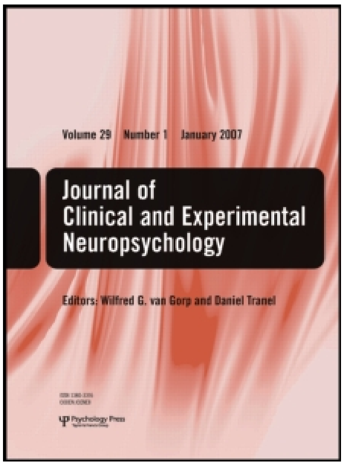

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D-KEFS Tower Test performance in patients with lateral prefrontal cortex lesions: The importance of error monitoring

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D-KEFS Tower Test performance in patients with lateral prefrontal cortex lesions: The importance of error monitoring

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This study investigated performance on the Delis–Kaplan Executive Function System (D-KEFS) Tower Test in a sample of 12 patients with focal lesions in the lateral prefrontal cortex (PFC) and 12 control participants. PFC patients performed worse overall, spent more time on each move, and committed significantly more rule violations. The rule violation measure demonstrated 83% sensitivity and 100% specificity in the detection of lesions. Findings highlight the importance of error monitoring in the assessment of executive functioning. These preliminary results suggest that the lateral PFC may be critical for self-monitoring/inhibition and speed of processing in planning tasks.

Keywords: Executive; Frontal; Error; Lesion; Tower; Self-monitoring.

One of the most commonly used tasks to measure planning and problem-solving ability is the Tower test (e.g., Tower of London, Tower of Hanoi; Culbertson & Zillmer, 2005; Shallice, 1982). On this task, patients must rearrange a set of disks placed on rods to match a predetermined arrangement. The examinee must keep in mind several rules while completing the task. Tower tests measure both spatial planning (Morris, Miotto, Feigenbaum, Bullock, & Polkey, 1997) and the ability to resolve conflicts between goals and subgoals (Goel & Grafman, 1995). Previous studies have found that patients with frontal lobe lesions perform worse than healthy control participants on various aspects of the Tower test (Andres & Van der Linden; 2001; Carlin et al., 2000; Goel & Grafman, 1995; Jacobs & Anderson, 2002; Lengfelder & Gollwitzer, 2001; Morris et al., 1997; Owen, Downes, Sahakian, Polkey, & Robbins, 1990; Rushe et al., 1999). Typical measures included in studies of the Tower tests include the total number of Tower problems completed, number of moves used, time spent completing the Tower problems, and time spent planning the first move. Some studies (Carlin et al.; Morris et al.; Owen et al.; Rushe et al.) have found that patients with frontal lobe lesions required significantly more moves and took significantly longer to complete the Tower of London and Hanoi problems. However, other studies have found that patients with frontal lesions are able to complete as many towers as can controls (Carlin et al.; Jacobs & Anderson).

An important component of Tower tests is the requirement to follow certain rules during the completion of the task (e.g., moving only one disk at a time). However, past studies with adult populations involving Tower tests (Andres & Van der Linden, 2001; Carlin et al., 2000; Goel & Grafman, 1995; Lengfelder & Gollwitzer, 2001; Morris et al., 1997; Owen et al., 1990; Rushe et al., 1999) have

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not investigated the degree of rule violations committed by patients with focal frontal lesions. Jacobs and Anderson (2002) and Levin et al. (1994) reported that patients with frontal lesions made more rule breaks, but their samples were limited to children. The ability to follow rules is an important component of the task that warrants investigation in adult populations.

Another concern with previous studies utilizing the Tower test is that they have been characterized by inconsistent administration methods. For example, previous studies using the Tower tests have varied by the number of moves required for each tower, how much time is allotted to complete each item, what happens when items are failed (i.e., moving on to the next item vs. redoing the failed item), the rules that examinees must follow, difficulty level, and scoring procedures (e.g., Anderson, Anderson, & Lajoie, 1996; Andres & Van der Linden, 2001; Goel & Grafman, 1995; Jacobs & Anderson, 2002). The clinician may struggle with determining which method of administration is optimal. Also, the Tower of London and Tower of Hanoi have been found to correlate poorly ($r = .37$), suggesting that the two tests assess different constructs (Humes, Welsh, Retzlaff, & Cookson, 1997). This low correlation may be due to the low internal consistency of the Tower of London, with split-half reliability of .19 and Cronbach alpha of .25 (Humes et al.). Floor effects may also be a critical issue on the Tower of Hanoi, in which administration begins with 5-move items, which can be difficult for patients with brain damage.

A newly standardized version of the Tower test has been developed for use with patients of ages 8–89 years as part of the Delis–Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001). It was created to score and norm not only the overall accuracy but also a number of process measures including error analyses for adults and children. The D-KEFS Tower Test provides a standardized method of administration and scoring that allows for the measurement of a number of processing variables involved in the task, such as number of rule violations, tower completion time, first-move time, number of moves, accuracy (correct/incorrect tower), and speed (both for the first move and for the total tower). Thus, the source of patients' difficulty can be discerned with greater specificity. Like previous Tower tests, it requires patients to rearrange disks on pegs in order to create a tower that the examiner indicates. On the D-KEFS Tower Test, however, there are nine different towers to be completed that range in difficulty, beginning with simple towers that require only 1–3 moves and becoming gradually more difficult, with towers requiring up to 26 moves. In this way, the rules of the test are established early on in the context of simple trials that almost all patients can complete without difficulty, and floor/ceiling effects are reduced.

A recent study found that the number of rule violations on the D-KEFS Tower Test differentiated between patients with clinically diagnosed frontotemporal dementia and patients with Alzheimer's disease (Carey et al., 2008). Both groups were impaired overall compared to nondemented control participants, but the frontotemporal dementia patients committed more rule violations than the patients with Alzheimer's disease. Carey et al. demonstrated the importance of monitoring errors as a way of assessing self-monitoring/inhibition on the D-KEFS Tower test. Studies involving error monitoring in other clinical populations are needed. To date, there has been no study reporting the effects, including errors made, of focal frontal lobe lesions on the D-KEFS Tower test. This study compared performance on the D-KEFS Tower Test by patients with focal lateral prefrontal cortex lesions to matched control participants. Based on previous literature, we predicted that patients with lateral prefrontal cortex (PFC) lesions would commit more rule violations than control participants and would take significantly longer to complete each tower.

METHOD

Participants

The current study included 12 patients (9 men and 3 women) with focal lesions in the lateral PFC who were recruited from a medical facility. Patients were included based on the following criteria: a single lesion, no prior neurologic or psychiatric history, and no history of substance abuse. All participants were native English speakers. Patients were tested at least one year postinjury. Length of time since lesion did not correlate significantly with any of the dependent variables. Lesion etiologies included embolic and hemorrhagic stroke ($n = 9$) and surgery for meningioma, cyst, and arteriovenous malformation ($n = 3$; see Table 1).

Computed tomography (CT) and/or magnetic resonance imaging (MRI) scans (1.5 T) were obtained on patients at least 5 weeks postonset and within a few months of testing. Patients' health status was followed either by medical records or by patient and caregiver reports, in order to detect any secondary events that could affect test performance. There were no such secondary incidents

TABLE 1
Demographic and descriptive variables of sample

Patient	*Age (years)*	*Education (years)*	*Sex*	*Etiology*	*Lesion side*	*Volume (cm^3)*	*Years post*
1	65	14	M	Stroke	Left	17.5	13
2	79	12	F	Stroke	Right	17.3	14
3	73	16	M	Stroke	Left	102.6	10
4	34	12	M	AVM	Right	24.5	13
5	54	11	M	Stroke	Left	18.0	1
6	77	12	F	Stroke	Right	12.9	2
7	68	16	F	Meningioma	Left	27.9	16
8	53	18	M	Cyst	Right	25.9	9
9	54	15	M	Stroke	Left	176.5	9
10	62	11	M	Stroke	Left	48.2	2
11	68	15	M	Stroke	Left	74.8	1
12	71	18	M	Stroke	Left	36.9	1
Mean (*SD*)							
Lateral PFC group	63.2 (12.7)	14.2 (2.6)	9 M, 3 F	9 stroke, 3 other	8 left, 4 right	48.6 (48.4)	7.6 (5.8)
Control group	65.8 (7.0)	14.7 (2.2)	8 M, 4 F	N/A	N/A	N/A	N/A

Note. M = male. F = female. AVM = arterio-venous malformation. Years post = years between lesion and testing. PFC = prefrontal cortex.

in the patient sample, and no patients were excluded due to a secondary event. Patients' lesions were reconstructed by a board-certified neurologist who was blind to diagnosis onto an 11-slice axial template based on the atlas of DeArmond, Fusco, and Dewey (1976) and then digitized, using in-house lesion reconstruction software (Frey, Woods, Knight, Scabini, & Clayworth, 1987) and MRIcro software (Rorden & Brett, 2000). Patients' lesion volumes ranged from 12.9 to 176.5 cubic centimeters (see Table 1). PFC lesions were defined as lesions anterior to the precentral gyrus. Patients' lesions were relatively focal, affecting either the right or the left lateral PFC. A total of 5 patients with lesions that extended significantly into other portions of frontal cortex (e.g., orbital regions) and/or involved other lobes or the cerebellum were excluded from the study.

A total of 12 controls (8 men, 4 women) with similar socioeconomic and educational backgrounds were recruited. The controls were neurologically normal and had no history of neurologic, psychiatric, or substance abuse issues. Patients and controls did not differ with respect to age, $t(22) = 0.64$, $p = .53$, or education, $t(22) = 0.52$, $p = .61$. Patients and controls were all right-handed. All participants read and signed consent forms prior to participation. The study was approved by the Institutional Review Board and was conducted in compliance with the Helsinki declaration.

Materials and procedure

The D-KEFS Tower Test was administered according to standardized instructions in the test manual (Delis et al., 2001). The test requires participants to build a series of nine towers that become progressively more difficult. The apparatus includes a three-peg base and five colored disks that vary in size from small to large. For each item, participants are given the base with disks placed in a prearranged manner and are shown a picture of what the tower's ending position should look like. They are instructed to build the tower using as few moves as possible. They are given two rules to follow: They can move only one piece at a time using just one hand, and a larger disk may never be placed on top of a smaller disk. The first time a participant violates one of these rules, she or he is reminded of the rule, and the disk is returned to its last location. On subsequent violations of the same rule, the participant is simply told that she or he made an error, and the disk is returned to its last location. The first tower is simple to make and requires only a single move. The subsequent eight towers require 2, 3, 4, 7, 9, 13, 20, and 26 moves. Participants are given 30–240 seconds to complete each tower, depending on the difficulty level of the tower. The test is discontinued if the examinee is unable to complete three consecutive towers in the allotted time.

During the procedure, the examiner records a number of variables, including the time to complete the first move; the time to complete the tower; the total number of moves, whether the tower was completed correctly or not, and the number of rule violations (i.e., moving more than one disk at a time or placing a larger disk on top of a smaller one). A number of additional variables are calculated from these raw data. The total achievement score is based on how many towers were correctly completed in the allotted time and how many moves were required to complete them. For each item, the participant gets one point for completing the tower in the allotted time and receives bonus points depending on how few moves were needed to complete the tower. These points are totaled to arrive at the total achievement score, which ranges from 0 to 30. The time-per-move ratio represents the mean amount of time that was spent on each move; it is a ratio of the total number of seconds spent solving a problem relative to the total number of moves used for that problem. Last, the move accuracy ratio represents the degree to which examinees make more moves than necessary; it is a ratio of the number of moves used by the examinee to solve the problem divided by the minimum number of moves necessary.

RESULTS

PFC patients were compared to controls on indices of D-KEFS Tower Test performance using a series of univariate analyses of variance. Individual scores from PFC patients and mean scores from controls on the D-KEFS Tower Test are presented in Table 2. The PFC patients completed fewer towers than did controls, $F(1, 22) = 17.41$, $p < .001$, $\eta^2 = .44$, and obtained significantly lower total achievement scores than did controls, $F(1, 22) = 6.44$, $p < .05$, $\eta^2 = .23$. PFC patients' time-per-move ratio was significantly higher than that of controls, $F(1, 22) = 17.63$, $p < .001$, $\eta^2 = .45$. PFC patients committed more rule violations than did the control participants, $F(1, 22) = 15.45$, $p < .01$, $\eta^2 = .41$, and PFC patients' rule violation per item was also higher than that of controls, $F(1, 22) = 13.00$, $p < .01$, $\eta^2 = .37$. Any participant who broke rules two or more times had a PFC lesion, and 12 out of the 14 frontal patients committed two or more rule violations. Size of lesion correlated with total rule violations, $r = .58$, $p = .05$, but did not correlate significantly with any other variable. In order to test whether the results were driven chiefly by the 2 participants with the largest lesions, the analyses were conducted with those 2 participants removed, and the same significant results were found.

The mean response time to make the first move on each tower did not differ between PFC patients and controls, $F(1, 18) = 0.41$, $p = .53$, $\eta^2 = .02$. Move accuracy ratio scores were also not significantly different between PFC patients and controls, $F(1, 22) = 2.36$, $p = .14$, $\eta^2 = .10$.

Next, sensitivity and specificity were calculated to assess the ability of the D-KEFS Tower Test to detect the presence of lesions. A total achievement score of 14 or below resulted in 75% sensitivity and 83% specificity for detecting lesions. If participants completed seven or fewer towers, this resulted in 75% sensitivity and 83% specificity. If the time-per-move ratio was 3.81 seconds or higher, this resulted in 75% sensitivity and 75% specificity. Last, committing two or more rule violations resulted in 83% sensitivity and 100% specificity.

Separate analyses for right versus left PFC patients were not possible due to the small sample sizes. However, left PFC patients performed worse numerically than did right PFC patients on total achievement score (left PFC mean = 11.8, SD = 4.0;

TABLE 2
Scores for participants on the D-KEFS Tower Test

Patient	*Total achievement score*	*Towers completed*	*Mean first-move time*	*Time-per-move ratio*	*Move accuracy ratio*	*Total rule violations*
1	21	8	4.33	4.74	1.24	0
2	13	7	2.22	3.50	2.31	2
3	13	5	2.50	8.33	1.17	12
4	24	9	4.56	3.45	1.11	0
5	10	6	13.56	8.07	1.20	5
6	14	8	4.67	3.88	1.94	3
7	10	5	10.22	8.81	1.15	4
8	17	7	1.56	3.20	2.40	2
9	12	6	13.22	6.64	1.53	6
10	9	5	8.56	7.85	1.00	2
11	10	4	4.29	5.79	1.95	9
12	9	5	7.56	8.20	1.26	7
	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)
Lateral PFC group	13.5 (4.9)	6.3 (1.5)	6.4 (4.2)	6.0 (2.2)	1.5 (0.5)	4.3 (3.7)
Control group	17.8 (3.4)	8.3 (0.8)	5.4 (3.0)	3.2 (0.8)	1.8 (0.4)	0.2 (0.4)

Note. D-KEFS = Delis–Kaplan Executive Function System. PFC = prefrontal cortex.

right PFC mean = 17.0, *SD* = 5.0), total towers completed (left PFC mean = 5.5, *SD* = 1.2; right PFC mean = 7.8, *SD* =1.0), and the time-per-move ratio (left PFC mean = 7.3, *SD* =1.4; right PFC mean = 3.5, *SD* =0.3).

DISCUSSION

The current study found that patients with focal damage in lateral prefrontal cortex (PFC) performed significantly worse overall on the D-KEFS Tower test than did age- and education-matched controls. PFC patients completed fewer towers, took significantly longer to complete each move, and committed more rule violations. These findings are generally consistent with earlier studies using experimental versions of the Tower test (Andres & Van der Linden, 2001; Carlin et al., 2000; Goel & Grafman, 1995; Jacobs & Anderson, 2002; Lengfelder & Gollwitzer, 2001; Morris et al., 1997; Owen et al., 1990; Rushe et al., 1999). However, PFC patients and controls did not differ with respect to the amount of time to make the first move on each tower.

The current study found that patients with lateral PFC damage displayed a propensity to commit rule violations, which is suggestive of a difficulty with self-monitoring and inhibition. In fact, all participants who committed two or more rule violations had PFC lesions. Only 2 control participants broke any rules, and each did so only once. The rule violation measure demonstrated 83% sensitivity and 100% specificity in the detection of frontal lesions. Results from this study are consistent with Carey et al. (2008), who found that the number of rule violations on the D-KEFS Tower Test differentiated between patients with frontotemporal dementia (i.e., with greater frontal involvement) and clinically diagnosed Alzheimer's disease (i.e., with less frontal lobe involvement), the former group having significantly more rule violations. Carey et al.'s results suggest a special role of the frontal lobes for error monitoring. These findings also expand upon a case study by Cato, Delis, Abildskov, and Bigler (2004), who found that a patient with ventromedial prefrontal damage performed within the average to superior range on most neuropsychological tasks, but showed marked impairments on measures of error rates, suggesting a speed/accuracy trade-off. Taken together, these results suggest that excessive rule breaking and thus a failure to inhibit on the D-KEFS Tower test may be related to frontal dysfunction. Before conclusions can be drawn regarding the role of frontal cortex, though, this study must be replicated with patients with focal nonfrontal lesions to determine whether the frontal lobes are uniquely related to skills tapped by the D-KEFS Tower test. Regardless, our findings, together with those of Carey et al. (2008) and Cato et al. (2004), illustrate the importance of assessing error rates in studies of executive functioning in patients.

Another finding in the present study was that the PFC group took a longer time to complete each move than did the control group. These results are consistent with Andres and Van der Linden (2001), Carlin et al. (2000), Morris et al. (1997), and Rushe et al. (1999), who found that frontal lobe damage was related to longer solution times. Jacobs and Anderson (2002), however, found no differences among patients with frontal, nonfrontal, or generalized pathology in total solution time and concluded that total solution time was too global a measure and varied too much among participants to be clinically useful. This suggests that this study should be replicated in patients with nonfrontal lesions to determine whether these findings are limited to frontal lobe damage or would be caused by damage to any part of the brain.

PFC patients and controls did not differ with respect to the amount of time spent making the first move on each tower, a finding consistent with previous studies (Andres & Van der Linden, 2001; Goel & Grafman, 1995; Jacobs & Anderson, 2002; Owen et al., 1990; Rushe et al., 1999). One might expect that PFC patients would show shorter planning times, reflecting more impulsive responding. However, PFC patients were slower overall relative to controls as reflected in the longer time-per-move ratio, and this overall slowing may have masked a tendency toward impulsive responding on the first move.

This study represents the first to report performance by patients with focal frontal lobe lesions on the D-KEFS Tower Test and helps to establish this test's validity. Findings suggest that this test is sensitive to brain damage, at least in the lateral prefrontal cortex. The importance of assessing errors, which has been neglected in previous research with Tower tests, was also shown to be a key component of the assessment of the effects of frontal lobe damage on executive functioning.

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REFERENCES

Anderson, P., Anderson, V., & Lajoie, G. (1996). The Tower of London Test: Validation and standardization for pediatric populations. *The Clinical Neuropsychologist*, *5*, 54–65.

Andres, P., & Van der Linden, M. (2001). Supervisory attentional system in patients with focal frontal lesions. *Journal of Clinical and Experimental Neuropsychology*, *23*, 225–239.

Carey, C. L., Woods, S. P., Damon, J., Halabi, C., Dean, D., Delis, D. C., et al. (2008). Discriminant validity and neuroanatomical correlates of rule monitoring in frontotemporal dementia and Alzheimer's disease. *Neuropsychologia*, *46*, 1081–1087.

Carlin, D., Bonerba, J., Phipps, M., Alexander, G., Shapiro, M., & Grafman, J. (2000). Planning impairments in frontal lobe dementia and frontal lobe lesion patients. *Neuropsychologia*, *38*, 655–665.

Cato, M. A., Delis, D. C., Abildskov, T. J., & Bigler, E. (2004). Assessing the elusive cognitive deficits associated with ventromedial prefrontal damage: A case of a modern-day Phineas Gage. *Journal of the International Neuropsychological Society*, *10*, 453–465.

Culbertson, W. C., & Zillmer, E. A. (2005). *Tower of London* (2nd ed.). Lutz, FL, Psychological Assessment Resources.

DeArmond, S. J., Fusco, M., & Dewey, M. (1976). *Structure of the human brain* (2nd ed.). New York: Oxford University Press.

Delis, D., Kaplan, E., & Kramer, J. (2001). *Delis–Kaplan Executive Function System*. San Antonio, TX: The Psychological Corporation, Harcourt Brace & Co.

Frey, R. T., Woods, D. L., Knight, R. T., Scabini, D., & Clayworth, C. (1987). Defining functional areas with averaged CT scans. *Society for Neuroscience Abstracts*, *13*, 1266.

Goel, V., & Grafman, J. (1995). Are the frontal lobes implicated in "planning" functions? Interpreting data from the Tower of Hanoi. *Neuropsychologia*, *33*, 623–642.

Humes, G. E., Welsh, M. C., Retzlaff, P., & Cookson, N. (1997). Towers of Hanoi and London: Reliability and validity of two executive function tasks. *Assessment*, *4*, 249–257.

Jacobs, R., & Anderson, V. (2002). Planning and problem solving skills following focal frontal brain lesions in childhood: Analysis using the Tower of London. *Child Neuropsychology*, *8*, 93–106.

Lengfelder, A., & Gollwitzer, P. M. (2001). Reflective and reflexive action control in patients with frontal brain lesions. *Neuropsychology*, *15*, 80–100.

Levin, H. S., Mendelsohn, D., Lilly, M. A., Fletcher, J. M., Culhane, K. A., Chapman, S. B., et al. (1994). Tower of London performance in relation to magnetic resonance imaging following closed head injury in children. *Neuropsychology*, *8*, 171–179.

Morris, R. G., Miotto, E. C., Feigenbaum, J. D., Bullock, P., & Polkey, C. E. (1997). Planning ability after frontal and temporal lobe lesions in humans: The effects of selection equivocation and working memory load. *Cognitive Neuropsychology*, *14*, 1007–1027.

Owen, A. M., Downes, J. J., Sahakian, B. J., Polkey, C. E., & Robbins, T. W. (1990). Planning and spatial working memory following frontal lobe lesions in man. *Neuropsychologia*, *28*, 1021–1034.

Rorden, C., & Brett, M. (2000). Stereotaxic display of brain lesions. *Behavioural Neurology*, *12*, 191–200.

Rushe, T. M., Morris, R. G., Miotto, E. C., Feigenbaum, J. D., Woodruff, P. W. R., & Murray, R. M. (1999). Problem-solving and spatial working memory in patients with schizophrenia and with focal frontal and temporal lobe lesions. *Schizophrenia Research*, *37*, 21–33.

Shallice, T. (1982). Specific impairments in planning. *Philosophical Transcripts of the Royal Society of London*, *298*, 199–209.