogeneity of strategy application performance in the groups with cerebral dysfunction. These analyses were conducted separately for the focal lesion and TBI groups.

Focal lesion participants

When focal lesion participants were classified according to lesion lateralization instead of frontal *versus* posterior, there was a trend for participants with right hemisphere lesions to have low efficiency scores (see Figure 4). Only 1 of the 6 (17%) participants with a unilateral left hemisphere lesion (UL) earned an efficiency score corresponding with nonstrategic performance, compared to 4 of the 7 (57%) participants with a unilateral right hemisphere lesion (UR; $p = .18$ by 1-tailed Fisher's Exact Test). There were no significant differences in age, education, or general intellectual measures across the three lesion groups.

Inferior medial lesions were also associated with nonstrategic performance. Of 5 participants in this study with inferior medial lesions, 4 had nonstrategic performance and 1 had marginally nonstrategic performance (efficiency score = .32). Taking inferior medial lesions into account clarifies the lateralization effect: The only UL participants with low efficiency scores had extensive medial lesions (#2058 and #2100).

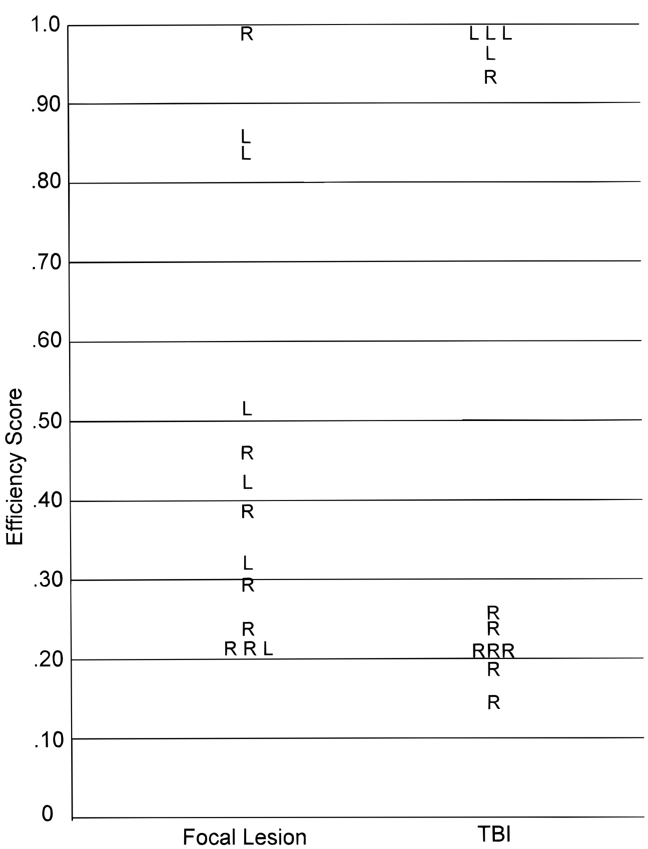

Fig. 4. Efficiency scores for participants with right- and left-hemisphere lesions. Each letter represents a participant with a right- or left-hemisphere lesion.

TBI participants

The presence of an anterior lesion in TBI was not consistently associated with nonstrategic performance; 4 of 9 (44%) TBI participants with anterior lesions had nonstrategic performance; the other 5 had strategic performance. Two of 4 TBI participants with lesions restricted to posterior regions had strategic performance. The single participant with a right basal ganglia lesion had nonstrategic performance.

Taking lesion lateralization into account resulted in a finding similar to that observed above: 7 of 8 (88%) UR participants had nonstrategic performance, compared to none of the 4 UL participants, whose scores ranged from .97 to 1.0 (see Figure 4). The only UR participant with strategic performance had a parietal lesion and was left-handed. The difference in distributions between the TBI participants with UR and UL lesions was significant [Wilcoxon two-sample $Z(N = 12) = 2.65$, $p < .01$]. Both of the TBI participants with BL lesions had strategic performance. Although the performance of these 2 participants contrasts with the performance of the focal lesion BL participants described above, the TBI participants' lesions were small in comparison to the focal lesion BL participants.

There were no significant differences in injury severity (GCS, LOC, or PTA), age, or general intellectual functioning across the lesion groups, but TBI participants with UR lesions had fewer years of education. Therefore, an analysis of covariance was conducted on transformed efficiency scores with years of education as a covariate. The effect of lesion lateralization was significant [$F(1,9) = 32.39$, $p < .0005$], and remained significant after adjusting for the covariate [$F(1,9) = 19.54$, $p < .005$].

Nonstrategic performance among TBI participants was not limited to those with focal lesions. The distribution of efficiency scores for the 23 TBI participants without lesions identified on CT was significantly different from the TBI controls [Wilcoxon two-sample $Z(N = 43) = 2.11$ $p < .05$], with 4 of these 23 participants (17%) showing nonstrategic performance, compared to 1 of 20 TBI controls (5%). The 5 TBI patients without CT were not included in this analysis.

The analyses of TBI severity (GCS, PTA, LOC) described above were conducted separately for the TBI participants with and without lesions. As with the sample taken

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as a whole, severity was not related to differences in efficiency scores within these two groups.

Reliability

To estimate reliability, separate efficiency scores were calculated for the first and second half of the test and the correlation between the two efficiency scores was corrected with the Spearman–Brown formula. For the entire sample, the reliability coefficient was .88. Because the homogeneity of performance among the neurologically normal participants (i.e., young, old, and TBI controls) reduced the reliability coefficient, separate reliability coefficients were calculated for participants with and without brain damage. For the 60 neurologically normal participants, the reliability coefficient was .80. For the remaining 63 participants with TBI and/or focal lesions, the coefficient was .92.

DISCUSSION

A new test of strategy application was designed to quantify deficits in supervisory processes following brain disease. The test was based on a theory that states that the supervisory system is called into play in unstructured, nonroutine situations where planning, error correction, and inhibition of strong habitual responses are required (Norman & Shallice, 1986). When these processes fail, behavior is governed by salient but irrelevant stimulus attributes rather than internally represented goals or intentions. Low efficiency scores on our test, which typically came about through selection of items based on spatial contiguity rather than point value, were assumed to reflect a failure of supervisory processes and unmodulated contention scheduling.[1] The validity of the test was supported by systematic differences in performance across three groups of participants, the lack of influence of processes subordinate to strategy application, and the pattern of relationships with other neuropsychological tests.

Strategy application is subserved by multiple supervisory processes that can be differentially affected according to type and location of brain damage. Exploratory analyses in our sample of focal lesion patients suggested hypotheses for future research concerning the behavioral–anatomical substrates of strategic disorders.

Specificity in the Assessment of Strategy Application

The prevalence of nonstrategic performance across the different subgroups was consistent with our prediction that performance would vary according to the degree of frontal systems dysfunction. Subtle but statistically significant deficits were present in older adults with high intellectual abilities and no evidence of significant health problems that could affect cognition. The TBI group was impaired relative to matched controls drawn from the same socioeconomic cohort. The focal frontal subgroup had the highest percentage of nonstrategic participants, nearly double that of the focal posterior subgroup. Although this comparison did not achieve statistical significance, there was most likely insufficient power to overcome the variability inherent in the performance of participants with brain disease.

The performance deficits were specific in that they could not be attributed to aspects of the test unrelated to strategy application, such as forgetting or misunderstanding the instructions. All participants repeated the instructions without error prior to the start of the test. After the test, nearly all participants with nonstrategic performance recalled instructions concerning point value.

Failure to recall the instruction concerning the 5-min time limit was statistically associated with nonstrategic performance, but it is unlikely that this lapse caused nonstrategic performance. First, the majority of nonstrategic participants recalled this instruction. Second, participants appeared to implicitly understand the concept of time limitations on this and other tests, even when explicit recall of the instruction was lacking. We observed that this instruction and the instruction to get as many points as possible received less attention in the pretest assessment, probably because they were easily understood or even obvious. The tendency for nonstrategic participants to omit these instructions on free recall in the posttest assessment was likely due to deficits in self-initiated encoding and retrieval of the instruction list rather than not knowing that the test was timed or that they were supposed to get as many points as possible.

Strategy Application *versus* Performance on Standard Neuropsychological Tests

We predicted that strategy application performance would be more strongly related to executive functioning tests than other standard neuropsychological tests. This prediction was based on the assumption that executive functioning tests are more reliant on self-initiated processes than are other neuropsychological tests. The profile of neuropsychological test scores of nonstrategic participants indicated deficits on measures involving processes directly related to strategy application performance: inhibiting an established response, error correction, and flexibility. There were other deficits, however, that could not be directly related to strategy application. The small but reliable difference on paired-associate recall suggested that nonstrategic participants had subtle problems with retention and retrieval of verbal information after a delay. Additionally, the Stroop results indicated that generalized slowing is part of their neuropsychological profile. These differences were significant after controlling for variance due to differences in years of education and estimated IQ.

[1] Although the results could be interpreted within other theoretical frameworks (e.g., Baddeley, 1986; Goldman-Rakic, 1987), we selected Norman and Shallice's model because of its history of application in multiple subgoal tasks and everyday functioning.

As stated in the introduction, we designed the strategy application task to measure abilities that are not captured in the standard neuropsychological test situation. We were motivated towards this goal by clinical experience and case studies in which real-life strategic behavior was impaired in spite of normal scores on standardized tests (Eslinger & Damasio, 1985; Shallice & Burgess, 1991a). Therefore, it could be argued that the validity of our task is compromised by the significant relations with standardized tests. The previously reported dissociations between neuropsychological test performance and real-life strategy application, however, were illustrated in case reports of specially selected participants. We suggest that strategic deficits and general neuropsychological impairment need not be mutually exclusive. Strategically impaired participants from a consecutive series should include individuals with deficits on standardized tests (especially tests reliant on self-initiated processes) as well as individuals without deficits.

We conducted a *post-hoc* analysis of participants' test profiles to see if our sample contained individuals with intact neuropsychological test scores but impaired strategy application test performance, as described in previous case studies. This analysis was restricted to the TBI participants, who were drawn from a consecutive series and had a matched control group. Of the 14 TBI participants with nonstrategic performance, 7 (50%) had normal scores (defined as within 2 *SD*s of the mean for the TBI controls) on 16 of the 17 measures listed in Table 3. The other 7 had widespread impairment on both executive and nonexecutive measures, often several standard deviations below the mean of the control group. Although the mean GCS scores for these two groups of participants did not differ, there was evidence of more significant injury in the neuropsychologically impaired group, where 4:7 had abnormal acute CT findings (compressed mesencephalic cisterns, diffuse edema, small ventricles), compared to only 1 in the neuropsychologically intact group.

These results indicate the presence of two subgroups of strategically impaired participants within our TBI series. One subgroup showed generalized neuropsychological dysfunction on standardized tests, possibly due to more extensive cerebral dysfunction as indexed on acute CT. In the other subgroup, standardized tests did not reveal significant neuropsychological impairment. It should be pointed out that the neuropsychological test battery was limited to a small number of widely used measures. Measurement of additional processes (e.g., working memory, attentional subtypes, monitoring, and interference control) will assist in the componential analysis of the task. Furthermore, as we did not assess strategy application performance outside of the laboratory, we cannot say that these participants had disrupted real-life strategic abilities. Both of these shortcomings should be addressed in future studies. Nevertheless, the results suggest that the frequently cited dissociation between standardized test performance and strategy application is present in some, but not all strategically impaired participants.

Dissociation of Knowledge From Action

Awareness of a strategy but failure to apply it reflects a dissociation of knowledge from action. This dissociation has been attributed to intact abilities in the encoding, retention, and explicit retrieval of goals in the face of deficits in the ability to use these goals to direct behavior in a given environmental context (Duncan, 1986; Kimberg & Farah, 1993; Shallice, 1982). Following the recommendation of Duncan (1986), we assessed the relation between awareness and application of strategy by asking participants to describe their approach to the test. In response to this query, 46% of participants with nonstrategic performance spontaneously acknowledged awareness of the more efficient strategy. We considered this response, which was not specifically probed for, to be strong evidence of the dissociation. In some cases, the dissociation was blatant. For example, while doing 1-point items, one bifrontal participant in the focal lesion group exclaimed, "This is crazy! There are no points here. What am I doing?" In other cases participants acknowledged that the appropriately encoded instruction did not guide their performance: "I didn't think of the rules when I started doing the task. They just vanished." Still other participants formulated a *post-hoc* explanation to account for their behavior (e.g., selecting 15-point items would have been "cheating"), but then acknowledged that this would have been allowed within the constraints of the task. A small percentage of the nonstrategic participants who did not spontaneously acknowledge the most efficient strategy did state that their understanding of the instructions precluded the selection of 15-point items to the exclusion of 1-point items. For these participants, there is reason to believe that the intention to selectively complete 15-point items was not established.

Although dissociation of knowledge from action is a classic clinical observation among individuals with frontal lesions (Duncan et al., 1995; Konow & Pribram, 1970; Luria, 1973), we are not aware of any group studies where this phenomenon has been demonstrated in participants with focal frontal or posterior lesions. By our conservative measure of spontaneous acknowledgment of the efficient strategy, this dissociation was not specific to focal frontal or even focal lesion participants, although different methods of evoking the dissociation may show greater specificity to frontal systems dysfunction.

Differential Effects According to Lesion Location

As with any human lesion study, the results must be interpreted within the limitations placed by the characteristics of the patient sample. Resections due to intractable epilepsy were overrepresented in the focal posterior group, introducing a possible confound of chronic lesion effects. Future research in this area should use a larger focal posterior group, including participants with right parietal lesions to address hypotheses concerning the effects of spatial attentional disorders. Other relevant patient groups could include those with pathology in subcortical nuclei or their frontal connections, the cerebellum, or major neurotransmitter systems (e.g., patients with Parkinson's disease). Finally, it should be noted that lesion localization in this study was accomplished with clinical scans, most of which were acute CT scans. Greater precision in lesion documentation can be achieved through MRI scans in the chronic phase.

Within these constraints, our predictions for the group analyses were largely supported, but there was considerable heterogeneity in performance among participants with cerebral dysfunction. To better understand potential functional–anatomical relationships in our sample, we conducted exploratory analyses of lesion type and location. Although *post hoc* and based on small numbers, the results were consistent with past research and are useful in making predictions for future research.

In both the focal lesion and TBI samples, strategy application performance was sensitive to right hemisphere lesions. While we did not hypothesize an effect of lesion lateralization, our findings are consistent with an emerging body of research on the functional lateralization of strategic processes. For example, Miotto et al. (1996) showed that the difference between right and left frontal participants' performance on a spatial working memory task could be accounted for by a deficit in strategy application which was specific to the right frontal participants. More broadly, Goldberg and colleagues have shown that the right hemisphere is preferentially involved in exploratory processing in novel situations where previously established routines do not apply (Goldberg & Costa, 1981; Podell et al., 1995).

Other research, while not linking the right hemisphere to strategy application *per se*, indicates that several processes subserving strategy application are right-lateralized. These processes include sustained attention (Pardo et al., 1991; Posner & Petersen, 1990; Wilkins et al., 1987), resisting distractibility (Woods & Knight, 1986), and on-line monitoring of responses (Petrides et al., 1993; Stuss et al., 1994a). Disruption in these abilities could account for the low efficiency scores in our right frontal participants. Deficits in sustained attention, or the ability to maintain an alert state, could affect performance at the start (when strategies are formulated) or during the task (when strategies must be actively maintained in consciousness to guide behavior). As for distractibility, the stimuli for our strategy application task were designed so that irrelevant features could influence performance in distractible participants. Accordingly, low efficiency scores on the strategy application task came about through selection of items based on spatial contiguity or simplicity rather than point value. The role of monitoring was apparent in the performance of strategic participants, who quickly recognized their error and made the appropriate adjustment when they were drawn to 1-point items. Assuming an established intention to maximize points and knowledge of how to do so, deficient monitoring due to right frontal lesions could cause a failure to detect inefficient performance and adjust behavior.

The processes described above have been related to the right frontal lobe, but our right-lateralized findings were not specifically frontal. There is evidence for a more general right hemispheric dominance for attention (Heilman & Abell, 1980; Knight, 1991), particularly on tasks involving the preparation and maintenance of alertness for detection of high-priority targets (Posner & Petersen, 1990). Right posterior lesions may exert an effect on strategy application through disruption of intrahemispheric attentional systems. Validation of this hypothesis will require a larger sample of participants with focal posterior lesions.

Every focal lesion participant in this study with large inferior medial lesions (in areas 10, 11, 12, 25, and 32) had compromised efficiency scores. Previous research has indicated that patients with lesions in this area do not take into account relevant environmental contingencies and therefore respond in a manner that reflects insensitivity to future consequences (Bechara et al., 1994; Damasio et al., 1991; Nauta, 1971). Similar deficits were proposed by Shallice and Burgess (1991b) to account for failures on their unstructured tasks (upon which our task is based). These deficits may not be observed on structured, examiner-guided tasks, including many tests of executive functioning. On the basis of these findings, more comprehensive investigation of the role of inferior medial lesions on unstructured tasks is warranted.

The Effects of Focal and Diffuse Injury in TBI

Behavior in the postacute phase of TBI can be affected by both diffuse and focal injuries (Levin et al., 1982). Among our TBI participants with focal lesions, lesion lateralization was related to performance, supporting the above-described role for the right hemisphere in processes subserving strategy application. Studies of lesion effects on supervisory abilities in TBI have yielded inconsistent results (Cockburn, 1995; Levin et al., 1991; Ponsford & Kinsella, 1992). Levin et al. (1994) found that frontal lesion volume improved prediction of performance on the Tower of London in children with TBI. In accordance with our findings, right frontal lesion volume provided a numerically larger increment in prediction. Although there was no effect for right posterior lesions, it is noted that Levin et al.'s frontal group included participants with lesions that encroached into posterior areas, leaving open the possibility that right posterior pathology influenced performance.

Diffuse injury in the absence of focal lesions can cause behavior similar in appearance to that caused by focal injury alone (Goldstein & Sheerer, 1941; Robinson et al., 1980; Stuss & Gow, 1992). The nonstrategic performance of a minority of our TBI participants without focal lesions on CT suggests that strategy misapplication can be related to diffuse injury. Indirect indices of the degree of diffuse injury (i.e., GCS, PTA, and LOC) were not related to performance. In previous research, these indices have not been consistently related to neuropsychological outcome (Cockburn, 1995; Goldstein et al., 1989; Levin et al., 1990; Whyte et al., 1995); positive findings have been restricted to general neuropsychological performance and speed of information processing (Dikmen et al., 1995; Haslam et al., 1995; Levin, 1992; Ponsford & Kinsella, 1992). Better prediction of behavior following diffuse injury may require supplementation of the standard indicators with more sensitive measures, such as small lesions visible on MRI but not CT (Gentry et al., 1988; Levin et al., 1992; Ogawa et al., 1992). Additionally, factors unrelated to injury severity can affect TBI outcomes (Alexander, 1995).

Given the sensitivity of the orbital and basal frontal regions to TBI, it is possible that undetected anatomical or physiological abnormalities in these regions may have affected performance under the same principles described above for the focal lesion participants with BL lesions. Although the normal performance of two TBI participants with BL lesions may seem to contradict this hypothesis, closer examination of their lesions indicated that they would not necessarily disrupt the critical inferior medial regions. One had small left and right inferior dorsolateral contusions; the other had a small left inferior medial contusion and a right dorsolateral intracerebral hematoma.

Strategy Application and Normal Aging

Our sample of normal elderly participants showed a trend toward less efficient performance than their younger counterparts. This effect became significant after statistically adjusting for group differences in estimated IQ. We predicted a modest age effect on our strategy application task based on prior research in which age-related cognitive changes have been linked to deficits in self-initiated processes (Craik et al., 1987). The neurophysiological, and neuroanatomical changes associated with aging (Coffey et al., 1992; Creasey & Rapoport, 1985; Flood & Coleman, 1988; Gur et al., 1987; Raz et al., 1997) affect the frontal systems hypothesized to mediate supervisory processes. In comparison with the other groups in this study, the direction and degree of the age-related deficit is consistent with mild changes in these systems. In other studies from our lab involving a direct comparison of normal elderly with focal lesion patients (Levine et al., 1997; Stuss et al., 1996), the results were analogous to those reported here: The age-related deficits were qualitatively, but not quantitatively similar to those produced by focal lesions.

Conclusions

Strategy application deficits pose significant barriers to functional adaptation after brain damage, but the structure inherent in laboratory assessment makes these deficits difficult to evaluate. The results of this study support the validity of a test that is suitable for laboratory assessment yet capable of assessing strategy application in a relatively unstructured context. Across three groups of participants, strategy application deficits varied systematically according to predictions based on prior research. Nonstrategic performance did not appear to be due to extraneous factors such as difficulty of test content, forgetting the instructions, or misunderstanding the instructions, but it was related to low scores on measures from standardized tests of executive functioning that involve supervisory processes. Many participants with nonstrategic performance showed evidence of a dissociation of awareness and behavior, although not all of these individuals had focal frontal lesions. Case studies emphasize strategy application disorders in the context of normal neuropsychological test performance. In this study, it was shown that strategically impaired participants drawn from a consecutive series can include those both with and without deficits on other neuropsychological tests.

Strategy application is not a unitary construct. It is supported by supervisory processes such as the formulation, maintenance, and execution of intentions; monitoring and error correction; and inhibition of habitual responses (i.e., resisting distractibility). Future studies should seek behavioral dissociation of these processes through the use of additional scores, manipulations, and neuropsychological tests. The lesion analyses in this study, while preliminary, served the purpose of generating hypotheses concerning inferior frontal regions and the right hemisphere that may be assessed in future work.

Given the complexity of strategy application, it should not be surprising that different types and location of cerebral dysfunction, both frontal and nonfrontal, could produce deficits. While the frontal lobes certainly play a role in mediating these processes, the heterogeneity within the frontal lobes and the extensive interconnections between the frontal lobes and other structures point to an approach based on neuroanatomical systems that are both localized and distributed (Mesulam, 1990; Stuss et al., 1995).

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