*Journal of the International Neuropsychological Society* (2001), **7**, 586–596.


# Verbal and design fluency in patients with frontal lobe lesions

JULIANA V. BALDO,[1] ARTHUR P. SHIMAMURA,[2] DEAN C. DELIS,[3] JOEL KRAMER,[4] AND EDITH KAPLAN[5]

[1]VA Northern California Health Care System, Martinez, CA
[2]University of California, Berkeley, CA
[3]University of California, San Diego, CA
[4]University of California, San Francisco, CA
[5]Boston University, Boston, MA

(Received November 16, 1999; Received May 2, 2000; Accepted July 6, 2000)

**Abstract**

The ability to generate items belonging to categories in verbal fluency tasks has been attributed to frontal cortex. Nonverbal fluency (e.g., design fluency) has been assessed separately and found to rely on the right hemisphere or right frontal cortex. The current study assessed both verbal and nonverbal fluency in a single group of patients with focal, frontal lobe lesions and age- and education-matched control participants. In the verbal fluency task, participants generated items belonging to both letter cues (*F*, *A*, and *S*) and category cues (animals and boys' names). In the design fluency task, participants generated novel designs by connecting dot arrays with 4 straight lines. A switching condition was included in both verbal and design fluency tasks and required participants to switch back and forth between different sets (e.g., between naming fruits and furniture). As a group, patients with frontal lobe lesions were impaired, compared to control participants, on both verbal and design fluency tasks. Patients with left frontal lesions performed worse than patients with right frontal lesions on the verbal fluency task, but the 2 groups performed comparably on the design fluency task. Both patients and control participants were impacted similarly by the switching conditions. These results suggest that verbal fluency is more dependent on left frontal cortex, while nonverbal fluency tasks, such as design fluency, recruit both right and left frontal processes. (*JINS*, 2001, *7*, 586–596.)

**Keywords:** Verbal fluency, Design fluency, Prefrontal cortex

## INTRODUCTION

Impaired verbal fluency is considered a hallmark of frontal lobe dysfunction (Benton, 1968; Bornstein, 1986; Milner, 1964; for a brief summary, see Baldo & Shimamura, 1998). Verbal fluency is measured by a patient's ability to generate items from a given cue or category. In some cases, the cues are phonemic (e.g., words beginning with the letter *F*) and in other cases, semantic (e.g., *animals*). In general, studies have found that verbal fluency is most sensitive to bilateral and left frontal lesions (Benton, 1968; Janowsky et al., 1989; Milner, 1964; Perret, 1974), although some studies have found that right frontal patients show disturbed verbal fluency as well (Baldo & Shimamura, 1998; Miceli et al., 1981; Miller, 1984). A recent study found that both category fluency (generating words belonging to a semantic category) and phonemic fluency (generating words beginning with a given letter) are significantly impaired in patients with either unilateral right or left frontal lobe injury (Baldo & Shimamura, 1998). Several neuroimaging studies as well have reported significant activation of the frontal lobes during verbal fluency tasks (Frith et al., 1991; Parks et al., 1988).

Another type of fluency that has been studied is design fluency, which is measured by a patient's ability to generate a series of novel (i.e., nonrepeating), abstract designs (Regard et al., 1982). Jones-Gotman and Milner (1977) reported that patients with right frontal and right frontocentral lesions were significantly impaired on a design fluency task. Similarly, Ruff et al. (1994) found that design fluency was

Reprint requests to: Juliana Baldo, VA Northern Calif. Health Care System, 150 Muir Road (126 S), Martinez, CA 94553. E-mail: juliana@socrates.berkeley.edu



https://doi.org/10.1017/S1355617701755063 Published online by Cambridge University Press

a sensitive measure of right anterior lesions. A recent neuroimaging study, however, reported that design fluency activated the frontal lobes bilaterally (Elfgren & Risberg, 1998). These results suggest that design fluency is mediated by right, or perhaps bilateral, frontal regions.

Various hypotheses have been offered to explain patients' impaired performance on fluency tasks. For example, in patients with dementia, it has been proposed that category fluency is impaired due to a compromised semantic store. These patients tend to perform proportionally better on letter fluency tasks, which require a search through lexical or phonemic memory, as opposed to semantic memory (Butters et al., 1987). Patients with frontal lobe lesions, however, tend to perform poorly on both letter and category fluency (Baldo & Shimamura,1998). Baldo and Shimamura suggested that fluency impairment in this patient group stems from a failure to develop retrieval strategies for searches through both lexical and semantic memory. Such an explanation is consistent with other deficits in these patients, such as impaired free recall and long-term memory retrieval (Gershberg & Shimamura, 1995; Mangels et al., 1996).

A related hypothesis is that patients with frontal lobe lesions perform poorly on fluency tasks due to an impaired switching strategy. In this paper, we refer to switching as the ability to shift attention between two sets or tasks. Switching may be endogenously derived (i.e., directed by the individual such as in the Wisconsin Card Sorting Task) or exogenously derived (i.e., with the guidance of external cues, such as on the Trail Making Test). Recently, Troyer et al. (1998) reported that patients with frontal lobe lesions made few transitions between subcategories on a semantic fluency task (e.g., switching from farm animals to pets to insects, given the category *animals*). That is, unlike control participants, these patients were less likely to jump from one subcategory to another and tended to perseverate on one subcategory.

The goal of the current study was to study both design and verbal fluency in a single group of patients with focal frontal lesions. To our knowledge, these two types of fluency tasks had not been tested together in focal frontal patients before. It was also of interest to characterize any switching impairments in these two fluency conditions. The design and verbal fluency tasks were part of a new battery consisting of nine tests of executive function, the Delis-Kaplan Executive Function Scale (Delis et al., in press). We expected that patients with frontal lobe lesions would exhibit impairment on these fluency tasks. More specifically, it was predicted that right frontal patients would be most impaired at design fluency and that patients with left frontal lesions would be most impaired at verbal fluency. Also, it was predicted that frontal patients would show a disproportionate cost in the new switching conditions in these fluency tasks, compared to control participants. That is, it was expected that patients would have difficulty switching back and forth between two different sets/categories on both types of fluency tasks.

## METHODS

### Research Participants

Eleven patients with focal frontal lobe lesions were recruited for this study (see Table 1). Lesions were identified from review of computed tomography (CT) and magnetic resonance (MR) scans. Patients with lesions extending into

**Table 1.** Participant characterization and fluency performance

| Patients | Gender | Lesion site | Volume (cc) | Age at test | Years post | Lesion etiology | Educ. (years) | WAIS–R PIQ | WCST Cat. | WCST P.E. | Verbal fluency | Design fluency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O.A. | M | L | 17.5 | 66 | 13 | Stroke | 14 | 134 | 1 | 26 | 12.2 | 7.3 |
| E.B. | F | R | 17.3 | 81 | 14 | Stroke | 12 | 114 | 4 | 22 | 14.7 | 6.7 |
| S.R. | F | R | 12.9 | 78 | 2 | Stroke | 12 | 93 | 2 | 40 | 11.3 | 6.7 |
| W.A. | F | L | 26.2 | 76 | 11 | Stroke | 14 | 132 | — | — | 7.4 | 9.7 |
| W.T. | M | R | 25.9 | 54 | 9 | Cyst | 18 | — | — | — | 13.8 | 10.3 |
| M.G. | M | R | 24.5 | 35 | 13 | AVM | 12 | — | — | — | 10.3 | 9.0 |
| M.K. | M | R | 200.4 | 67 | 18 | Aneurysm | 17 | — | — | — | 10.8 | 4.7 |
| L.S. | F | L | 27.9 | 70 | 16 | Mening. | 16 | — | 4 | 23 | 3.9 | 5.0 |
| W.E. | M | L | 41.1 | 69 | 2 | Stroke | 14 | 104 | 1 | 35 | 7.8 | 3.0 |
| J.C. | M | L | 102.6 | 74 | 10 | Stroke | 16 | 103 | 6 | 12 | 6.2 | 5.3 |
| J.M. | M | L | 18.8 | 54 | 1 | Stroke | 11 | 91 | — | — | 7.0 | 7.0 |
| | | | | | | Means | | | | | | |
| Frontal | 7M,4F | 6L,5R | 46.8 | 65.8 | 9.9 | — | 14.2 | 110.1 | 3 | 26.3 | 9.6 | 6.8 |
| Control | 8M,3F | — | — | 68.1 | — | — | 14.6 | — | | | 18.2 | 10.2 |

*Note.* Dashes indicate data that are not available or not applicable. L = left hemisphere; R = right hemisphere; AVM = arterio–venous malformation; Mening. = meningioma; Educ. = education; WCST = Wisconsin Card Sorting Test; Cat. = number of categories sorted; P.E. = number of perseverative errors; WAIS–R PIQ = Wechsler Adult Intelligence Scale–Revised Performance IQ. Verbal and design fluency data are averaged over three conditions as described in text.

nonfrontal regions were excluded. Patients' lesions were mostly confined to ventral and dorsolateral prefrontal cortex, although some of the lesions extended medially (see Figure 1 for lesion reconstructions). Six patients had focal left hemisphere lesions, and 5 had focal right hemisphere lesions. In seven of the patients, lesions were due to an infarct of the anterior branch of the middle cerebral artery. In the other patients, lesions were due to surgical treatment for an aneurysm, arterial-venous malformation, cyst, or meningioma. The average time since onset of injury was 9.9 years, and thus most of the patients' lesions were chronic. Patients with left hemisphere lesions had an average lesion volume of 39.0 ± 29.5 cc, and patients with right hemisphere lesions had an average lesion volume of 56.2 ± 72.3 cc. Lesion volumes were determined by lesion reconstruction software that used a standard brain to estimate the area of lesion across a series of planes (Frey et al., 1987). All patients were in the normal range on the Western Aphasia Battery (Kertesz,1982), except for one mildly aphasic patient (J.C.) who had an Aphasia Quotient of 90 (out of 100), where 93.7 is normal. Another patient with moderate aphasia was excluded from the study. All patients were premorbidly right-handed, although 2 patients (W.A., J.C.) used their nondominant, left hand for the design fluency task due to right hemiplegia.

The control group was 11 healthy control participants recruited from the same community as the patients. Control participants were all right-handed. Patients and control participants did not differ in terms of age [$F(1,20) = .26$, $p = .61$], or education [$F(1,20) = .21$, $p = .65$; see Table 1]. Right hemisphere and left hemisphere patients were also comparable in terms of age ($M = 63.0 \pm 8.5$ and $68.2 \pm 3.2$, respectively) and education ($M = 14.2 \pm .75$ and $14.2 \pm 1.4$, respectively). All testing was conducted at the Veterans Administration Northern California Health Care System in Martinez, CA. Patients and control participants were screened for history of dementia, drug abuse, and psychiatric illness, and control participants were additionally screened for prior neurologic history. All participants read and signed consent forms prior to participating in the study.

## Materials and Procedure

The design and verbal fluency tasks were given as part of a larger neuropsychological battery, the Delis-Kaplan Executive Function Scale (D–KEFS; Delis et al., in press). In this battery, design fluency is administered first, and verbal fluency is administered after several other subtests. Most participants completed both design and verbal fluency tasks in the same session, but a few patients and control participants returned for a second session, in which the verbal fluency task was administered.

The order of conditions within each task was fixed, with the switching conditions always being administered last. Although this design does not control for order effects, it does allow the patients to have a good understanding of the task. Thus, any deficits on switching can be attributed to a deficiency in patients' ability to switch sets, rather than a lack of understanding of the task.

### *Design fluency*

There were three conditions in the design fluency task: *basic*, *filter*, and *switch* (described below). The three conditions were administered in this order. Participants used their dominant, right hand to draw, except for 2 patients who used their nondominant, left hand, due to right hemiplegia.

For all three conditions, participants were first shown a practice page with three squares, each of which contained an array of dots (see Figure 2). The instructions for each condition were given orally and were also presented in writing in a booklet, so that participants could refer to the rules at any time during the task. Participants were instructed to make a different design in each square by connecting dots, always using straight lines. Participants could lift the pen from the page; that is, the designs did not have to be made with one, continuous stroke. They were told that the designs should be drawn using only *four* straight lines to connect the dots and that each line had to touch at least one other line at a dot. The examiner demonstrated this last rule by drawing two lines that met at a dot. Participants were told that the lines could cross each other in the design and that it did not matter whether or not the designs could be named. Participants practiced drawing three designs. The examiner gave feedback and corrected errors during this practice phase.

Following practice in each condition, participants were presented with a page of 35 squares, and the rules for drawing designs were reiterated. The arrays in every square were identical and were the same as those used in the practice phase for each condition. Participants were told that they would have 60 s to draw as many different designs as they could. During this testing phase, the examiner prompted the participant once (i.e., explained the error) if s/he drew three consecutive, incorrect designs (e.g., perseverated on the same design or used only three lines). The participant was allowed to finish any design in progress when the time limit was reached.

In the basic condition, the squares contained an array of five filled (black) dots, and participants had to draw designs by connecting the filled dots (see Figure 2). In the filter condition, the squares contained an array of five filled and five empty dots, and participants were instructed to draw the designs by connecting the empty dots only. Thus, they had to "filter" out the filled dots (that they had previously connected in the basic condition) and only connect the empty dots. In the switch condition, the arrays again consisted of five filled and five empty dots, although the dots were arranged differently from the filter condition. In this switch condition, participants were asked to draw designs by switching back and forth between connecting empty and filled dots. They were told that they could begin either with an empty or a filled dot.

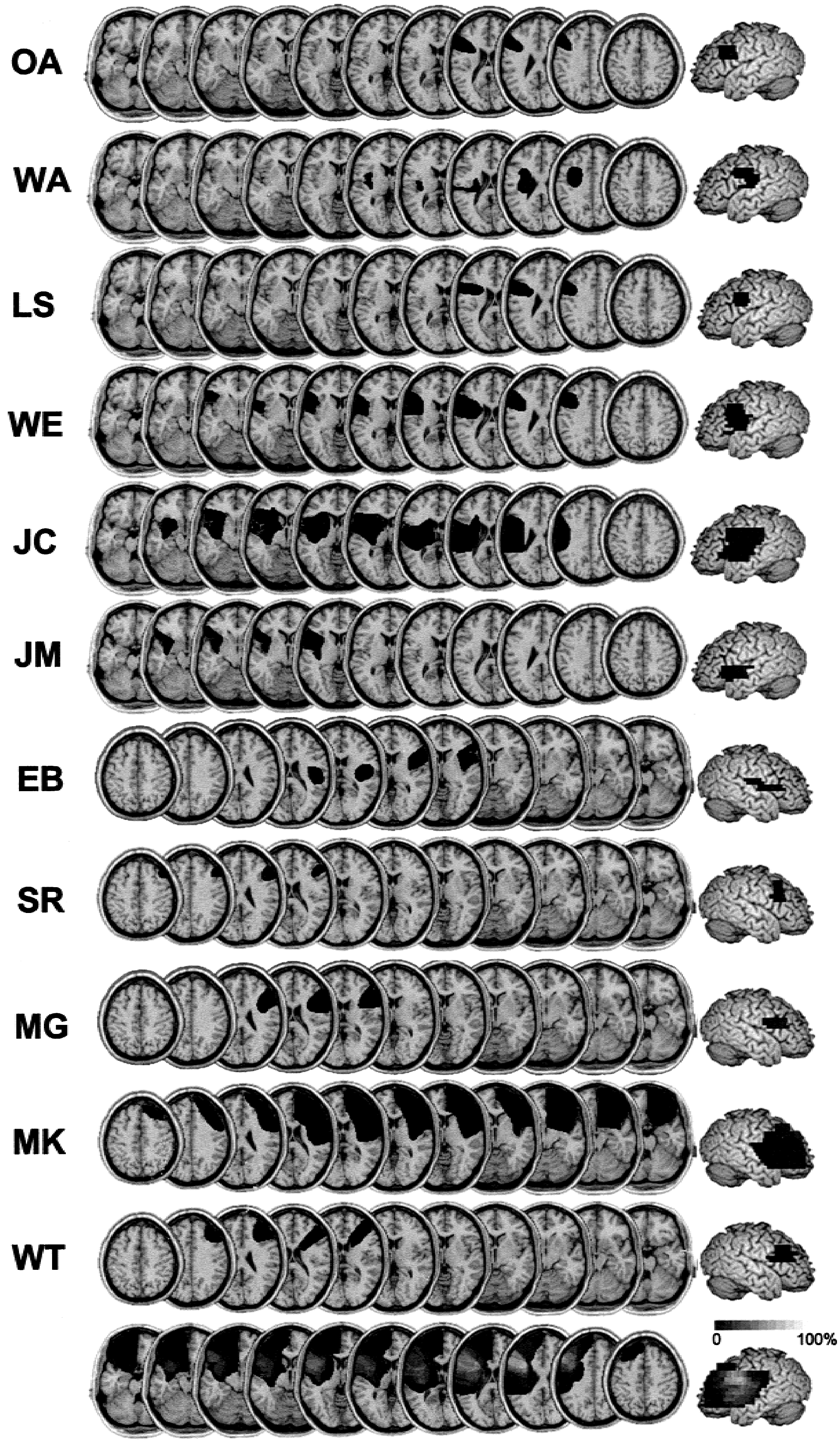


**Fig. 1.** Lesion reconstructions, based on computed tomography and/or magnetic resonance scans. Lesions were reconstructed onto a standard brain template. The lateral views on the right show the lesions projected onto the lateral surface of the brain. The last row of horizontal slices represents an average of all patients' lesions, with a legend signifying the amount of lesion overlap (from zero to 100%).

https://doi.org/10.1017/S1355617701755063 Published online by Cambridge University Press

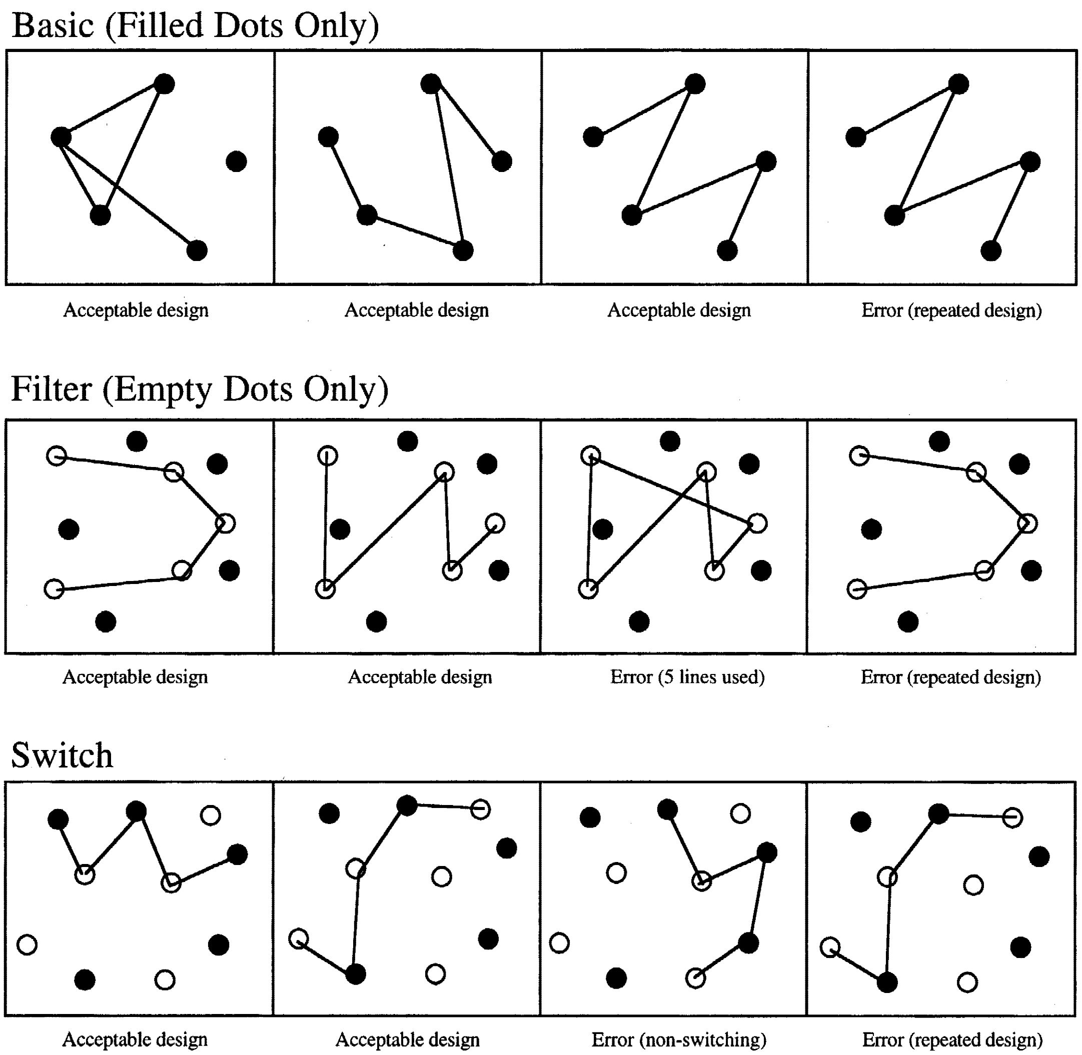


**Fig. 2.** Examples of the stimuli used in the three conditions of the design fluency task, including examples of both acceptable and unacceptable designs.

The main dependent variable was the number of correct designs completed in 60 s. In addition, the number of errors was calculated, based on a percentage of the number of errors divided by the total number of designs, in order to control for overall output. Errors representing inappropriate designs (e.g., designs with five lines) and perseverative errors (i.e., repetitions of the same design) were calculated separately.

In order to have a measure of motor speed, which might have an impact on design fluency performance, participants performed a separate motor speed task that was part of another test within the D–KEFS. The motor speed task consisted of 32 large, open circles scattered across a 43 × 28 cm page. The circles were connected by a dotted line along a path. Participants had to begin at the dot marked "START" and connect the dots as quickly as possible, using the dotted line as a guide. Thus, the task required little in terms of higher cognitive abilities and simply required tracing over a line. The dependent variable was the number of seconds to reach the end of the path at the circle marked "END."

### *Verbal fluency*

There were three conditions in the verbal fluency task: letter (*F*, *A*, and *S*), category (*animals* and *boys' names*) and switch (switching between *fruits* and *furniture*). The conditions were administered to all participants in this order. Instructions were given orally by the examiner and were presented in written form as well. Participants were given 60 s to verbally generate items in each condition. Responses were recorded on paper by the examiner.

First, participants had to generate as many words as possible that started with the letter *F*. Participants were given several rules to follow, namely, that the words could not be names of people, places, or numbers, and that they could

https://doi.org/10.1017/S1355617701755063 Published online by Cambridge University Press

not be repeated sequences (e.g., take, takes, taking, etc.). The next two letter items (*A* and *S*) were given subsequently. Second, participants had to generate exemplars belonging to the category *animals*, and subsequently, *boys' names*. Last, in the switch condition, participants were asked to switch back and forth between naming fruits and furniture (e.g., *apple . . couch . . banana . . desk*). They were told that they could begin either with a piece of fruit or furniture.

Verbal fluency rates were based on the number of correct items produced by the participants. Items were counted as correct if they met the constraints of the condition and were not repetitions. Letter fluency scores were based on the average number of items generated across the three letter conditions. Category scores were the average number of items generated in the two categories. Switch scores were based on the correct number of items ( *fruits* and *furniture*) generated in this condition.

## RESULTS

Data analysis for both design and verbal fluency were initially conducted to compare control participants to patients with frontal lobe lesions. These initial analyses allowed us to determine whether, as a group, frontal lobe patients demonstrated impaired performance on the fluency tasks and switching conditions. Interaction contrasts comparing right to left hemisphere patients are presented subsequently for both tasks.

### Design Fluency

Data from the design fluency task were analyzed with a $3 \times 2$ analysis of variance (ANOVA) with Condition (basic, filter, or switch) as a within-subjects factor, and Group (frontal or control) as a between-subjects factor. Fluency rates were based on the number of correct (i.e., acceptable) designs made by a participant. Designs were deemed acceptable if they met the constraints of the condition (e.g., contained four lines) and were not repetitions of designs already drawn in that condition. Error rates (percentage of perseverative and unacceptable designs) are considered separately below.

There was a main effect of Group [$F(1,20) = 13.26$, $p < .01$], as the frontal lobe patients produced fewer designs than control participants (see Figure 3). There was a main effect of Condition [$F(2,40) = 13.74$, $p < .0001$], as all participants produced the fewest items in the switch condition. The number of designs produced in the basic and filter conditions did not differ across both participant groups [$F(1,20) = .85$, $p = .37$]. The Condition $\times$ Group interaction was not significant [$F(2,40) = 1.85$, $p = .17$], as the pattern of performance across conditions was similar for patients and control participants. That is, patients did not show a disproportionate cost in the switch condition. Rather, both groups showed a comparably large cost in the switch condition.

An interaction contrast was conducted to compare performance in patients with left and right hemisphere lesions.

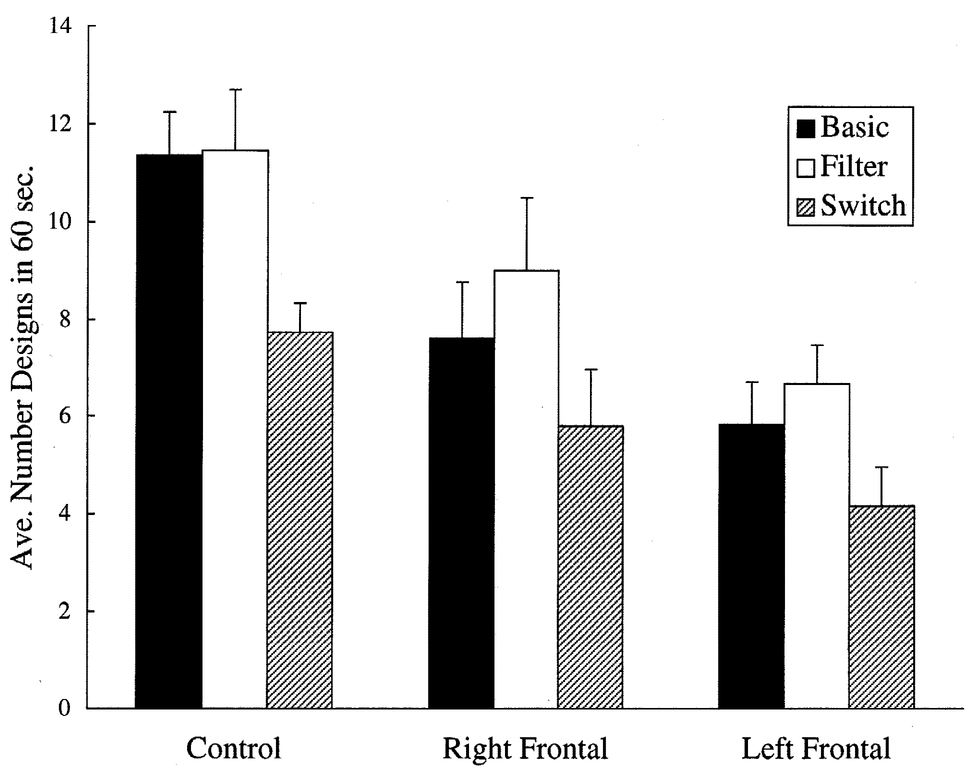


**Fig. 3.** Average number of designs made by right and left frontal lobe patients and control participants in the design fluency task, across the three task conditions; *basic*, *filter*, and *switch*.

https://doi.org/10.1017/S1355617701755063 Published online by Cambridge University Press

There was no statistical difference between patient groups in their ability to generate designs [$F(1,9) = 1.90$, $p = .20$]. There was a main effect of Condition, as both groups generated the fewest designs in the switch condition [$F(2,18) = 4.51$, $p < .05$]. The pattern of performance across the switching and nonswitching conditions in the design fluency task was comparable for right and left frontal patients [$F(2,18) = .46$, $p = .64$]. Although the power was low (12.0%) in this contrast analysis due to the small group sizes, the pattern of data across conditions is comparable for the two patient groups (see Figure 3). It is possible that a numeric, right hemisphere advantage was not found to be significant due to the small sample. However, the prediction was that the right hemisphere patients would show impaired, not superior, performance compared to left frontal patients, and this certainly was not the case.

To insure that performance on design fluency was not unduly influenced by motor speed, a simple regression was performed, using average design fluency performance and the number of seconds to complete the motor speed task as variables. All participants, patients and controls, were included in this analysis. This analysis showed no relationship between the average number of designs produced and motor speed, $R = .36$, $p = .10$.

There were numerous errors made in the design fluency task. Initial interaction contrasts with only the two patient groups (right *vs.* left frontal patients) showed no differences between patient groups in terms of error rates, and thus the following analyses present data collapsed across these groups (i.e., for frontal patients *vs.* control participants). Error data were analyzed with a $3 \times 2$ ANOVA with Condition (basic, filter, or switch) as a within-subjects factor and Group (frontal or control) as a between-subjects factor. Perseverative errors (i.e., repeated designs, with or without intervening designs) and inappropriate design errors (e.g., designs with 5 lines) were considered separately. Error data are presented in Table 2 for both patient groups and control participants.

In terms of perseverative errors, there was no statistical difference between patients with frontal lesions and control participants [$F(1,20) = 1.56$, $p = .22$], although numerically patients made proportionally more errors (see Table 2). There was a significant main effect of Condition [$F(2,40) = 4.08$, $p < .05$], as both groups made proportionally the least number of perseverative errors in the switch condition (see Table 2). This drop in the switch condition may have been due to the smaller overall output in this condition: the fewer the designs, the less opportunity to repeat one. The effect of Condition did not interact with group [$F(2,40) = .22$, $p = .80$]. That is, patients' and control participants' error patterns were comparable across the three conditions. Frontal patients did not demonstrate a disproportional error rate in the switch condition.

In terms of errors representing inappropriate designs, there was no statistical difference between patients with frontal lesions and control participants [$F(1,20) = .04$, $p = .85$]. Thus, patients and control participants were similarly likely to generate unacceptable designs proportional to their overall output. The effect of Condition was significant [$F(2,40) = 13.70$, $p < .0001$], as the majority of inappropriate designs were drawn in the switch condition. The interaction of Group × Condition was not significant [$F(2,40) = .35$, $p = .70$], suggesting that the tendency to make inappropriate designs was comparable across conditions for patients and control participants.

## Verbal Fluency

Fluency rates from the verbal fluency task were analyzed with a $3 \times 2$ analysis of variance (ANOVA) with Condition (letter, category, or switch) as a within-subjects factor, and Group (frontal or control) as a between-subjects factor. Error rates are addressed separately below.

There was a main effect of Group [$F(1,22) = 29.38$, $p < .0001$], as the frontal lobe patients produced fewer correct responses than control participants (see Figure 4). There was a main effect of Condition [$F(2,44) = 41.68$, $p < .0001$], as all participants produced fewer items in the letter and switch conditions, compared to the category condition. The Condition × Group interaction was significant [$F(2,44) = 4.89$, $p < .05$]. As can be seen in Figure 4, frontal lobe patients produced proportionately fewer items in the letter condition, compared to control participants. However, the switching cost did not appear disproportionate in patients. To analyze this further, a separate interaction contrast was run, comparing just category *versus* switch conditions in patients and control participants. This interaction was significant [$F(1,22) = 5.55$, $p < .05$], and

**Table 2.** Pattern of errors on design fluency task

| Group | % Inappropriate errors ± S.E. | | | % Perseverative errors ± S.E. | | |
|---|---|---|---|---|---|---|
| | Basic | Filter | Switch | Basic | Filter | Switch |
| Control | 0.6 ± 0.6 | 4.5 ± 2.3 | 22.7 ± 5.7 | 14.0 ± 2.7 | 12.4 ± 0.3 | 3.8 ± 2.1 |
| RH Front | 0.0 ± 0.0 | 2.1 ± 2.1 | 18.7 ± 7.2 | 14.6 ± 9.9 | 14.1 ± 10.6 | 5.0 ± 3.3 |
| LH Front | 6.9 ± 3.3 | 2.4 ± 2.4 | 20.5 ± 13.8 | 16.7 ± 4.0 | 22.8 ± 4.7 | 12.2 ± 7.2 |

*Note*. RH Front = right frontal; LH Front = left frontal. The percentage of inappropriate errors (e.g., using five lines) ± standard error in the design fluency task is presented for all groups in the first three columns. The percentage of perseverative errors (i.e., repetitive designs) ± standard error is presented in the last three columns.

https://doi.org/10.1017/S1355617701755063 Published online by Cambridge University Press

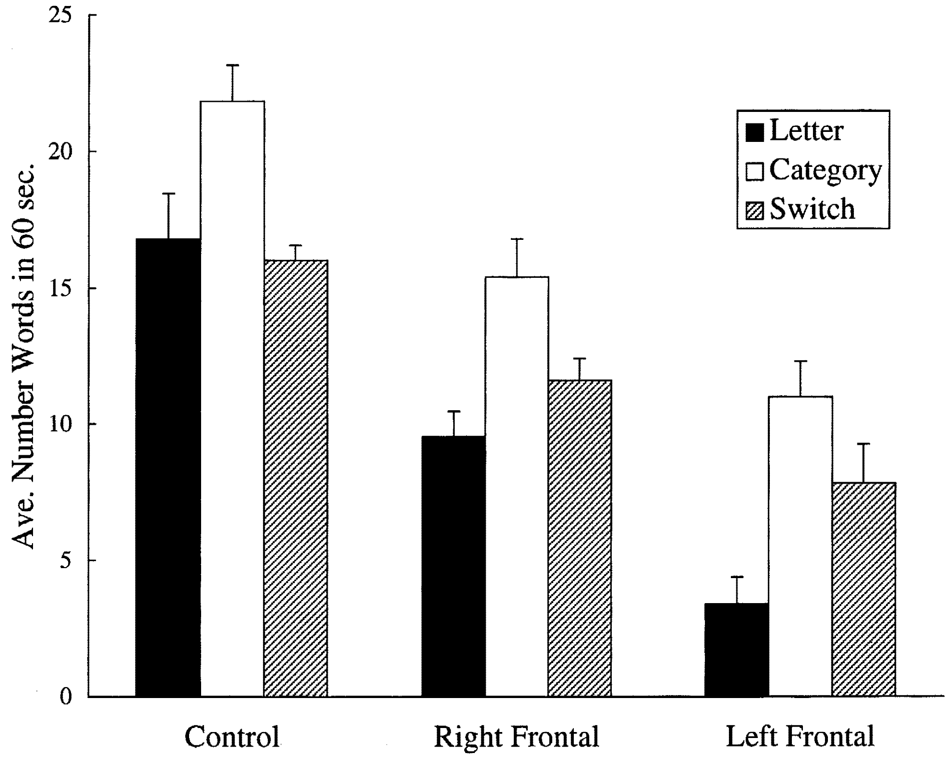


**Fig. 4.** Average number of words generated by right and left frontal lobe patients and control participants in the verbal fluency task, across the three task conditions: *letter*, *category*, and *switch*.

was due to a larger discrepancy or switching cost in control participants, not patients.

On the verbal fluency task, interaction contrasts revealed that patients with left hemisphere lesions were impaired relative to right hemisphere patients [$F(1,9) = 10.80$, $p <$ .01 (power = 42.3%)]. That is, patients with left hemisphere lesions generated fewer items overall than right-sided patients. There was a main effect of Condition [$F(2,18) = 38.49$, $p < .0001$], as all patients showed a cost in the switching condition, as well as a larger cost in the letter condition. Lesion side did not interact with Condition [$F(2,18) = 3.35$, $p = .36$], as left and right frontal patients showed parallel patterns of performance on switching and non-switching conditions.

Error rates were extremely low for both patients and control participants on the verbal fluency task, including both repetitive errors (e.g., saying "monkey" twice), as well as inappropriate items (e.g., saying "clock" under the animal category). Across the verbal fluency conditions, control participants made an average of 0.4 errors, and patients made an average of 0.5 errors per condition. The majority of participants in both groups made no errors. Due to the paucity of data points, error rates on the verbal fluency task were not analyzed further.

### Fluency Task × Hemisphere Interactions

It was of interest to directly assess whether there was any evidence of an interaction of lesion lateralization and type of fluency task. However, because the three conditions within each of the two fluency task conditions were not parallel (i.e., basic, filter, switch *vs.* letter, category, switch), it was not possible to analyze design and verbal fluency with an omnibus ANOVA. Therefore, average performance scores across the three conditions in the verbal and design fluency tasks were used to compare the two groups, with a $2 \times 2$ ANOVA of Task (verbal or design fluency) and Hemisphere (left or right). There was a main effect of Hemisphere [$F(1,9) = 8.86$, $p < .05$], as left frontal patients were more impaired on both tasks, compared to right frontal patients. There was an effect of Task [$F(1,9) = 16.33$, $p < .01$], as both patient groups generated fewer designs than words. The Hemisphere × Task interaction approached significance [$F(1,9) = 4.07$, $p = .07$], as there was a larger discrepancy between verbal and design performance in right-sided patients than left frontal patients. This was due to the fact that left frontal patients exhibited more consistently poor performance across the two tasks, while right frontal patients showed a larger drop in design fluency performance compared to verbal fluency.

## DISCUSSION

In this study, we assessed verbal and design fluency in standard conditions and in conditions that necessitated task switching. The verbal and design fluency tasks were part of a larger battery of executive functions, the Delis-Kaplan

https://doi.org/10.1017/S1355617701755063 Published online by Cambridge University Press

Executive Function Scale (Delis et al., in press). Overall, patients with frontal lobe lesions were impaired on both verbal and design fluency tasks. Patients with left frontal lobe lesions were more impaired than right hemisphere patients on the verbal fluency task, but right and left hemisphere patients performed more comparably on the design fluency task.

Previous studies with frontal lobe patients have assessed verbal and design fluency separately. Design fluency has been linked to right frontal function and verbal fluency to left frontal function (Jones-Gotman & Milner, 1977; Milner, 1964; Perret, 1974; Ruff et al., 1994). In the current study, both types of fluency tasks were administered to a single group of patients with focal, frontal lesions. Our finding of greater left hemisphere involvement for verbal fluency is consistent with previous findings. However, in the current study, patients with left frontal lesions performed comparably to right hemisphere patients on a design fluency task. If anything, there was a slight advantage for right hemisphere patients, which is the opposite of what was expected. This finding, though not in line with previous patient studies, is consistent with a recent neuroimaging study that found bilateral activation when normal participants performed a design fluency task (Elfgren & Risberg, 1998).

The pattern of performance by patients in our study suggests that, while verbal fluency is more dependent on left frontal cortex (presumably due to access to linguistic processes), design fluency depends on both right and left frontal cortex. One possible explanation is that many visuospatial tasks recruit both right and left hemisphere mechanisms in order to analyze both global and local information, respectively (Robertson & Delis, 1986). Alternatively, it may be that monitoring and updating responses in putatively nonverbal tasks still require, to some extent, verbal mediation via left frontal regions. For example, in our design fluency task, participants were required to connect dots in an array. In Jones-Gotman and Milner (1977), patients drew designs freely on a page with few constraints. The more constrained nature of our task (i.e., drawing designs within a dot array using only four straight lines) may have required left frontal functions such as verbal working memory. The considerable advantage of this more constrained task, however, was that the number and quality of designs, as well as the number of perseverative designs, could be more objectively measured and quantified.

A switching variable was introduced in the current study such that participants were required to alternate between two sets or categories during the fluency tasks. In one condition of the verbal fluency task, participants were required to alternate between naming fruits and furniture. In the design fluency task, participants were required to form designs by alternating between empty and filled dots in an array. Both patients and control participants exhibited costs in their performance on these switching conditions. Patients with frontal lobe lesions did not, however, exhibit disproportionate impairment in the switching conditions on either the design or verbal fluency tasks.

One possible explanation for the comparable cost of task switching in patients and controls was the chronic nature of the patients' lesions. It would be of interest to test patients with more uniformly acute lesions. The advantage of this chronic patient group was that their behaviors were well-stabilized, and we were assured that any deficits were attributable to the observed lesions. The advanced age of both patients and control participants also may have obscured some differences between groups, as overall performance may have been diminished.

Another explanation for the comparable switching costs in patients and control participants was the explicit nature of the task instructions—participants were provided with the subcategories to switch between in the verbal fluency task and had visual cues to guide their switching on design fluency. Previous, conventional studies of task switching in frontal lobe patients did not make explicit demands to switch or shift categories. For example, patients with frontal lobe lesions are impaired in the propensity to shift categories on the Wisconsin Card Sorting Test (Milner, 1963) and in other tests of concept identification (Owen et al., 1993). On such tests, individuals are not told that the category selected by the experimenter will be switched at some later time. To be successful on such tests, participants must spontaneously shift based on inference, with no external support. Similarly, on conventional verbal fluency tasks, shifting between subcategories is an excellent strategy to generate items, but no external cues are provided to guide this strategy. Troyer et al. (1998) assessed switching by participants' tendency to switch between subcategories on a verbal fluency task and found that patients with frontal lobe lesions were less likely to switch between subcategories. Thus, in this less directed task, where frontal patients had to spontaneously utilize a switching strategy, they showed impaired performance compared to control participants.

In our study, patients appeared to be able to switch as well as control participants, when they were explicitly instructed to do so. Thus, it is important to make the distinction between endogenously and exogenously directed switching, as it is possible that these two types of shifting are differentially sensitive to focal frontal damage. Specifically, it appears that switching in response to exogenous cuing may remain intact following focal frontal lesions (current study), while switching based on endogenous (i.e., self) cuing may not (Troyer et al., 1998).

This hypothesis parallels findings from memory studies in frontal lobe patients that report that these patients do not spontaneously make use of strategic cues present in the material. For example, on free recall tasks, patients with focal frontal lesions fail to take advantage of the presence of semantically related items (i.e., impaired semantic clustering). However, when instructed to take advantage of semantic categories to improve performance, frontal patients' performance approaches that of control participants (Gershberg & Shimamura, 1995; Hirst & Volpe, 1988). These findings suggest that patients with frontal lobe lesions lack the ability to generate/utilize internally derived strategies, but they are able to take advantage of strategies when given explicit instructions.

To the extent that the frontal lobes contribute to aspects of attentional shifting, it may be possible to detect specific task switching deficits under certain conditions. Dunbar and Sussman (1995) used a Stroop-like task in which participants were presented a picture with an incongruent word (e.g., the word "dog" superimposed on a picture of a rabbit). Patients with frontal lobe lesions were not significantly affected by incongruous stimuli if the task only involved word naming or picture naming. However, the patients were particularly affected if they had to switch between word naming and picture naming within the same block of trials. Neuroimaging studies have indicated increased activation in prefrontal cortex when switching demands are great, such as in divided attention tasks (D'Esposito et al., 1995) or in the *n-back* task, in which participants must constantly update information held in working memory (Cohen et al., 1997).

In the current study, patients with frontal lobe lesions were impaired overall on tasks of verbal and design fluency. A switching variable did not, however, differentially affect the frontal lobe patients as was expected. It would be interesting to test patients on a fluency task in which they were required to switch back and forth between more diverse sets, such as between naming animals and words beginning with the letter *F*. Such a cross-category switching task may prove to be more attention demanding and thus more disruptive to patients with focal frontal lobe lesions.

## ACKNOWLEDGMENTS

We are indebted to all the research participants who contributed to this study. This paper benefited greatly from the excellent comments of three anonymous reviewers. We would also like to thank Robert Knight and Clay Clayworth for their assistance. This research was supported by National Institutes of Health Grants MH48757 and NS17778 (awarded to A. Shimamura), a National Research Service Award (awarded to J. Baldo), and The Psychological Corporation.

## REFERENCES

Baldo, J. & Shimamura, A. (1998). Verbal and category fluency in patients with frontal lobe lesions. *Neuropsychology*, *12*, 259–267.

Benton, A. (1968). Differential behavioral effects on frontal lobe disease. *Neuropsychologia*, *6*, 53–60.

Bornstein, R. (1986). Contribution of various neuropsychological measures to detection of frontal lobe impairment. *International Journal of Clinical Neuropsychology*, *8*, 18–22.

Butters, N., Granholm, E., Salmon, D., Grant, I., & Wolfe, J. (1987). Episodic and semantic memory: A comparison of amnesic and demented patients. *Journal of Clinical and Experimental Neuropsychology*, *9*, 479–497.

Cohen, J., Perlstein, W., Braver, T., Nystrom, L., Noll, D., Jonides, J., & Smith, E. (1997). Temporal dynamics of brain activation during a working memory task. *Nature*, *386*, 604–608.

Delis, D., Kaplan, E., & Kramer, J. (in press). *Delis-Kaplan Executive Function Scale*. San Antonio, TX: The Psychological Corporation.

D'Esposito, M., Detre, J., Alsop, D., Shin, R., Atlas, S., & Grossman, M. (1995). The neural basis of the central executive system of working memory. *Nature*, *378*, 279–281.

Dunbar, K. & Sussman, D. (1995). Toward a cognitive account of frontal lobe function: Simulating frontal lobe deficits in normal subjects. In J. Grafman, K.J. Holyoak, & F. Boller (Eds.), *Annals of the New York Academy of Sciences*, *Vol. 769* (pp. 289–304).

Elfgren, C. & Risberg, J. (1998). Lateralized blood flow increases during fluency tasks: Influence of cognitive strategy. *Neuropsychologia*, *36*, 505–512.

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

Frith, C., Friston, K., Liddle, P., & Frackowiak, D. (1991). A PET study of word finding. *Neuropsychologia*, *29*, 1137–1148.

Gershberg, F. & Shimamura, A. (1995). Impaired use of organizational strategies in free recall following frontal lobe damage. *Neuropsychologia*, *13*, 1305–1333.

Hirst, W. & Volpe, B. (1988). Memory strategies with brain damage. *Brain and Cognition*, *8*, 379–408.

Janowsky, J., Shimamura, A., Kritchevsky, M., & Squire, L. (1989). Cognitive impairment following frontal lobe damage and its relevance to human amnesia. *Behavioral Neuroscience*, *103*, 548–560.

Jones-Gotman, M. & Milner, B. (1977). Design fluency: The invention of nonsense drawings after focal cortical lesion. *Neuropsychologia*, *15*, 653–674.

Kertesz, A. (1982). *Western Aphasia Battery*. New York: Grune & Stratton.

Mangels, J., Gershberg, F., Shimamura, A., & Knight, R. (1996). Impaired retrieval from remote memory in patients with frontal lobe damage. *Neuropsychology*, *10*, 32–41.

Miceli, G., Caltagirone, C., Gainotti, G., Masullo, C., & Silveri, M. (1981). Neuropsychological correlates of localized cerebral lesions in non-aphasic brain-damaged patients. *Journal of Clinical Neuropsychology*, *3*, 53–63.

Miller, E. (1984). Verbal fluency as a function of a measure of verbal intelligence and in relation to different types of cerebral pathology. *British Journal of Clinical Psychology*, *23*, 53–57.

Milner, B. (1963). Effects of different brain lesions on card sorting. *Archives of Neurology*, *9*, 100–110.

Milner, B. (1964). Some effects of frontal lobectomy in man. In J. Warren & K. Akert (Eds.), *The frontal granular cortex and behavior* (pp. 313–331). New York: McGraw-Hill.

Owen, A.M., Roberts, A.C., Hodges, J.R., Summers, B.A., Polkey, C.E., & Robbins, T.W. (1993). Contrasting mechanisms of impaired attentional shifting in patients with frontal lobe damage or Parkinson's disease. *Brain*, *116*, 1159–1175.

Parks, R., Loewenstein, D., Dodrill, K., Barker, W., Yoshii, F., Chang, J., Emran, A., Apicella, A., Sheramata, W., & Duara, R. (1988). Cerebral metabolic effects of a verbal fluency test: A PET scan study. *Journal of Clinical and Experimental Neuropsychology*, *10*, 565–575.

Perret, E. (1974). The left frontal lobe of man and the suppression of habitual responses in verbal categorical behaviour. *Neuropsychologia*, *12*, 323–330.

Regard, M., Strauss, E., & Knapp, P. (1982). Children's production on verbal and non-verbal fluency tasks. *Perception and Motor Skills*, *55*, 839–844.

Robertson, L. & Delis, D. (1986). "Part-whole" processing in unilateral brain-damaged patients: Dysfunction of hierarchical organization. *Neuropsychologia*, *24*, 363–370.

Ruff, R., Allen, C., Farrow, C., Niemann, H., & Wylie, T. (1994). Figural fluency: Differential impairment in patients with left versus right frontal lobe lesions. *Archives of Clinical Neuropsychology*, *9*, 41–55.

Troyer, A., Moscovitch, M., Winocur, G., Alexander, M., & Stuss, D. (1998). Clustering and switching on verbal fluency: The effects of focal frontal- and temporal-lobe lesions. *Neuropsychologia*, *36*, 499–504.