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Impaired behavior on real-world tasks following damage to the ventromedial prefrontal cortex

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Abstract

Patients with damage to the ventromedial prefrontal cortices (VMPC) commonly manifest blatant behavioral navigation defects in the real world, but it has been difficult to measure these impairments in the clinic or laboratory. Using a set of “strategy application” tasks, which were designed by Shallice and Burgess (1991) to be ecologically valid for detecting executive dysfunction, we investigated the hypothesis that VMPC damage would be associated with defective performance on such tasks, whereas damage outside the VMPC region would not. A group of 9 patients with bilateral VMPC damage was contrasted with comparison groups of participants with (a) prefrontal brain damage outside the VMPC region ($n=8$); (b) nonprefrontal brain damage ($n=17$); and (c) no brain damage ($n=20$). We found support for the hypothesis: VMPC patients had more impaired performances on the strategy application tasks, especially on a Multiple Errands Test that required patients to execute a series of unstructured tasks in a real-world setting (shopping mall). The results are consistent with the notion that efficacious behavioral navigation is dependent on the VMPC region. However, the strategy application tasks were relatively time consuming and effortful, and their diagnostic yield over and above conventional executive functioning tests may not be sufficient to warrant their inclusion in standard clinical assessment.

INTRODUCTION

Damage to the ventromedial prefrontal cortex (VMPC) is well known to cause severe impairments of real-world behavior, leading in particular to disruption of social conduct and interpersonal behavior, impaired occupational functioning, and defective emotional regulation and decision making. Such deficits, however, have been notoriously difficult to capture in clinical and experimental laboratory settings. For example, it has been noted by many investigators that patients with VMPC lesions often—perhaps even typically—perform normally on tasks such as the Wisconsin Card Sorting Test, Trail Making Test, Tower of London (and its variants), Category Test, and Stroop Color–Word Interference Test. Not all VMPC patients pass all of these types of test, of course, but some of the patients with the most egregious real-world behavioral defects do have sterling laboratory performance profiles (cf. Eslinger & Damasio, 1985). One frequently cited explanation for this seeming paradox is that the laboratory tasks provide considerable structure, direction, and guidance, so that patients do

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not have to cope with the types of ambiguous, open-ended, unconstrained situations that are more commonly faced in the real world (e.g., Lezak, Howieson, & Loring, 2004, pp. 611–638).

Against this background, it is interesting to consider some notable task exceptions. One is the Iowa Gambling Task (IGT), which was developed by Bechara and colleagues (Bechara, Damasio, Damasio, & Anderson, 1994) in part to address the limitations of extant laboratory tasks of decision making. The IGT has proven remarkably effective at exposing decision-making deficits in VMPC patients and in a number of other populations with known or suspected dysfunction of VMPC and VMPC-related neural systems (e.g., Bechara, 2004; Bechara, Tranel, & Damasio, 2000; Denburg, Tranel, & Bechara, 2005; Fellows & Farah, 2005; Rogers et al., 1999; Stout, Bussemeyer, Lin, Grant, & Bonson, 2004; for review, see Yechiam, Bussemeyer, Stout, & Bechara, 2005). The IGT, however, is *sine qua non* a decision-making task, and despite its popularity in the research literature, the relationship between IGT performance and real-world behavior remains largely unexplored (see Anderson, Barrash, Bechara, & Tranel, 2006, for a partial exception).

Several other researchers have devoted considerable effort to developing tests that would be more ecologically valid as a means to assess the typical “dysexecutive syndrome” in patients with brain injuries. For example, Wilson, Evans, Emslie, Alderman, and Burgess (1998) developed a battery of tests known as the Behavioural Assessment of the Dysexecutive Syndrome (BADS). The BADS included a modified version of the Six Elements Test (SET); the SET, in turn, had originally been described by Shallice and Burgess (1991), along with another so-called “strategy application” task (the Multiple Errands Test, or MET), as a more sensitive means of flushing out the behavioral navigation defects of brain-injured patients. The MET, in particular, was designed to mimic various “real-world” demands and activities (e.g., shopping in a business precinct). These semiquantitative tasks provided relatively unstructured, open-ended situations with multiple subgoals, and they lacked the constraint and direction typical of clinical neuropsychological measures.

In the initial report on the SET and MET, Shallice and Burgess (1991) described three patients who had frontal lobe injuries as a consequence of severe head trauma, and who manifested impaired performances on the SET and MET despite relatively normal intelligence, language, and perception. Since then, these tasks (and various modifications) have been utilized by a number of researchers to investigate executive functioning in normals and various patient populations (e.g., Alderman, Burgess, Knight, & Henman, 2003; Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Channon & Crawford, 1999; Duncan, Johnson, Swales, & Freer, 1997; Goel & Grafman, 2000; Goldstein, Bernard, Fenwick, Burgess, & McNeil, 1993; Jellic, Henquet, Derix, & Jolles, 2001; Kafer & Hunter, 1997; Kliegel, McDaniel, & Einstein, 2000; Knight, Alderman, & Burgess, 2002; Levine, Dawson, Boutet, Schwartz, & Stuss, 2000a; Levine et al., in press; Levine et al., 1998; Wilson et al., 1998), especially with an eye to rehabilitation planning (e.g., Levine et al., 2000b; Manly, Hawkins, Evans, Woldt, & Robertson, 2002). By now, there are consistent findings supporting the conclusion that these tasks are useful to characterize and quantify executive functioning deficits, and Burgess and his colleagues have made a convincing argument that “strategy application” types of task may be superior to traditional clinical neuropsychological tests (e.g., Wisconsin Card Sorting Test, WCST; Tower of London) at probing “real-world” deficits in executive functioning (Burgess et al., 2006).

Most of the published work involving the SET and MET (and their spin-offs) has focused on the construct validity of the tasks vis-à-vis executive functioning. Very few previous studies have given attention to neuroanatomical issues. The gist of most of the available work is that executive dysfunction—and failure on the SET and MET—is associated with frontal lobe damage. Beyond that, however, it is difficult to be more specific. For example, it is not clear

if damage to the medial orbital and lower medial prefrontal sectors (the region that we have termed the ventromedial prefrontal cortices, or VMPC; see Tranel, Damasio, Denburg, & Bechara, 2005, for a precise description) is typical of patients who fail the SET and MET. In most previous studies, neuroanatomical issues were not addressed at all (e.g., Alderman et al., 2003; Burgess et al., 1998; Duncan et al., 1997; Jelicic et al., 2001; Kafer & Hunter, 1997; Kliegel et al., 2000; Knight et al., 2002; Wilson et al., 1998). Shallice and Burgess (1991) provided brief descriptions of the lesions in their original three cases, but other than mentioning frontal lobe damage, no specific details are provided, and it is not clear whether or not the VMPC was affected by the lesions (for two of these patients, a single computed tomography, CT, cut is provided in the recent review paper of Burgess et al. (2006), but this does not clarify whether there is VMPC involvement). Levine et al. (1998) included 10 patients with focal frontal lesions in their study (which involved a modified version of the SET), but at least half of these patients actually did not have VMPC damage (and lesion localization was based on acute clinical CT scans in most of the patients). Burgess, Veitch, de Lacy Costello, and Shallice (2000; also see Burgess, 2000), using mostly tumor cases (many of which were gliomas), undertook a neuroanatomical analysis of performance on a task that roughly resembled the SET and found that defects were associated with medial and polar left prefrontal structures (but not VMPC), and right dorsolateral prefrontal structures. An important caveat about many of the published studies is that the “frontal” patients tend to be severe head injury cases, making lesion localization somewhat hazardous to begin with.

The issue of whether or not the VMPC is specifically involved in tasks such as the SET and MET is important, because the real-world behavioral navigation impairments that are the real crux of the “dysexecutive syndrome” have been repeatedly linked to VMPC damage (e.g., Anderson et al., 2006; Barrash, Tranel, & Anderson, 2000; Shuren & Grafman, 2002; Stuss & Levine, 2002). Damage to superior mesial or dorsolateral sectors, for example, does not typically lead to blatant impairments of social conduct and associated functions (e.g., Anderson & Tranel, 2002). (A partial exception is the analysis by Burgess, 2000; Burgess et al., 2000, which linked the general construct of “multitasking” to medial and polar left prefrontal structures and right dorsolateral prefrontal cortex.) Moreover, there is a strong link between the VMPC and numerous facets of emotional processing (e.g., A. R. Damasio, 1994), and the role of emotional dysfunction in real-world behavioral incompetency in VMPC patients has been recently documented (Anderson et al., 2006; we return to this issue in the Discussion).

In the current study, we sought to replicate and extend the initial findings of Shallice and Burgess (1991), using a closely adapted version of their task and focusing on a carefully selected group of patients with focal, stable damage to VMPC. This group was contrasted with comparison groups of participants with (a) prefrontal brain damage outside the VMPC region; (b) nonprefrontal brain damage; and (c) no brain damage. We hypothesized that VMPC damage would be associated with defective performance on strategy application tasks, whereas damage outside the VMPC region would not. A secondary goal was to explore the extent to which defects on conventional neuropsychological tests of “executive functioning” would be manifest in VMPC patients and whether performance on conventional executive functioning tests would be related to performance on the strategy application tasks.

METHOD

Participants

The brain-damaged participants for this study were selected from the Patient Registry in the Division of Cognitive Neuroscience at the University of Iowa. The patients have undergone extensive screening and comprehensive characterization of neuropsychological functioning (Tranel, in press) and neuroanatomical status (H. Damasio & Frank, 1992; Frank, Damasio, & Grabowski, 1997), in connection with their participation in our general research program. In

keeping with the conditions for enrollment in our Patient Registry, the participants had to be free of a history of mental retardation, learning disability, psychiatric disorder, or substance abuse. (The screening of participants for enrollment in our Patient Registry is conducted by a team composed of a board-certified neuropsychologist and a board-certified neurologist, prior to the collection of any experimental data. Extensive interview data, information from standard questionnaires (e.g., the Michigan Alcohol Screening Test, Selzer, 1971), and data from the medical record are used to assure that enrolled patients satisfy the criteria for inclusion in our Patient Registry. The neuropsychological, neuroanatomical, and experimental studies were conducted when the participants were in the chronic phase of recovery: specifically, 3 or more months after the onset of brain damage. All participants provided informed consent, which complied with the local Institutional Review Board and with pertinent federal guidelines for human research participation.

We formed four groups of participants, as follows:

1. Ventromedial prefrontal group (VMPC; n=9)—This was the main target group for the study, and it included 9 patients with bilateral damage to the VMPC region. For the purposes of this study, the VMPC was defined as the region that encompasses the medial orbital sector and the lower medial prefrontal sector of the prefrontal lobes (Brodmann areas medial 11, 25, 12, ventromedial 10, and anteroventral 32; see Tranel et al., 2005, for a detailed illustration of this region). The lesions were caused by cerebrovascular accident ($n=5$) or resection of benign tumor ($n=4$).

2. Prefrontal comparison group (PFC; n=8)—This was a brain-damaged comparison group that included patients with prefrontal damage outside the VMPC region: specifically, in left or right prefrontal sectors exclusive of those identified in (1) above. Participants in this group had lesions that were neuroanatomically heterogeneous; some were circumscribed to the right or left dorsolateral or lateral orbital region, and some were large frontoparietal lesions. Participants in the prefrontal comparison group were also selected so as to have demographic characteristics similar to those of the VMPC group. The lesions were caused by cerebrovascular accident ($n=6$); resection of arteriovenous malformation (AVM; $n=1$), or benign tumor ($n=1$).

3. Nonprefrontal comparison group (nonPFC; n=17)—This was a brain-damaged comparison group that included patients with damage outside the prefrontal region: specifically, in left or right hemisphere structures exclusive of structures anterior to and including the premotor cortices. Participants in this group were also selected so as to have demographic characteristics similar to those of the VMPC group. The lesions were caused by cerebrovascular accident ($n=11$), resection of AVM ($n=3$), temporal lobectomy ($n=2$), or herpes simplex encephalitis ($n=1$).

For the three brain-damaged groups, the neuroanatomical classification was based on the following methods. Neuroanatomical analysis was derived from magnetic resonance (MR) data or, for a few patients in whom an MR could not be obtained due to the presence of metal clips, on computerized axial tomography data. All neuroimaging data were obtained at 3 or more months postlesion onset, and lesion locations were mapped according to our standard procedures (H. Damasio & Frank, 1992; Frank et al., 1997). Based on the neuroanatomical analysis, participants were classified into one of the three brain-damaged groups specified above (additional details regarding this type of neuroanatomical classification are provided in Anderson et al., 2006). The classification of participants into the different neuroanatomical groups was reviewed and confirmed by H. Damasio.

We used the MAP-3 and Brainvox techniques developed by H. Damasio (2000) to calculate lesion overlap maps for the three patient groups. In brief, this allows a determination of how

many patients in each group have lesions at any particular voxel; this calculation is color coded and rendered in standard brain space (see H. Damasio, Tranel, Grabowski, Adolphs, & Damasio, 2004, for details of this procedure). Figure 1, Figure 2, and Figure 3 provide lesion overlap maps for the VMPC, PFC, and nonPFC groups, respectively. Figure 1 shows that the highest area of lesion overlap in the VMPC group (coded in red) is in the medial orbital and lower medial prefrontal region, bilaterally. In the PFC group (Figure 2), the most common area of damage is in right posterolateral orbital and left posterior dorsolateral regions; none of the patients had lesions encroaching on the VMPC region. Figure 3 shows that for the nonPFC group, none of the patients had lesions that encroached on prefrontal cortices.

4. Normal comparison group (NC; n=20)—This was a normal comparison group, composed of 20 participants who were free of neurological and psychiatric disease. The normal participants were recruited through the Department of Neurology and were compensated for their participation. These participants had to be unfamiliar with the local urban area (so that they would be operating from the same knowledge base, more or less, as the brain-damaged participants, most of whom are from areas outside of Iowa City), and this was ascertained by one of the experimenters (J.H.N.). Participants in the normal comparison group were also selected so as to have demographic characteristics similar to those of the VMPC group.

Demographic data for the four groups of participants are provided in Table 1. The groups were well matched on demographic characteristics, with similar ages, educational levels, gender ratios, and handedness distributions. The VMPC and PFC groups had somewhat longer chronicity (time since lesion onset) than the nonPFC group, but this was not statistically significant in a one-way analysis of variance (ANOVA).

Procedure

Neuropsychological assessment—All brain damaged participants were administered a comprehensive battery of neuropsychological tests, in accordance with their participation in our general research program (see Tranel, in press). The tests probe various cognitive domains including orientation and attention, IQ, verbal and visual memory, speech and language, visuo-perceptual and visuo-constructional abilities, and executive functions. For the purposes of the current study, the following specific tests were deemed most relevant, and specific data for these tests are provided (see Table 2):

1. IQ: Wechsler Adult Intelligence Scale-R (Verbal IQ; Performance IQ)
2. Memory: Verbal=Auditory-Verbal Learning Test; Visual=Benton Visual Retention Test
3. Executive functions: Wisconsin Card Sorting Test; Trail Making Test (Trail Making B minus Trail Making A)

Experimental measures

Six Elements Test: This set of tasks was modeled closely on the Shallice and Burgess Six Elements Test protocol (Shallice & Burgess, 1991). Participants completed the tests in a laboratory setting, set up so that the participant performed the tasks under observation, but without the examiner in the room (via a one-way window). The participants were instructed to complete six tasks (two sets of three tasks) within a time limit of 15 minutes, in a manner that would maximize their scores. The following tasks were utilized:

1. Naming A and Naming B subtasks. *These subtasks involved writing down the names of objects presented in a pictorial format in two notebooks labeled “Naming A” and “Naming B.” Each notebook contained 50 pictures of common natural and artificial entities.*

2. Arithmetic A and Arithmetic B subtasks. *These subtasks required participants to examine flashcards with addition, subtraction, multiplication, and division problems, and to answer the problems. Each set of flashcards contained 30 different problems, ordered to be increasingly difficult across the set.*
3. Dictation A and Dictation B. *These subtasks required participants to provide verbal descriptions of (A) how they arrived at the University of Iowa Hospitals and Clinics (UIHC), and (B) their intended route back home. The participants provided the information orally, and their responses were recorded on a tape recorder (the participants did not have to operate any equipment). (Many of the brain-damaged patients have had multiple visits to UIHC, which could give them an advantage over the normal comparison participants on the dictation tasks. However, this was probably at least partially offset by the fact that more of the normal comparison participants were from closer to Iowa City than the patients. Moreover, a qualitative analysis of the dictation protocols generated by the patient groups and the normal group did not suggest that any group had a particular advantage on these tasks.)*

Participants were given five rules for these tasks (after Shallice and Burgess, 1991):

- You are not allowed to do the two subtasks of the same type one after the other.
- Each of the six subtasks is given equal weight.
- Within the Naming and Arithmetic subtasks, points will be given for correct answers.
- For the pictures/problems, earlier items will be given more credit than later ones.
- Errors and omissions will count against you.

The instructions that Shallice and Burgess (1991) used were followed virtually verbatim in our Six Elements Test. The tasks and rules were explained to the participants, and then the participants were asked to recite the tasks and rules. They were corrected if any errors were noted in their descriptions. A printed version of the tasks and rules was also available throughout the 15-minute duration of the test. Participants were reminded that they should try to maximize their score and that they would have 15 minutes to work on the tasks. The experimenter recorded the number of tasks attempted and the time spent on each subtask. The maximum time spent on any one subtask was recorded. Task completion credit was given for tasks that were completed correctly according to the rules. An overall score was calculated by dividing the number of tasks completed correctly by the total number of tasks.

Multiple Errands Test: Subsequent to the completion of the Six Elements Test, participants were instructed about the second part of the experiment, which required in vivo participation at a mall located in a downtown urban campus. Participants were escorted to the mall via the University of Iowa's Cambus transportation system. While still at the hospital, participants were provided with the following tasks and rules (presented in both written and spoken formats):

Tasks for Multiple Errands Test

1. Buy one cookie.
2. Buy one package of cough drops.
3. Buy one Kleenex package.
4. Buy one postcard.
5. Buy one book marker.
6. Buy one candle.

7. You must meet up with the experimenter 15 minutes after starting your tasks. (*This was explained as a “check-in point,” and participants were reminded that they had more than 15 minutes to complete all of the tasks.*)
8. You must gather the following pieces of information and write them down on the note card provided:
 - a. The name of the store in the Old Capital Mall likely to have the most expensive item.
 - b. The price of one dozen roses.
 - c. The number of fast food eating establishments in the Old Capital Mall.
 - d. The forecast high temperature for Denver, Colorado today.

Rules for Multiple Errands Test (the rules followed those used by Shallice and Burgess):

- You are to spend as little money as possible (within reason).
- You are to take as little time as possible (without rushing excessively).
- No store should be entered other than to buy something.
- Please tell the experimenter when you leave a store what you have bought.
- You are not to use anything not bought on your adventure (other than your own watch) to assist you.
- You may do the tasks in any order.

After arriving at the mall and before starting the experiment, participants were tested on their recall of the rules (the rules were repeated if the participant did not get them correct). A card containing all of the mall tasks and rules was carried by each participant throughout the experiment. The participants were instructed not to go beyond the sidewalk surrounding the entire mall. Additionally, participants were told that the experimenter was not permitted to help execute any tasks. Each participant was provided with \$10.00, and they were not permitted to use any of their own money. Throughout the Multiple Errands Task, participants were followed around the mall in a covert manner (two experimenters, who were blind to the group membership of the participants and to the hypotheses of the study, assisted in this process). Participants were not corrected when errors were made, and they were allowed to discontinue the task at any time. All participants were fully debriefed upon their return to the hospital.

As defined by Shallice and Burgess (1991), errors during the execution of tasks were recorded as *inefficiencies* (when a more effective strategy could have been applied), *rule breaks* (where a specific rule is broken), *interpretation failure* (where the requirements of a particular task are misunderstood), and *task failure* (a task is either not carried out or not completed satisfactorily). The *total mall errors* were calculated by summing across these error types. Also, the experimenters monitored and recorded *mall attempts* (number of tasks attempted), *mall completions without errors* (number of tasks completed according to the rules), *total mall completions* (number of tasks completed, both with and without errors), and *total time* (the total time the participant spent on the mall tasks). For the purposes of this scoring, the total number of tasks was considered to be 11: This includes the six purchasing tasks, the check-in task, and the four information-gathering tasks. The mall completions without errors score is a subset of the total mall completions (with and without errors).

Data analysis—The primary dependent variables were the various measures for the Six Elements Test and the Multiple Errands Test, as specified above. The groups were compared on these variables using multivariate analysis of variance (MANOVA) and correcting for multiple comparisons (Bonferroni) wherever appropriate. We also conducted correlational

analyses, to explore the relationships between performances on the SET and MET and the various neuropsychological measures. The correlational analyses were conducted in the brain-damaged participants (overall $N=34$).

RESULTS

Neuropsychological data

Neuropsychological data for the various groups are provided in Table 2. One-way ANOVAs (with 4 levels of group for the Verbal IQ and Performance IQ variables, and 3 levels of group for the other neuropsychological variables, Bonferroni corrected) failed to yield significant between-group differences on any of the neuropsychological measures (all $ps > .10$). Of particular note, the VMPC group did not differ from the PFC and nonPFC groups on the Wisconsin Card Sorting Test, for number of categories completed and number of perseverative errors, nor did the VMPC group differ from the other brain-damaged groups on the Trail Making Test measure. At a group level, none of the neuropsychological test performances enumerated in Table 2 falls in the impaired range, where “impaired” is defined in the conventional fashion as 2 or more standard deviations below normal. At the level of individual patients, some patients did have impaired performances on certain tests. The key finding for the current study, however, is the lack of group differences on the neuropsychological measures, particularly the “executive function” tests (WCST, Trail Making).

Six Elements Test

A one-way MANOVA on the three variables from the SET, with Group (4 levels) as the independent variable, did not yield any significant between-group differences (see Table 3). The VMPC group attempted fewer tasks (3.7) than the PFC (4.8), nonPFC (4.2), and normal comparison (4.9) groups, but this difference was not statistically significant ($p=.126$, $\eta^2=.107$).

Multiple Errands Test

Two one-way MANOVAs with Group (4 levels) as the independent variable were conducted on the dependent variables from the MET (see Table 4). In one of these, the various error measures (inefficiencies, rule breaks, interpretation failures, task failures, and total errors) served as the dependent variables; in the other, the additional mall measures (attempts, completions without errors, total completions, total time) served as the dependent variables. The MANOVA on the error scores yielded significant between-group differences for task failures, $F(3, 50)=8.49$, $p=.000$, $\eta^2=.338$, and total mall errors, $F(3, 50)=6.78$, $p=.001$, $\eta^2=.289$, and the interpretations failure measure was close to significance, $F(3, 50)=2.56$, $p=.065$, $\eta^2=.133$. Follow-up pairwise contrasts (using Bonferroni adjustment for multiple comparisons) indicated that the VMPC group had significantly more task failures than the normal comparison group ($p=.000$) and significantly more total mall errors than the normal comparison group ($p=.000$) and the nonPFC comparison group ($p=.020$). Insofar as the other MET variables are concerned, the MANOVA yielded significant between-group differences for mall attempts, $F(3, 50)=3.49$, $p=.022$, $\eta^2=.173$, mall completions without errors, $F(3, 50)=8.94$, $p=.000$, $\eta^2=.349$, and total mall completions, $F(3, 50)=4.97$, $p=.004$, $\eta^2=.230$. Follow-up pairwise contrasts (using Bonferroni adjustment for multiple comparisons) indicated that the VMPC group had significantly fewer mall attempts ($p=.020$) and total mall completions ($p=.004$) than the normal comparison group and significantly fewer mall completions without errors than the normal ($p=.000$) and nonPFC ($p=.048$) comparison groups. The PFC group had significantly fewer mall completions without errors than the normal group ($p=.005$).

In sum, the data from the MET indicate that the VMPC group had a higher number of overall mall errors (7.6) than the PFC (5.9) and nonPFC (4.5) brain-damaged comparison groups and the normal comparison group (3.4). Compared to the normal group, the VMPC group had more

than twice as many small errors. The VMPC group tended to have higher error scores on the various error subtypes, too, especially rule breaks and task failures. The VMPC group had fewer small attempts and fewer small completions (both without errors and total) than the other brain-damaged groups and the normal comparison group. The total time was highest in the VMPC group, although this was not statistically significant and did not differ much from that of the nonPFC group.

Correlations with neuropsychological measures

The correlation matrix for the neuropsychological measures and various measures from the SET and MET is enumerated in Table 5. Of the various neuropsychological measures, Trail Making (time, Part B minus Part A) yielded significant correlations with two SET measures (attempts, overall score) and with the small attempts measure from the MET (these are all negative, as would be expected—i.e., poorer performance on Trails, increased time, was correlated with poorer performance on SET and MET tasks). The Categories completed score from the WCST correlated significantly and negatively with MET total error score and significantly and positively with MET small attempts score. The Perseverative Errors score from the WCST also correlated significantly and negatively with MET small attempts. All of these correlations are in the expected direction—that is, poorer performance on the neuropsychological measures was associated with poorer performance on the SET and MET. The magnitude of the relationships is generally moderate (in the .4 to .6 range), suggesting that the WCST and Trail Making tests do share some common variance with the SET and MET tests, but that there is also a substantial degree of nonoverlap. The IQ and memory measures did not correlate significantly with any of the SET and MET measures.

DISCUSSION

The data from this study confirm previous findings from Shallice, Burgess, and colleagues (Shallice & Burgess, 1991; Burgess et al., 2006), indicating that failure on various “real-world” types of strategy application task—in particular, the Multiple Errands Test (MET)—is common following frontal lobe damage. Our data extend previous work by indicating that this pattern is especially characteristic of damage to the ventromedial prefrontal sector of the frontal lobes. Our findings also indicate that performances on the SET and MET were not correlated with IQ or memory measures, but there was a modest relationship between some SET and MET variables and scores on the Wisconsin Card Sorting Test and the Trail Making Test.

Our findings provide partial support for the main hypothesis. Specifically, it was found that damage to the VMPC sector was associated with defective performance on the MET, as hypothesized. Damage to the prefrontal cortex more generally (outside the VMPC sector) also tended to be associated with poorer performances on strategy application tasks—specifically, the PFC group had more errors on the MET, and fewer small completions, than did the nonPFC and normal comparison groups, although the PFC group was less discrepant from the comparison groups than was the VMPC group. Overall, though, poor performances on the MET tasks were more characteristic of participants with VMPC damage, and the VMPC participants clearly had the worst MET performances of any of the other groups in the study.

As far as conventional neuropsychological tests such as the Wisconsin Card Sorting Test are concerned, we went into the study with two goals: One was to explore whether such “executive functioning” tests would discriminate participants with VMPC damage, and the other was to explore the extent to which SET and MET performances would correlate with neuropsychological measures. Regarding the first goal, we found that the VMPC group did not differ from the other brain-damaged groups on neuropsychological measures and, in particular, did not differ on the two executive functioning tests—namely, the Wisconsin Card Sorting Test and the Trail Making Test. In fact, as a group, the VMPC group was virtually

indistinguishable from the nonPFC comparison group. This outcome confirms previous work that has demonstrated that conventional executive functioning tests are not particularly sensitive to VMPC integrity (e.g., Anderson, Tranel, Grabowski, Adolphs, & Damasio, 1991; Grafman, Jonas, & Salazar, 1990; Miyake et al., 2000; Stuss et al., 2000). As far as correlations with SET and MET variables are concerned, we did find a couple of consistent, modest relationships: (a) The Trail Making Test (calculated as time for Part B minus time for Part A) correlated significantly with two SET variables and one MET variable; (b) the MET mall attempts variable correlated significantly with two variables from the WCST and with the Trail Making Test. The degree of correlation was such that roughly 20 to 35% of the variance on certain SET and MET variables could be explained by WCST and/or Trail Making Test performances. Our results are generally consistent with data reported by Knight et al. (2002), who found correlations in the .5 to .6 range between the Modified Card Sorting Test percentage Perseverative Errors score and several MET variables (the investigators used a simplified version of the MET).

Overall, our results really do not provide compelling support for the utility of the SET and MET procedures for assessing behavioral navigation impairments in brain-damaged patients, at least insofar as clinical application is concerned. There are several reasons for this conclusion. As far as the SET is concerned, we actually did not find evidence of compelling task failures in the VMPC group. The only measure on which the group was below all of the other groups was number of tasks attempted, and this was not statistically significant. This result does not support the conclusion that the SET would be diagnostically useful on a case-by-case basis, especially in regard to linking up the test with specific neuroanatomical underpinnings. The MET yielded more encouraging results, and the VMPC group was consistently below the other comparison groups on nearly every measure from the MET, including total errors and numbers of attempts and completions. Even here, though, the between-group differences were not dramatic, and it would be hard to argue that the test would be diagnostically useful on a case-by-case basis. One also has to factor in the time and effort that these tasks require, not only from the participants but also from the experimenter. The MET, in particular, is time- and labor-intensive for all concerned. Thus, taking into account both the magnitude of between-group differences and the time and effort requirements of the tests, it seems unreasonable to suggest that the SET and MET could be easily incorporated as standard parts of a neuropsychological diagnostic procedure. The fact that two conventional procedures—the WCST and Trail Making Test—correlated moderately with some SET and MET variables also makes it difficult to stake a strong claim for the utility of these “strategy application” procedures.

We should hasten to add that we have no disagreement with the general objective of developing more “ecologically valid” measures of executive functioning, as characterized by the research program of Burgess and colleagues (see Burgess et al., 2006). Those researchers provide a detailed and convincing set of arguments for why extant clinical measures (such as the WCST) are lacking and why certain experimental measures (such as the MET) may offer hope for improvement. And it could be that applications to patients with frontal damage caused by other etiologies, such as head injury and malignant brain tumors (as is more common in the patient populations reported by Burgess and colleagues; see also Levin, Goldstein, Williams, & Eisenberg, 1991), would return a higher yield, especially when rehabilitation planning is factored into the equation. The patients we used in our study all had focal, stable brain injuries caused mainly by stroke or surgical resection of benign tumors, and this may account for some of the differences between our conclusions and those set forth by Burgess and colleagues (e.g., Burgess et al., 2006). In addition, if procedures such as the MET could be set up as virtual environments and run on a computer within the context of a neuropsychological testing room, this might greatly reduce the time and effort demands associated with the actual shopping mall visit and, in turn, improve the net diagnostic yield for the MET.

On the upside, the MET in particular was useful to capture “real-world” behavioral navigation defects in patients with frontal lobe damage, and our study shows that this relationship is strongest for bilateral VMPC damage. Prefrontal lesions outside the VMPC region did not lead to as severe of impairments, and lesions outside the prefrontal cortices were not associated with strategy application task failure. These results add neuroanatomical specificity to previous work, especially the elegant program of research by Burgess and colleagues on these and related “multitasking” measurements (see Burgess et al., 2006, for review). Recently, we have demonstrated that impairments in real-world competencies in patients with VMPC damage are substantially accounted for by emotional disturbances, especially heightened emotional reactivity and hypoemotionality (Anderson et al., 2006). In that study, too, there was a considerable degree of anatomical specificity in the findings, and prefrontal damage outside the VMPC region did not consistently lead to either emotional disturbance or impaired real-world competencies. Collectively, these studies add empirical support to the notion that the VMPC is critical for successful real-world behavioral navigation. The measurement of these competencies in the clinic or laboratory, however, remains a challenge.

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REFERENCES

- Alderman N, Burgess PW, Knight C, Henman C. Ecological validity of a simplified version of the multiple errands shopping test. *Journal of the International Neuropsychological Society* 2003;9:31–44. [PubMed: 12570356]
- Anderson SW, Barrash J, Bechara A, Tranel D. Impairments of emotion and real world complex behavior following childhood- or adult-onset focal lesions in prefrontal cortex. *Journal of the International Neuropsychological Society* 2006;12:224–235. [PubMed: 16573856]
- Anderson SW, Damasio H, Jones RD, Tranel D. Wisconsin Card Sorting Test performance as a measure of frontal lobe damage. *Journal of Clinical and Experimental Neuropsychology* 1991;13:909–922. [PubMed: 1779030]
- Anderson, SW.; Tranel, D. Neuropsychological consequences of dysfunction in human dorsolateral prefrontal cortex. In: Boller, F.; Grafman, J.; Grafman, J., editors. *Handbook of neuropsychology*. 2nd ed. Vol. 7. The frontal lobes. Amsterdam: Elsevier; 2002. p. 145-156.
- Barona A, Reynolds CR, Chastain R. A demographically based index of premorbid intelligence for the WAIS-R. *Journal of Consulting and Clinical Psychology* 1984;52:885–887.
- Barrash J, Tranel D, Anderson SW. Acquired personality disturbances associated with bilateral damage to the ventromedial prefrontal region. *Developmental Neuropsychology* 2000;18:355–381. [PubMed: 11385830]
- Bechara A. The role of emotion in decision-making: Evidence from neurological patients with orbitofrontal damage. *Brain and Cognition* 2004;55:30–40. [PubMed: 15134841]
- Bechara A, Damasio AR, Damasio H, Anderson SW. Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition* 1994;50:7–15. [PubMed: 8039375]
- Bechara A, Tranel D, Damasio H. Characterization of the decision-making deficit of patients with ventromedial prefrontal cortex lesions. *Brain* 2000;123:2189–2202. [PubMed: 11050020]
- Burgess PW. Strategy application disorder: The role of the frontal lobes in human multitasking. *Psychological Research* 2000;63:279–288. [PubMed: 11004881]
- Burgess PW, Alderman N, Evans J, Emslie H, Wilson BA. The ecological validity of tests of executive function. *Journal of the International Neuropsychological Society* 1998;4:547–558. [PubMed: 10050359]
- Burgess PW, Alderman N, Forbes C, Costello A, Coates LM-A, Dawson DR, et al. The case for the development and use of “ecologically valid” measures of executive functions in experimental and

- clinical neuropsychology. *Journal of the International Neuropsychological Society* 2006;12:194–209. [PubMed: 16573854]
- Burgess PW, Veitch E, de Lacy Costello A, Shallice T. The cognitive and neuroanatomical correlates of multitasking. *Neuropsychologia* 2000;38:848–863. [PubMed: 10689059]
- Channon S, Crawford S. Problem-solving in real-life type situations: The effects of anterior and posterior lesions on performance. *Neuropsychologia* 1999;37:757–770. [PubMed: 10408644]
- Damasio, AR. *Descartes' error: Emotion, reason and the human brain*. New York: Grosset/Putnam; 1994.
- Damasio, H. The lesion method in cognitive neuroscience. In: Boller, F.; Grafman, J., editors. *Handbook of neuropsychology*. 2nd ed.. Vol. 1. Amsterdam: Elsevier; 2000. p. 77–102.
- Damasio H, Frank R. Three-dimensional in vivo mapping of brain lesions in humans. *Archives of Neurology* 1992;49:137–143. [PubMed: 1736845]
- Damasio H, Tranel D, Grabowski T, Adolphs R, Damasio A. Neural systems behind word and concept retrieval. *Cognition* 2004;92:179–229. [PubMed: 15037130]
- Denburg NL, Tranel D, Bechara A. The ability to decide advantageously declines prematurely in some normal older persons. *Neuropsychologia* 2005;43:1099–1106. [PubMed: 15769495]
- Duncan J, Johnson R, Swales M, Freer C. Frontal lobe deficits after head injury: Unity and diversity of function. *Cognitive Neuropsychology* 1997;14:713–741.
- Eslinger PJ, Damasio AR. Severe disturbance of higher cognition after bilateral frontal lobe ablation: Patient EVR. *Neurology* 1985;35:1731–1741. [PubMed: 4069365]
- Fellows LK, Farah MJ. Different underlying impairments in decision making following ventromedial and dorsolateral frontal lobe damage in humans. *Cerebral Cortex* 2005;15:58–63. [PubMed: 15217900]
- Frank RJ, Damasio H, Grabowski TJ. Brainvox: An interactive, multimodal, visualization and analysis system for neuroanatomical imaging. *NeuroImage* 1997;5:13–30. [PubMed: 9038281]
- Goel V, Grafman J. Role of the right prefrontal cortex in ill-structured planning. *Cognitive Neuropsychology* 2000;17:415–436.
- Goldstein LH, Bernard S, Fenwick PBC, Burgess PW, McNeil J. Unilateral frontal lobectomy can produce strategy application disorder. *Journal of Neurology, Neurosurgery, and Psychiatry* 1993;56:274–276.
- Grafman J, Jonas B, Salazar A. Wisconsin Card Sorting Test performance based on location and size of neuroanatomical lesion in Vietnam veterans with penetrating head injury. *Perceptual and Motor Skills* 1990;71:1120–1122. [PubMed: 2087366]
- Jelicic M, Henquet CE, Derix MM, Jolles J. Test–retest stability of the behavioural assessment of the dysexecutive syndrome in a sample of psychiatric patients. *International Journal of Neuroscience* 2001;110:73–78. [PubMed: 11697212]
- Kafer KL, Hunter M. On testing the face validity of planning/problem-solving tasks in a normal population. *Journal of the International Neuropsychological Society* 1997;3:108–119. [PubMed: 9126852]
- Kliegel M, McDaniel MA, Einstein GO. Plan formation, retention, and execution in prospective memory: A new approach and age-related effects. *Memory and Cognition* 2000;28:1041–1049.
- Knight C, Alderman N, Burgess PW. Development of a simplified version of the multiple errands test for use in hospital settings. *Neuropsychological Rehabilitation* 2002;12:231–255.
- Levin, HS.; Goldstein, FC.; Williams, DH.; Eisenberg, HM. The contribution of frontal lobe lesions to the neurobehavioral outcome of closed head injury. In: Levin, HS.; Eisenberg, HM.; Benton, AL., editors. *Frontal lobe function and dysfunction*. New York: Oxford University Press; 1991. p. 318–338.
- Levine B, Dawson D, Boutet I, Schwartz ML, Stuss DT. Assessment of strategic self-regulation in traumatic brain injury: Its relationship to injury severity and psychosocial outcome. *Neuropsychology* 2000a;14:491–500. [PubMed: 11055251]
- Levine B, Robertson I, Clare L, Carter G, Hong J, Wilson BA, et al. Rehabilitation of executive functioning: An experimental-clinical validation of goal management training. *Journal of the International Neuropsychological Society* 2000b;6:299–312. [PubMed: 10824502]
- Levine B, Robertson I, Fahy L, Mandic M, Palmer H, McHugh T, et al. The psychometric characteristics of simulated real-life tasks. *Journal of Clinical and Experimental Neuropsychology*. (in press)

- Levine B, Stuss DT, Milberg WP, Alexander MP, Schwartz M, MacDonald R. The effects of focal and diffuse brain damage on strategy application: Evidence from focal lesions, traumatic brain injury and normal aging. *Journal of the International Neuropsychological Society* 1998;4:247–264. [PubMed: 9623000]
- Lezak, MD.; Howieson, DB.; Loring, DW. *Neuropsychological assessment*. 4th ed.. New York: Oxford University Press; 2004.
- Manly T, Hawkins K, Evans J, Woldt K, Robertson LH. Rehabilitation of executive function: Facilitation of effective goal management on complex tasks using periodic auditory alerts. *Neuropsychologia* 2002;40:271–281. [PubMed: 11684160]
- Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD. The unity and diversity of executive functions and their contributions to complex “Frontal Lobe” tasks: A latent variable analysis. *Cognitive Psychology* 2000;41:49–100. [PubMed: 10945922]
- Rogers RD, Everitt BJ, Baldacchino A, Blackshaw AJ, Swainson R, Wynne K, et al. Dissociable deficits in the decision-making cognition of chronic amphetamine abusers, opiate abusers, patients with focal damage to prefrontal cortex, and tryptophan-depleted normal volunteers: Evidence for monoaminergic mechanisms. *Neuropsychopharmacology* 1999;20:322–339. [PubMed: 10088133]
- Selzer ML. The Michigan Alcoholism Screening Test: The quest for a new diagnostic instrument. *American Journal of Psychiatry* 1971;127:1653–1658. [PubMed: 5565851]
- Shallice T, Burgess PW. Deficits in strategy application following frontal lobe damage in man. *Brain* 1991;114:727–741. [PubMed: 2043945]
- Shuren JE, Grafman J. The neurology of reasoning. *Archives of Neurology* 2002;59:916–919. [PubMed: 12056926]
- Stout JC, Busemeyer JR, Lin A, Grant SR, Bonson KR. Cognitive modeling analysis of the decision-making processes used by cocaine abusers. *Psychonomic Bulletin & Review* 2004;11:742–747. [PubMed: 15581127]
- Stuss DT, Levine B. Adult clinical neuropsychology: Lessons from studies of the frontal lobes. *Annual Review of Psychology* 2002;53:401–433.
- Stuss DT, Levine B, Alexander MP, Hong J, Palumbo C, Hamer L, et al. Wisconsin Card Sorting Test performance in patients with focal frontal and posterior brain damage: Effects of lesion location and test structure on separable cognitive processes. *Neuropsychologia* 2000;38:388–402. [PubMed: 10683390]
- Tranel, D. Theories of clinical neuropsychology and brain-behavior relationships: Luria and beyond. In: Morgan, JE.; Ricker, JH., editors. *Handbook of clinical neuropsychology*. Amsterdam: Swets & Zeitlinger; (in press)
- Tranel D, Damasio H, Denburg NL, Bechara A. Does gender play a role in functional asymmetry of ventromedial prefrontal cortex? *Brain* 2005;128:2872–2881. [PubMed: 16195242]
- Wilson BA, Evans JJ, Emslie H, Alderman N, Burgess PW. The development of an ecologically valid test for assessing patients with a dysexecutive syndrome. *Neuropsychological Rehabilitation* 1998;8:213–228.
- Yechiam E, Busemeyer JR, Stout JC, Bechara A. Using cognitive models to map relations between neuropsychological disorders and human decision-making deficits. *Psychological Science* 2005;16:973–978. [PubMed: 16313662]

Figure 1.

Lesion overlap map for the 9 patients with ventromedial prefrontal cortex (VMPC) damage. The figure shows mesial and lateral views of the left (left upper panels) and right (right upper panels) hemispheres, and a ventral view (middle upper panel). The blue lines correspond to the coronal sections in the bottom two rows, ordered from front to back (left is on the right in these sections). The color bar indicates extent of lesion overlap, coded so that dark red corresponds to 5 or more lesion overlaps, light red to 4 overlaps, and so on. All of the patients in this group have damage that includes the VMPC region.

Figure 2.

Lesion overlap map for the 8 patients with prefrontal cortex (PFC) damage outside the ventromedial prefrontal cortex (VMPC) region. The figure shows mesial and lateral views of the left (left upper panels) and right (right upper panels) hemispheres, and a ventral view (middle upper panel). The blue lines correspond to the coronal sections in the bottom two rows, ordered from front to back (left is on the right in these sections). The color bar indicates extent of lesion overlap, coded so that dark red corresponds to 5 or more lesion overlaps, light red to 4 overlaps, and so on. None of the patients in this group has damage that encroaches on the VMPC region.

Figure 3.

Lesion overlap map for the 17 patients with nonprefrontal (nonPFC) damage. The figure shows mesial and lateral views of the left (left panels) and right (right panels) hemispheres, and a ventral view (middle panel). The color bar indicates extent of lesion overlap, coded so that dark red corresponds to 5 or more lesion overlaps, light red to 4 overlaps, and so on. None of the patients in this group has damage that encroaches on the ventromedial prefrontal cortex (VMPC) or prefrontal cortex (PFC) regions.

TABLE 1

Participant demographic data

Variable	VMPC (n=9)	PFC (n=8)	NonPFC (n=17)	Normal (n=20)
Age	50.8 (13.3)	51.3 (15.5)	51.1 (14.0)	54.0 (14.8)
Education	12.6 (2.2)	14.0 (2.0)	13.4 (2.8)	13.3 (2.1)
Gender	4F/5M	3F/5M	8F/9M	12F/8M
Handedness ^a	8R/1L	8R/0L	16R/1L	18R/2L
Chronicity ^b	10.0 (9.1)	8.3 (6.7)	5.6 (3.9)	NA

Note. VMPC=patients with damage to ventromedial prefrontal cortex. PFC=patients with damage to prefrontal cortex. NonPFC=patients with nonprefrontal cortex damage. NA=not applicable.

^aHandedness was measured with the modified Oldfield–Geschwind questionnaire, and participants were categorized as being right-handed (R) or left-handed (L) based on their responses to this questionnaire.

^bChronicity refers to the time, in years, since lesion onset for the patients participating in the experiments described in this study.

TABLE 2

Neuropsychological data

Test/index	VMPC (n=9)	PFC (n=8)	NonPFC (n=17)	Normal (n=20)
Verbal IQ	105.8 (13.7)	105.7 (11.7)	98.4 (12.5)	106.0 (6.4)
Performance IQ	102.7 (17.8)	112.4 (16.1)	104.5 (17.0)	105.3 (4.7)
AVLT: Trial 5	10.8 (2.6)	11.0 (2.2)	11.7 (2.9)	NA
AVLT: 30 min recall	7.0 (4.9)	9.3 (3.2)	9.2 (4.1)	NA
AVLT: Recognition	13.4 (2.4)	14.2 (1.3)	14.3 (0.6)	NA
VRT: Correct	6.8 (1.7)	7.5 (1.1)	7.2 (1.9)	NA
VRT: Errors	4.8 (2.5)	3.7 (1.5)	4.4 (3.0)	NA
WCST: Categories	5.0 (1.7)	5.8 (0.4)	5.3 (1.7)	NA
WCST: Perseverative Errors	15.0 (10.0)	10.7 (4.6)	16.2 (13.6)	NA
Trail Making (B – A)	50.6 (24.5)	43.4 (25.7)	52.3 (54.5)	NA

Note. For the three brain-damaged groups, Verbal IQ and Performance IQ are from the WAIS–R; for the normal group, the IQ scores are derived from the Barona index (Barona, Reynolds, & Chastain, 1984). VMPC=patients with damage to ventromedial prefrontal cortex. PFC=patients with damage to prefrontal cortex. NonPFC=patients with nonprefrontal cortex damage. AVLT=Auditory–Verbal Learning Test; scores for Trial 5, 30-minute delayed recall, and Recognition (30-minute delayed) are raw scores out of 15 maximum. VRT=Visual Retention Test; Correct is number correct raw score (maximum=10); Errors is number of errors raw score. WCST=Wisconsin Card Sorting Test; Categories is number of categories completed (maximum=6); Perseverative Errors is raw score. Trail Making is the Trail Making Test, Parts A and B; score is time in seconds for completion of Part B minus time in seconds for completion of Part A. NA=not applicable. Mean values are given, with standard deviations in parentheses.

TABLE 3

Six Elements Test: Mean values as a function of group

Measure	VMPC (n=9)	PFC (n=8)	NonPFC (n=17)	Normal (n=20)
Number of tasks attempted	3.7 (1.5)	4.8 (1.4)	4.2 (1.6)	4.9 (1.1)
Maximum time ^a	6.5 (1.5)	6.1 (3.1)	6.5 (2.8)	5.6 (1.3)
Overall score ^b	44.7 (23.6)	56.4 (25.1)	43.1 (25.7)	62.5 (20.1)

Note. VMPC=patients with damage to ventromedial prefrontal cortex. PFC=patients with damage to prefrontal cortex. NonPFC=patients with nonprefrontal cortex damage. Standard deviations in parentheses.

^a In minutes, any one task.

^b Overall score=number of tasks completed correctly divided by the total number of tasks (there are 6 possible tasks).

TABLE 4
Multiple Errands Test: Mean values as a function of group

Measure	VMPC (n=9)	PFC (n=8)	NonPFC (n=17)	Normal (n=20)
Inefficiencies	0.4 (0.7)	0.3 (0.7)	0.6 (0.9)	0.4 (0.8)
Rule breaks	1.1 (0.9)	0.6 (0.5)	0.5 (0.7)	0.6 (0.9)
Interpretation failures	2.3 (1.7)	2.3 (2.1)	1.0 (1.3)	1.1 (1.4)
Task failures	3.8 (1.6)	2.7 (1.0)	2.4 (1.6)	1.3 (1.0)
Total mall errors ^a	7.6 (2.7)	5.9 (2.4)	4.5 (2.9)	3.4 (1.9)
Mall attempts	9.3 (2.2)	10.5 (0.5)	10.1 (1.3)	10.8 (0.4)
Mall completions (without errors)	5.1 (2.7)	5.9 (2.2)	7.3 (2.0)	8.7 (1.3)
Total mall completions (with or without errors)	7.2 (1.8)	8.1 (1.0)	8.4 (2.0)	9.5 (1.1)
Total time ^b	34.8 (11.0)	29.8 (8.0)	34.6 (7.2)	30.7 (8.7)

Note. VMPC=patients with damage to ventromedial prefrontal cortex. PFC=patients with damage to prefrontal cortex. NonPFC=patients with nonprefrontal cortex damage. Standard deviations in parentheses. There were 11 mall tasks, all told. See text for details regarding definition of variables from the Multiple Errands Test.

^aTotal mall errors=sum of the 4 different error types.

^bIn minutes.

TABLE 5

Correlations between strategy application tests and neuropsychological tests

Neuropsychological test measure	Strategy application test measure				
	Six Elements Test		Multiple Errands Test		
	Attempts	Overall score	Total errors	Mail attempts	Total comp.
Verbal IQ	-.01	.16	.03	.12	.06
Performance IQ	.27	.30	.09	.25	-.02
AVLT: 30 min recall	-.01	.07	-.26	.23	.03
VRT: Correct	.00	-.11	-.15	.24	.20
VRT: Errors	-.03	.10	.13	-.21	-.20
WCST: Categories	.12	.20	-.42*	.49**	.32
WCST: Persev. Errors	-.20	-.35	.31	-.65**	.24
Trail Making (B - A)	-.46*	-.41*	.30	-.46*	-.12
Total time					-.11
					.06
					.19
					.16
					-.14
					-.08
					.04
					.14

Note. SET=Six Elements Test; MET=Multiple Errands Test. Total comp.=total completions. AVLT=Auditory-Verbal Learning Test. VRT=Visual Retention Test. WCST=Wisconsin Card Sorting Test. Persev. Errors=Perseverative Errors. Statistically significant correlations are in italics.

* $p < .05$.

** $p < .01$.