Clustering and switching on verbal fluency: the effects of focal frontal- and temporal-lobe lesions

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Abstract—We examined the hypothesis that, on verbal fluency, clustering (i.e. generating words within subcategories) is related to temporal-lobe functioning, whereas switching (i.e. shifting between subcategories) is related to frontal-lobe functioning. Tests of phonemic and semantic fluency were administered to 53 patients with focal frontal-lobe lesions (FL), 23 patients with unilateral temporal-lobe lesions (TL) and 55 matched controls. Performance by FL patients was consistent with our hypothesis: in comparison to controls, patients with left-dorsolateral or superior-medial frontal lesions switched less frequently and produced normal cluster sizes on both phonemic and semantic fluency. Performance by TL patients was not consistent across fluency tasks and provided partial support for our hypothesis. On phonemic fluency, TL patients were unimpaired on both switching and clustering. On semantic fluency, TL patients were impaired on switching in comparison to controls and left TL patients produced smaller clusters than right TL patients. The best indices for discriminating the patient groups, therefore, were phonemic-fluency switching (impaired only with frontal lesions) and semantic-fluency clustering (impaired only with temporal-lobe lesions). © 1998 Elsevier Science Ltd. All rights reserved

Key Words: focal brain lesions; temporal-lobe lesions; frontal-lobe lesions; semantic fluency; phonemic fluency.

Verbal fluency tasks involve generating words according to specified rules within 60 s intervals. On phonemic fluency, participants are asked to generate words beginning with a specific letter, such as f, a and s [1, 2]. On semantic fluency, participants are asked to generate words belonging to a semantic category, such as animals [20]. As reviewed subsequently, phonemic fluency is often thought to be a test of frontal-lobe functioning and semantic fluency a test of temporal-lobe functioning. However, there is emerging evidence that performance on these fluency tasks, as measured by the total number of words generated, is not specific to lesions in any single brain region and additionally, is sensitive to diffuse brain damage.

Frontal-lobe dysfunction is generally thought to be associated with impaired phonemic fluency and relatively intact semantic fluency. Among patients with focal frontal-lobe lesions (FL), in a majority of empirical studies, impaired performance is obtained on phonemic fluency, both in comparison to control subjects [1, 4, 5, 17, 21, 22, 23] and in comparison to patients with posterior cortical lesions [3, 16–18, 22, 23]. This finding, however, is not without contradiction. In some studies, phonemic fluency performance by FL patients has been found to be similar to that of patients with posterior cortical lesions [11, 25, 28] or to patients with diffuse brain injury [22]. The patterns of performance by FL patients on semantic fluency are also contradictory. Although FL patients are not impaired on semantic fluency in some studies [3, 4, 11, 20, 28], impaired levels of performance have been obtained in others [5, 21, 24, 25]. Thus, it is clear that FL patients exhibit impairment on verbal fluency tasks, although the specific patterns of performance vary somewhat between studies.

The cause of the fluency impairment among FL patients appears to be related to poor initiation and/or flexibility of search and retrieval processes. Consistent with this idea, a patient with bilateral frontal-lobe lesions, in comparison to age-matched controls, generated fewer
words on a standard uncued version of semantic fluency (i.e. *animals*) but improved to the level of controls when semantic subcategory cues were provided (e.g. *farm animals* and *jungle animals*) [24]. Additionally, FL patients, in comparison to patients with posterior lesions, performed more poorly on a fluency task requiring alternation between *animals* and *s* words, despite no group differences when *animals* and *s* words were generated separately [28]. Both of these studies suggest a specific difficulty switching between categories or subcategories. Additionally, the fluency impairment among FL patients does not appear to be due to a failure to use a strategy of generating words within subcategories. On phonemic and semantic fluency, patients with frontal tumors and patients with posterior tumors did not differ in the proportion of words produced within clusters of three or more words, in the size of the largest cluster, or in the number of clusters produced [12, 13].

Temporal-lobe dysfunction, in contrast to frontal dysfunction, is generally thought to be associated with impaired semantic fluency and relatively intact phonemic fluency. Presumably, this impairment reflects temporal-lobe related semantic-memory deficits. However, fluency studies of patients with focal temporal-lobe lesions (TL) have been somewhat contradictory. TL patients performed better than FL patients on phonemic fluency [3, 19, 23], but were no more impaired than FL patients on semantic fluency [3, 20]. Patients with focal temporal-lobe atrophy, or ‘semantic dementia’, were mildly impaired on phonemic fluency and severely impaired on semantic fluency [9]. Additionally, patients who had undergone temporal lobectomy for the control of epilepsy were impaired on both semantic and phonemic fluency [14, 15]. Therefore, the specific relationship between location of focal brain lesion and performance on phonemic and semantic fluency is unclear.

The effect of lesion laterality, regardless of location within the hemisphere, on fluency performance has been examined in a number of studies. Generally, patients with unilateral left-hemisphere lesions performed more poorly than patients with unilateral right hemisphere lesions on both phonemic and semantic fluency [10, 14–17, 19, 20, 22, 23, 28]. Patients with bilateral lesions performed the worst [1]. In some studies, patients with right-hemisphere lesions performed as well as non-lesion controls [19, 20], whereas in others, patients with right hemisphere lesions were impaired [14, 15, 23]. Overall, therefore, the patient groups ranging from most impaired to least impaired, respectively, are those with bilateral lesions, unilateral left-hemisphere lesions, and unilateral right-hemisphere lesions.

As reviewed previously, it is evident that the number of words generated on verbal fluency tests is not necessarily sensitive to lesions in any one particular brain region. We have argued [26] that two important cognitive components of fluency performance are clustering and switching. That is, optimal fluency performance involves producing clusters of semantically or phonemically related words and once a subcategory is exhausted, switching to another. We have demonstrated that switching was specifically decreased by divided attention [26] and was consistently impaired in Parkinson’s disease [27], providing preliminary evidence that switching is related to frontal-lobe functioning. The purpose of the present study was to examine clustering and switching on fluency tasks among patients with focal brain lesions. We hypothesized that, in comparison to controls, switching would be impaired in patients with frontal-lobe lesions (regardless of lesion laterality) and clustering would be impaired in patients with temporal-lobe lesions (especially left-temporal lesions). Our expectations regarding laterality were based on the nature of the fluency components: switching is a cognitive-shifting task without obvious implications for lateralization, whereas phonemic clustering is a language-related task and semantic clustering is a verbal semantic-memory task, both of which may be more dependent on the left hemisphere.

**Methods**

**Participants**

Participants were patients with focal frontal-lobe or focal temporal-lobe lesions. Because of group differences in demographic characteristics (i.e. age), each was matched with its own control group. Demographic characteristics are presented in Table 1.

FL patients were grouped according to lesion site and fluency performance via classification and regression tree analyses, as reported elsewhere [25]. All lesions were documented on CT or MRI scans. Fourteen patients had lesions of the left dorsolateral and/or lenticular striate frontal regions (LDLF group). Eleven patients had lesions of the right dorsolateral and/or lenticular striate frontal regions (RDLF group). Seventeen patients had superior medial frontal lesions from either left, right, or bifrontal damage (SMF group); right and left lesions were considered together because of previous evidence of lack of lateralized function in the superior medial frontal regions [25]. Eleven patients had inferior medial frontal lesions from either left, right, or bifrontal damage (IMF group). A small subgroup of patients (11%) with lesions in more than one frontal region were classified according to the maximum lesion area. The etiology of frontal pathology included cerebral vascular accident (n = 37), tumor (n = 8), traumatic brain injury (n = 8), and lobectomy (n = 1). The mean time since lesion onset was at least 3 months for all patients. Thirty-seven healthy control subjects were matched with the FL patients as closely as possible for demographic characteristics. There were no group differences in age, F(4,85) < 1, or sex, χ²(4, n = 90) = 6.33, P > 0.10. However, there were group differences in education, F(4,85) = 4.28, P = 0.003.

Among the 23 TL patients, 9 had unilateral left-temporal-lobe lesions (LTL) and 14 had unilateral right-temporal-lobe lesions (RTL). The etiologies of the temporal-lobe lesions were lobectomy for intractable epileptic seizures (n = 20) and cerebral vascular accident (n = 5). Lesions were documented on CT or MRI scans or by surgical report. Results of sodium amytal testing were available for 19 of the 20 patients with temporal lobectomy; all were left-hemisphere language dominant. Eighteen healthy control subjects were matched for demographic characteristics with the TL patients. There were no
significant differences between the LTL, RTL and control groups in age, $F(2, 38) < 1$, sex, $\chi^2(2, n = 41) = 1.41, P = 0.50$, or education, $F(2, 38) < 1$.

Procedures and scoring

Tests of phonemic fluency (i.e. FAS test) [1, 2] and semantic fluency (i.e. animals) were administered on an individual basis. Sixty seconds were allotted for each of the three phonemic trials and one semantic trial. Three scores were obtained on each fluency test: (a) total number of words generated, excluding errors and repetitions; (b) mean cluster size; and (c) number of switches. Detailed scoring rules for cluster size and switches have been provided elsewhere and produce scores with high interrater reliabilities (i.e. $r > 0.95$) [26]. Briefly, on phonemic fluency, clusters consisted of successively generated words that began with the same first two letters (e.g. arm and art), differed only by a vowel sound (e.g. foot and fat), rhymed (e.g. flight and fright), or were homonyms (e.g. sail and sale). On semantic fluency, clusters consisted of successively generated words belonging to the same semantic subcategory, such as farm animals, pets, aquatic animals, or insects. Cluster size was counted beginning with the second word in each cluster and mean cluster size was calculated for the phonemic test and for the semantic test. Switches were calculated as the number of transitions between clusters, including single words, for the phonemic and semantic tests. The raw number of switches was utilized rather than correcting for the number of words generated (i.e. a proportion score), because this index best represented the behaviour of interest. That is, optimal fluency performance, as measured by the raw number of correct words generated, requires the use of a large number of different subcategories, which is achieved by frequent switching. Optimal fluency performance would not be achieved with a high proportion switching score but a low raw switching score (e.g. 4 switches out of 5 words).

Analyses

To correct for group differences in education among the FL patient and control groups, fluency performance was analysed with analysis of covariance (ANCOVA), with education as the covariate. Group differences between the TL patient and control groups were conducted with ANOVA. Post-hoc pairwise comparisons (Bonferroni’s test) were used to test whether each patient group differed from its respective control group. Additionally, we performed one-tailed $t$-tests on cluster size between the LTL and RTL groups, based on our directional hypotheses. For the overall ANCOVAs, ANOVAs, and $t$ tests, an $z$ level of 0.05 was used; for the multiple post-hoc pairwise comparisons, Bonferroni-corrected $z$-levels were used.

Results

Fluency data for the patient and control groups, on both phonemic and semantic fluency, are presented in Table 2.

Frontal groups

Switching performance by the FL patient and control groups was consistent with our hypotheses. That is, phonemic fluency switching showed significant group differences, $F(4, 84) = 16.01, P < 0.001$, with impaired performance by the LDLF group, $F(1, 84) = 50.93, P < 0.001$ and the SMF group, $F(1, 84) = 21.69, P < 0.001$, in comparison to controls. Similarly, semantic fluency switching showed significant group differences, $F(4, 84) = 4.72, P = 0.001$, with impaired performance by the LDLF group, $F(1, 84) = 13.59, P < 0.001$ and the SMF group, $F(1, 84) = 10.32, P = 0.002$, in comparison to controls.

Clustering performance by the FL groups was also consistent with our hypotheses. There were no group differences in clustering on either phonemic fluency, $F(4, 84) = 1.10, P = 0.364$, or semantic fluency, $F(4, 84) < 1$.

The number of words generated on phonemic fluency showed overall group differences, $F(4, 84) = 19.80, P < 0.001$, with impaired performance by the LDLF group, $F(1, 84) = 67.18, P < 0.001$ and the SMF group, $F(1, 84) = 27.68, P < 0.001$. The number of words generated on semantic fluency also showed overall group differences, $F(4, 84) = 12.08, P < 0.001$, with impaired performance by the LDLF group, $F(1, 84) = 37.07, P < 0.001$, the RDLF group, $F(1, 84) = 12.63, P = 0.001$, the SMF group, $F(1, 84) = 13.83, P < 0.001$ and the IMF group, $F(1, 84) = 8.54, P = 0.004$.
Table 2. Fluency data for patient groups and controls

<table>
<thead>
<tr>
<th></th>
<th>LDLF</th>
<th>RDLF</th>
<th>SMF</th>
<th>IMF</th>
<th>Ctl</th>
<th>LTL</th>
<th>RTL</th>
<th>Ctl</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phonemic fluency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switches</td>
<td>12.5</td>
<td>25.3</td>
<td>16.4</td>
<td>25.7</td>
<td>29.6***</td>
<td>24.0</td>
<td>26.3</td>
<td>28.4</td>
</tr>
<tr>
<td>Cluster size</td>
<td>0.33</td>
<td>0.28</td>
<td>0.38</td>
<td>0.30</td>
<td>0.41</td>
<td>0.49</td>
<td>0.47</td>
<td>0.39</td>
</tr>
<tr>
<td>Words generated</td>
<td>17.2</td>
<td>32.9</td>
<td>22.9</td>
<td>34.2</td>
<td>42.7***</td>
<td>33.6</td>
<td>38.9</td>
<td>41.1</td>
</tr>
<tr>
<td></td>
<td>(9.0 )</td>
<td>(10.9)</td>
<td>(8.0)</td>
<td>(11.5)</td>
<td>(11.4)</td>
<td>(10.4)</td>
<td>(10.8)</td>
<td>(11.6)</td>
</tr>
<tr>
<td><strong>Semantic fluency</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switches</td>
<td>5.8</td>
<td>6.9</td>
<td>5.9</td>
<td>7.4</td>
<td>9.4***</td>
<td>7.9</td>
<td>7.3</td>
<td>10.8*</td>
</tr>
<tr>
<td>Cluster size</td>
<td>1.21</td>
<td>1.02</td>
<td>1.34</td>
<td>0.97</td>
<td>1.22</td>
<td>0.91</td>
<td>1.35</td>
<td>1.16†</td>
</tr>
<tr>
<td>Words generated</td>
<td>11.9</td>
<td>14.1</td>
<td>14.4</td>
<td>15.1</td>
<td>20.2***</td>
<td>15.2</td>
<td>18.8</td>
<td>22.5**</td>
</tr>
<tr>
<td></td>
<td>(4.0 )</td>
<td>(2.7 )</td>
<td>(5.1)</td>
<td>(2.5)</td>
<td>(4.8 )</td>
<td>(3.3 )</td>
<td>(5.5)</td>
<td>(4.7 )</td>
</tr>
</tbody>
</table>

*Note:* LDLF = left dorsolateral frontal, RDLF = right dorsolateral frontal, SMF = superior medial frontal, IMF = inferior medial frontal, Ctl = controls, LTL = left temporal lobe, RTL = right temporal lobe. Standard deviations are shown in parentheses.

$P < 0.05$, $**P < 0.01$, $***P < 0.001$ for overall analyses; † $P < 0.05$ for left vs right temporal groups.

**Temporal groups**

Findings with the TL patients and controls were less clear, but provide some support for our hypotheses. On phonemic fluency switching, there were no overall group differences, $F(2,38) < 1$. On semantic fluency switching, there were overall group differences, $F(2,36) = 5.02$, $P = 0.012$, with impaired performance by the RTL group in comparison to controls, $F(1,36) = 8.48$, $P = 0.006$.

On phonemic fluency cluster size, there were no overall group differences, $F(2,38) < 1$, and there was no difference between LTL and RTL patients, $t(21) = 0.20$, $P = 0.846$. On semantic fluency cluster size, there were no overall group differences, $F(2,36) = 1.66$, $P = 0.204$; however, consistent with our a priori hypothesis, LTL patients produced smaller clusters than RTL patients, $t(19) = 1.81$, $P = 0.043$.

For the number of words generated, there were no group differences on phonemic fluency, $F(2,38) = 1.38$, $P = 0.263$. There were group differences on semantic fluency, $F(2,24) = 5.77$, $P = 0.009$, with impaired performance by the LTL group in comparison to controls, $F(1,36) = 14.59$, $P = 0.001$.

**Discussion**

Our findings provide general support for the idea that switching on verbal fluency is related to frontal-lobe functioning, whereas clustering is related to temporal-lobe functioning. The pattern of performance by the FL patients was completely consistent with our hypothesis. That is, in comparison to controls, FL patients as a group switched less frequently and produced normal cluster sizes on both phonemic and semantic fluency. Performance by TL patients was not consistent across fluency tasks and provided partial support for our hypothesis. On phonemic fluency, TL patients were unimpaired on both switching and clustering. On semantic fluency, TL patients were impaired on switching in comparison to controls and LTL patients produced smaller clusters than RTL patients. The best indices for discriminating the patient groups, therefore, were phonemic-fluency switching (impaired only with frontal lesions) and semantic-fluency clustering (impaired only with temporal-lobe lesions). This is consistent with previous research [27] in which these same indices discriminated between dementia groups. Phonemic-fluency switching was impaired only in Parkinson’s dementia (in which frontal and subcortical regions are preferentially involved) and semantic-fluency clustering was impaired only in Alzheimer’s dementia (in which temporal and parietal regions are preferentially involved). We have obtained converging evidence, therefore, that switching is related to frontal-lobe functioning whereas clustering is related to temporal-lobe functioning.

The patients with frontal lesions were not homogeneous in their fluency performance, but, rather, showed subgroup performance differences. Specifically, switching was impaired in the LDLF and SMF groups and unimpaired in the RDLF and IMF groups. This is consistent with research indicating impaired initiation of behaviour and perseveration in patients with dorsolateral frontal lesions [18] and superior-medial frontal lesions (i.e. supplementary motor area and anterior cingulate gyrus) [6, 7]. Presumably, switching on verbal fluency tasks would require initiation of numerous searches through semantic...
and lexical memory, and cognitive flexibility to rapidly shift between subcategories.

Although switching was impaired on both fluency tasks in our FL patients, switching on semantic fluency was also impaired in our TL patients. It is possible that this unexpected switching deficit resulted from damage to pathways connecting the anterior frontal and temporal regions subsequent to anterior temporal lobectomy. Thus, the switching impairment in our TL patients may be a result of additional frontal dysfunction. On the other hand, it is also possible that switching on semantic fluency is mediated both by frontal and anterior–temporal regions. It is apparent that the frontal lobes are directly involved in switching, either for initiating switches or for locating a new subcategory or both. The frontal lobes may also require information indicating that the point of diminishing returns has been reached in searching a particular semantic cluster. Perhaps it is this information that is not efficiently transmitted in the semantic fluency task in TL patients. In contrast, because phonemic processing is not as dependent on the anterior temporal lobe as semantic processing, switching was normal in TL patients on this task. If the frontal lobes are the repository of the switching mechanism itself, frontal damage should lead to deficits in switching on both tasks, as seen in our FL patients.

Although semantic-fluency clustering was impaired in our LTL patients, somewhat unexpectedly, phonemic-fluency clustering was not impaired in this group. This is similar to previous findings that impaired clustering is not always consistent across fluency tasks [26, 27]. Rather, it appears that different cognitive processes are involved, at least to some degree. Semantic-fluency clustering may depend on access to and integrity of semantic stores, whereas phonemic-fluency clustering may depend on fund of word knowledge and the ability to analyse the phonemic characteristics of words. Thus, despite the fact that clustering on phonemic and semantic fluency both involve the ability to classify and group words with similar characteristics, additional cognitive processes vary between these tasks, resulting in the possibility of inconsistent performance across fluency tasks.

Our frontal-lesion findings share some similarities with those of Laine [12, 13], who found that patients with frontal tumors produced normal cluster sizes on verbal fluency in comparison to patients with posterior tumors. They also found no group differences in the number of clusters of three or more words, which was their measure of “shifting”, whereas our FL patients were impaired on switching when clusters of all sizes, including single words, were considered. This suggests that switching alone, regardless of the size of clusters between which the patient is switching, may be the crucial ability that is sensitive to lesions of the frontal lobe.

The lateralizing effects we obtained for clustering and switching were generally consistent with our expectations. We had no a priori reason to expect switching, a cognitive-shifting task, to be differentially affected by right- versus left-hemisphere lesions. Indeed, we found that switching was significantly impaired in patients with left-frontal, superior-medial-frontal, and right-temporal lesions. On the other hand, we expected that clustering words in phonemic or semantic subcategories, which is a language-related task, would be more greatly affected by left-temporal lesions. This is indeed the pattern we obtained for semantic-fluency clustering, although phonemic-fluency clustering was unimpaired in all patient groups.

The pattern of findings in Table 2 may appear to suggest that switching and number of words generated are highly dependent variables, because group differences in the number of words generated were always associated with group differences in switching. However, additional research has indicated that a decrease in the number of words generated can be obtained without decreased switching but, rather, with decreased clustering (i.e. among patients with Alzheimer’s disease) [27]. Impaired switching, therefore, is not necessary for obtaining a decreased number of words generated.

Consistent with the idea that phonemic fluency is a test of frontal-lobe functioning, the number of words generated on phonemic fluency was impaired in the FL group but not the TL group in comparison to controls. This is not only a test of frontal functioning, however, as impaired performance has also been obtained by patients with parietal-lobe lesions [25]. Number of words generated on semantic fluency, on the other hand, was impaired in both of our patient groups, suggesting that performance on this test is not specific to temporal-lobe functioning. This is consistent with a number of previous studies [5, 21, 24]. Specific effects, therefore, were obtained for the clustering and switching components, but not for the total number of words generated.

The conclusions drawn in this study are limited by several factors, including small TL patient sample sizes, heterogeneity of lesion size and etiology, and possible diffuse brain dysfunction in addition to focal lesions among the patients with tumors or traumatic brain injury. Additionally, because of the early age at seizure onset in the temporal lobectomy groups, some functional reorganization may have occurred. Despite these sample characteristics, which likely reduced the probability of finding group differences, we obtained significant differences for most of our critical comparisons.

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