

Clustering and Switching as Two Components of Verbal Fluency: Evidence From Younger and Older Healthy Adults

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Although verbal fluency is a frequently used neuropsychological test, little is known about the underlying cognitive processes. The authors proposed that 2 important components of fluency performance are clustering (i.e., the production of words within semantic or phonemic subcategories) and switching (i.e., the ability to shift between clusters). In Experiment 1, correlational data from 54 older and 41 younger adults indicated that both components were highly correlated with the number of words generated on semantic fluency, whereas switching was more highly correlated than clustering with the number of words generated on phonemic fluency. On semantic fluency, younger participants generated more words and switched more frequently than older participants; on phonemic fluency, older participants produced larger clusters than younger participants. In Experiment 2, among 22 young adults, divided attention decreased the number of words generated and decreased switching on phonemic fluency only. Overall, findings suggest that clustering and switching are dissociable fluency components and that switching is related to frontal-lobe functioning.

Verbal fluency is a commonly used neuropsychological test, both in clinical and experimental settings. Typical administration procedures allow 60 s for the participant to generate as many words as possible according to specific rules. For phonemic fluency, words must begin with a specified letter, such as *f*, *a*, or *s* (Benton, 1968; Borkowski, Benton, & Spreen, 1967). For semantic fluency, words must belong to specified semantic categories, such as *animals* or *vegetables* (Newcombe, 1969). In the present study, we investigated two of the component processes underlying performance on fluency tests.

A specific pattern of age differences in fluency performance has been demonstrated. Older participants tend to generate fewer words than younger participants on semantic

fluency (Kozora & Cullum, 1995; Tomer & Levin, 1993; Tröster, Salmon, McCullough, & Butters, 1989; Whelihan & Leshner, 1985; Wiederholt et al., 1993). In contrast, age differences on phonemic fluency are typically smaller or absent (Axelrod & Henry, 1992; Bolla, Lindgren, Bonaccorsy, & Blecker, 1990; Boone, Miller, Lesser, Hill, & D'Elia, 1990; Koss, Haxby, DeCarli, Schapiro, & Paroport, 1991; Kozora & Cullum, 1995; Mittenberg, Seidenberg, O'Leary, & DiGiulio, 1989; Tomer & Levin, 1993), although significant age differences have been reported in some studies (Parkin & Walter, 1991; Veroff, 1980).

The most common fluency measure derived is the number of correct words generated on each task. There is emerging evidence, however, that fluency is a multifactorial task, and this score alone may not fully capture all of the important aspects of any given participant's performance. To address this, qualitative aspects of fluency performance have been studied via examination of perseveration and intrusion errors, and on semantic fluency, production of category labels (as opposed to specific exemplars) and number of exemplars generated per superordinate category (Crowe, 1992; Kozora & Cullum, 1995; A. Martin & Fedio, 1983; Ober, Dronkers, Koss, Delis, & Friedland, 1986; Tröster et al., 1989). Furthermore, to examine the ongoing underlying cognitive processes involved in fluency, a limited number of studies have examined the degree to which words are generated within semantic or phonemic clusters (Auriacombe et al., 1993; Bayles, Trosset, Tomoeda, Montgomery, & Wilson, 1993; Gruenewald & Lockhead, 1980; Raskin, Sliwinski, & Borod, 1992). Generally, these studies suggest a frequent production of phonemic clusters on phonemic fluency tests and semantic clusters on semantic fluency tests, whereas semantic clusters on phonemic tests and phonemic clusters on semantic tests are rarely produced.

Consistent with the idea that fluency is a multifactorial

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task, a variety of studies have provided evidence that fluency performance involves multiple brain regions. Lesion studies, for example, have indicated that fluency can be impaired with lesions to the frontal lobes (Coslett, Bowers, Verfaellie, & Heilman, 1991; Crowe, 1992; Miceli, Caltagirone, Gainotti, Masullo, & Silveri, 1981; Miller, 1984; Newcombe, 1969; Pendleton, Heaton, Lehman, & Hulihan, 1982; Perret, 1974) or with lesions to the temporal lobes (Corcoran & Upton, 1993; R. C. Martin, Loring, Meador, & Lee, 1990; Newcombe, 1969). There is some evidence that phonemic fluency is more sensitive to frontal lesions (Coslett et al., 1991; Milner, 1964; Perret, 1974), whereas semantic fluency is more sensitive to temporal lesions (Newcombe, 1969), although this pattern is not always obtained (Joanette & Goulet, 1986).

Studies using functional brain imaging also implicate multiple brain regions in modified versions of fluency tasks. Using functional magnetic resonance imaging (fMRI), phonemic fluency performance, in comparison to resting state, was associated with activation in the frontal lobes (premotor cortex, Broca's area, and dorsolateral prefrontal cortex) and in the temporal lobes (anterior, middle, and posterior regions; Cuenod et al., 1995). Similarly, using positron emission tomography (PET), bilateral frontal and temporal areas were activated during phonemic fluency performance in comparison to resting state (Parks et al., 1988). In PET studies employing more specific control conditions, activations during phonemic and semantic fluency tasks have been noted in the left dorsolateral prefrontal gyrus and the left parahippocampal gyrus (Frith, Friston, Liddle, & Frackowiak, 1991), and in the left ventrolateral, dorsolateral, and medial regions of the frontal lobes and in the left inferior temporal lobe (Klein, Milner, Zatorre, Meyer, & Evans, 1995). Furthermore, the total number of words generated on fluency tasks has been found to be correlated significantly, either positively or negatively, with PET activation in bilateral frontal and temporal brain regions during rest (Boivin et al., 1992) or during fluency performance (Parks et al., 1988).

Further evidence of the multifactorial nature of fluency tasks has been provided by temporal and semantic analyses of word generation over extended time periods (e.g., 15 or 30 min for a single task). It has been noted that the production of words is not evenly distributed over time, but that words tend to be produced in "spurts," or temporal clusters, with a short time interval between words in a cluster and a longer pause between clusters (e.g., Bousfield & Sedgewick, 1944). On semantic fluency tasks, the words that comprise these temporal clusters tend to be semantically related (Gruenewald & Lockhead, 1980; Pollio, 1964; Rosen & Engle, 1995). This response pattern has led to the suggestion that performance on semantic fluency involves two processes: (a) a search for semantic fields or subcategories, which corresponds to the pause between clusters; and (b) a search for and production of words within the fields or subcategories once these are identified, which corresponds to the spurts (Gruenewald & Lockhead, 1980; Wixted & Rohrer, 1994).

An additional two-component model of fluency perfor-

mance has been proposed by Chertkow and Bub (1990). They found that patients with Alzheimer's disease rarely generated items on semantic fluency tests for which they were unable to answer semantic-probe questions, implicating the involvement of semantic memory stores in fluency performance. However, there was no direct correspondence between the specific semantic categories on which patients were relatively impaired at answering semantic-probe questions and the categories on which they showed decreased verbal fluency, suggesting the additional involvement of search processes. The authors concluded that adequate semantic fluency performance requires both intact semantic memory stores and effective search processes.

In the present article, we propose a theoretically based methodology for examining the underlying cognitive components of fluency performance that have been implicated in the literature. Our approach includes analysis of an additional component of fluency, switching, that has not been emphasized previously. A consideration of optimal fluency performance might suggest the production of clusters of semantically or phonemically related words, and once a subcategory is exhausted, switching to another. Accordingly, we suggest that two important components of fluency performance include (a) clustering, the production of words within semantic or phonemic subcategories; and (b) switching, the ability to shift efficiently to a new subcategory. The definitions of these two components imply that clustering relies upon temporal-lobe processes such as verbal memory and word storage, whereas switching relies upon frontal-lobe processes such as strategic search processes, cognitive flexibility, and shifting.

The two components we propose share some similarities with the previously reviewed models (Chertkow & Bub, 1990; Gruenewald & Lockhead, 1980; Wixted & Rohrer, 1994). That is, clustering involves accessing and using a word store, and switching involves search processes. Our components, however, expand upon previous models of fluency performance by being more widely applicable and more easily examined in individual participants. Using our methodology, clustering and switching can be examined in both semantic and phonemic fluency tests, and they can be quantified for individual participants via an examination of protocols obtained from standard administration and recording procedures.

To explore these components, in Experiment 1, we examined the statistical relations between number of words generated, clustering, and switching on both phonemic and semantic fluency tests. Age differences on these variables were also explored. In Experiment 2, we examined the relation between frontal-lobe functioning and the fluency variables of clustering and switching by manipulating attentional load.

Experiment 1

Method

Participants. Participants consisted of 41 younger university students and 54 healthy older volunteers. In the younger group, ages ranged from 18 to 35 years, with a mean of 22.3 years

($SD = 3.8$), and in the older group, ages ranged from 60 to 89 years with a mean of 73.3 years ($SD = 6.5$). We used extreme age groups because the magnitude of age effects on fluency performance tends to be moderate rather than large, as previously reviewed. The mean level of education was 14.4 years ($SD = 1.6$) for the younger group and 13.2 years ($SD = 2.7$) for the older group. As would be expected in the general population, the younger group was more highly educated than the older group, $t(92) = 2.64, p = .010$, although both groups were more highly educated than their age peers in the general Canadian population (i.e., 12.8 and 9.6 years of education for the younger and older groups, respectively; Statistics Canada, 1993). The proportion of female participants in the younger (63%) and older (50%) groups was not significantly different, $\chi^2(1, n = 95) = 1.70, p > .50$. For the older group, the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) was used as a screening measure for abnormal cognitive decline, and all participants scored above the standard cutoff of 24 points. Participants were screened via detailed interview for neurologic and psychiatric disorders that could affect test performance. Participants with other age-related medical problems (e.g., osteoporosis, arthritis, glaucoma) were not excluded.

Procedures and scoring. As part of a larger research battery, tests of phonemic and semantic fluency were administered on an individual basis. For the phonemic fluency test, participants were instructed to generate words beginning with *f*, *a*, or *s*, excluding proper names and variants of the same word (e.g., the same word with different suffixes). For the semantic fluency test, participants were instructed to generate names of animals. Sixty seconds was allotted for each of the three phonemic trials and one semantic trial.

Three scores were obtained on each fluency test: (a) number of words generated, excluding errors and repetitions, (b) mean cluster size, and (c) number of switches. Detailed rules for scoring switching and clustering are provided in the Appendix. Briefly, on phonemic fluency, clusters were defined as groups of successively generated words that began with the same first two letters (e.g., *art*, *arm*), differed only by a vowel sound (e.g., *fit*, *fat*, *foot*), rhymed (e.g., *sand*, *stand*), or were homonyms (e.g., *some*, *sum*). Homonyms were scored when indicated as such by participants during word generation, for example, by saying "some and the other sum" or by spelling the words aloud. On semantic fluency, clusters were defined as groups of successively generated words belonging to the same semantic subcategory, such as farm animals, pets, African animals, Australian animals, North American wildlife, and various zoological categories (e.g., primates, birds, insects). The determination of potential semantic subcategories, as listed in the Appendix, was derived from the actual patterns of words generated by participants during test performance, rather than on an a priori organizational scheme. The large number of subcategories reflects the considerable individual variations in approach to this task and gives participants the benefit of the doubt regarding their use of clusters.

Cluster size was counted beginning with the second word in each cluster, and the 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. Errors and repetitions were included in calculations of cluster size and switching because these were thought to provide information about the underlying cognitive processes regardless of whether or not they were included in the total number of words generated.

All protocols were scored by the first author, and half of the protocols were scored for cluster size and number of switches by an independent rater. Interrater reliabilities, calculated with Pearson correlation coefficients, were high for phonemic fluency cluster size, $r(42) = .99$, and switching, $r(42) = .99$, as well as for

semantic fluency cluster size, $r(42) = .95$, and switching, $r(42) = .96$.

Results

With one exception, in each age group on each fluency task, the total number of words generated was significantly correlated both with number of switches and with cluster size at the $p < .05$ level. The exception was for the correlation between total words generated and cluster size on phonemic fluency in the younger group, $r(40) = .09, p = .57$; however, with the removal of one clear outlier, this value increased substantially, $r(39) = .31, p = .048$. As shown in Table 1, despite uniformly significant correlation coefficients between switches or cluster size and total words generated, there was a wide range in the absolute sizes of the coefficients. The differences between dependent r s, therefore, were examined with t tests, as described by Cohen and Cohen (1983). For both age groups, the total number of words generated on phonemic fluency was correlated more highly with number of switches than with cluster size: For the younger group, $t(38) = 3.88, p < .001$, and for the older group, $t(51) = 3.07, p < .01$. On semantic fluency, the difference between these correlations was not statistically significant: For the younger group, $t(37) = 1.83, p > .05$, and for the older group, $t(51) = 0.55, p > .50$. Correlations between switches and cluster size were negative and, with one exception, statistically significant for each age group on each task.

Raw scores obtained by the two age groups on the fluency tasks are presented in Table 2. On phonemic fluency, t tests indicated no age-group differences in number of words generated, $t(93) = 0.27, p = .79$, or in number of switches, $t(93) = 1.12, p = .26$. The older group produced slightly larger cluster sizes than the younger group on this task, $t(93) = -2.21, p = .03$. On semantic fluency, the younger group generated more words, $t(93) = 4.00, p < .001$, and switched more often than the older group, $t(93) = 3.54, p = .001$. There was no group difference in cluster size on this task, $t(93) = 0.29, p = .77$.

To examine the combined influence of demographic variables on fluency task performance, regression analyses

Table 1
Correlation Coefficients for Fluency Variables

Variable	Phonemic fluency		Semantic fluency	
	Cluster size	Switches	Cluster size	Switches
Younger participants				
Switches	-.20		-.41**	
Words generated	.31* ($n = 41$)	.85***	.31* ($n = 40$)	.66***
Older participants				
Switches	-.31*		-.51***	
Words generated	.31* ($n = 54$)	.78***	.38** ($n = 54$)	.53***

Note. Coefficients for the younger participants on semantic fluency were derived after the removal of one outlier.

* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 2
Fluency Performance by Younger and Older Participants

Variable	Phonemic fluency		Semantic fluency	
	Younger	Older	Younger	Older
<i>n</i>	41	54	41	54
Words generated	41.88 (11.45)	41.26 (10.90)	21.81 (5.65)	17.76*** (4.20)
Switches	28.90 (8.57)	27.00 (7.86)	10.61 (3.48)	8.50*** (2.33)
Cluster size	0.36 (0.21)	0.49* (0.32)	1.09 (0.54)	1.06 (0.53)

Note. Standard deviations are shown in parentheses. Statistical analyses were conducted within each fluency task, across age groups.

* $p < .05$. *** $p < .001$.

were performed with age, sex, and education as the predictor variables and fluency measures as the criterion variables. Consistent with the *t*-test analyses, age possessed unique predictive value for cluster size on phonemic fluency, $sr^2(90) = .03$, $p = .047$; for total number of words generated on semantic fluency, $sr^2(90) = .07$, $p = .001$; and for number of switches on semantic fluency, $sr^2(90) = .09$, $p = .003$. Education and sex did not possess unique predictive value for any of the fluency variables (all $ps > .05$).

Discussion

Correlational analyses indicated that clustering and switching were differentially related to semantic and phonemic fluency. Clustering and switching were equally highly correlated with total number of words generated on semantic fluency, indicating that both are important for optimal performance on this fluency task. In contrast, switching was more highly correlated than clustering with total number of words generated on phonemic fluency, indicating that switching is more important for optimal performance on this fluency task. Thus, the fluency component that we hypothesized to be related to frontal-lobe functioning (i.e., switching) is strongly related to the fluency task generally thought to be mediated by the frontal lobes (i.e., phonemic fluency). Semantic fluency, on the other hand, appears to rely, at least to some extent, on both the frontal- and temporal-lobe mediated components.

Given the time constraint of fluency tests, the negative correlation between clustering and switching was not surprising. That is, larger cluster sizes would necessarily be associated with less switching, and vice versa, among participants who perform this task rapidly. However, both of these variables are positively correlated with the number of words generated, and this implies that optimal fluency performance requires some type of balance between clustering and switching. One might expect extreme values of either of these components to be associated with the generation of fewer words overall. The possibility of the presence of this inverted U-shape relation between clustering or switching and total words generated is consistent with data from the outlier described previously. This participant produced a very large cluster size, yet, as one might expect,

did not generate a large number of words. In our total sample, however, an inverted U-shape relation was not present, presumably because most of these bright, well-educated participants adopted successful strategies on these tasks, with an optimal balance between clustering and switching. To examine an inverted U-shape function, it would be necessary to have a wider distribution of clustering and switching scores.

Consistent with previous reports of age differences in fluency performance (e.g., Axelrod & Henry, 1992; Bolla et al., 1990; Kozora & Cullum, 1995; Mittenberg et al., 1989; Tomer & Levin, 1993; Tröster et al., 1989), the older participants in our study generated fewer words on semantic fluency than the younger participants, whereas there was no age-group difference in the total number of words generated on phonemic fluency. Furthermore, in comparison to the younger participants, older participants tended to switch less frequently on semantic fluency, and this may have been the source of the smaller total number of words generated on this task. Indeed, the correlational data suggest that switching is an important component of optimal performance on semantic fluency; therefore, decreased switching is likely to affect total number of words generated.

Somewhat surprisingly, the older participants in our study tended to produce larger cluster sizes on phonemic fluency than the younger participants. It is possible that this age difference may reflect differences in vocabulary size. There is evidence that, other things being equal, older adults can have larger vocabularies than younger adults (Lachman, Lachman, & Taylor, 1982; Wechsler, 1981). This more extensive vocabulary may provide the older participants with a larger pool from which to draw phonemically related words, so that more words are generated before a phonemic subcategory is exhausted. Despite the small but significant age difference in cluster size, however, there was no resulting difference in total number of words generated on phonemic fluency. This is consistent with the correlational data suggesting that cluster size is not an important component in phonemic fluency; thus, variations in this component are not likely to affect the total number of words generated.

Demographic variables other than age, including sex and level of education, were not uniquely related to clustering or switching. The lack of significant relations indicates that our finding of age-group differences in clustering and switching was not confounded by differences in level of education or sex proportion.

Experiment 2

Experiment 1 provided indirect preliminary evidence of a relation between frontal-lobe processes and switching. The purpose of Experiment 2 was to examine possible frontal-lobe involvement in fluency performance by manipulating attentional load. Divided attention (DA) paradigms require the participant to perform a primary task, the task of interest, while concurrently performing a secondary, interfering task. These paradigms have been used to simulate frontal-lobe dysfunction in healthy participants. Normal young adults under DA conditions tend to display some of the same

performance characteristics as patients with frontal-lobe lesions. For example, healthy participants under DA conditions, in comparison to conditions of full attention, recalled fewer words on a list-learning task despite normal learning curves and failed to release from proactive interference (Moscovitch, 1994); completed fewer categories and produced more perseverative errors on the Wisconsin Card Sorting Test (Dunbar & Sussman, 1995); and had greater difficulty inhibiting reflexive eye movements in the antisaccade task (Roberts, Hager, & Heron, 1994).

The effects of DA on fluency performance have been examined in several studies. These effects tend to be greatest when both the fluency task and the secondary, concurrent task make demands on the same neural substrate. For example, phonemic fluency, but not semantic fluency, was reduced when participants concurrently performed a motor sequencing task thought to be mediated by prefrontal regions (Moscovitch, 1992, 1994). Written semantic fluency, on the other hand, was reduced to a greater extent when participants performed a verbal memory-span task thought to be mediated by temporal brain regions than when they performed a counting task (Baddeley, Lewis, Eldridge, & Thomson, 1984). A clear double dissociation was demonstrated in the finding that phonemic fluency was reduced to a greater extent when participants concurrently performed a motor-sequencing (frontal-lobe mediated) task as opposed to an object-decision (temporal-lobe mediated) task, and the reverse pattern was found for semantic fluency (A. Martin, Wiggs, Lalonde, & Mack, 1994). In Experiment 2, we examined the effect of DA on the fluency components of clustering and switching. Because the secondary task we employed is believed to interfere with frontal-lobe functions, we expected a greater decrease in switching than in clustering under conditions of DA.

Method

Fluency protocols from Moscovitch (1994; Experiment 3) were re-analyzed for this experiment.

Participants. Twenty-two right-handed undergraduate university students participated in this study. Ages ranged from 17 to 35 years, with a mean age of 20.7 years ($SD = 4.2$), and 68% of the participants were female. Students proficient at playing a musical instrument requiring rapid finger movements were excluded because it was thought that the secondary (finger-tapping) task would not be sufficiently demanding for these individuals.

Procedures and scoring. The phonemic fluency test consisted of six 60-s trials, using the letters *p*, *b*, *l*, *r*, *w*, and *h*. The semantic fluency test consisted of 60-s trials, including types of weather, natural landscape and geographical formations, buildings and dwellings, and trees. An additional semantic trial, first names of people, was not included in the present analyses because of the difficulty in determining the subcategories that participants may have used. In order to maintain an equivalent number of trials under each condition, another semantic trial, subjects of study, was excluded from these analyses. Thus, four semantic fluency trials were analyzed in this experiment.

For each participant, half of the phonemic trials and half of the semantic trials were performed under conditions of DA, and the remaining trials were performed under conditions of full attention. On DA trials, participants concurrently engaged in a finger-tapping

task requiring them to tap the fingers of the right hand in a specific sequence (i.e., index, ring, middle, small) as quickly and as accurately as possible. The order in which the tests were administered and the assignment of full versus divided attention were counterbalanced across participants.

Total number of words generated, cluster size, and switches were scored for each fluency task, according to the same rules described in Experiment 1. Subcategories for scoring clusters on the semantic trials were identified for weather (e.g., forms of rain, cold weather, storms, temperature, humidity), natural landscape and geographical formations (e.g., bodies of water, hills, valleys, flora/fauna), buildings and dwellings (e.g., residential, business, government, famous buildings, religious), and trees (i.e., broadleaf, evergreen, exotic, fruit/nut).

Results

As previously reported (Moscovitch, 1994), and as shown in Table 3, performing fluency under DA conditions, in comparison to full attention, resulted in a decrease in the total number of words generated on phonemic fluency, $t(21) = 7.11$, $p < .001$, and did not affect the number of words generated on semantic fluency, $t(21) = 0.53$, $p = .60$. Furthermore, DA resulted in decreased switching on phonemic fluency, $t(21) = 3.90$, $p = .001$, but did not affect switching on semantic fluency, $t(21) = 1.20$, $p = .24$. DA did not affect cluster size on either phonemic fluency, $t(21) = 0.94$, $p = .36$, or semantic fluency, $t(21) = -0.56$, $p = .58$.

Discussion

Switching, and not clustering, was decreased by DA in comparison to full attention. Because the secondary task of sequential finger tapping is thought to be dependent on frontal-lobe functioning, this finding provides further support for the idea that switching is a frontal-lobe-mediated component of fluency. Furthermore, the specific effect of divided attention on switching provides an explanation for previous reports of greater decreases in performance on phonemic fluency, relative to semantic fluency, when the participant is concurrently engaged in a sequential finger-tapping task (Martin et al., 1994; Moscovitch, 1994). The results from Experiment 1 indicate that overall performance

Table 3
Fluency Performance by Young Participants Under Conditions of Full and Divided Attention ($n = 22$)

Variable	Phonemic trials		Semantic trials	
	Full attention	Divided attention	Full attention	Divided attention
Words generated	42.18 (10.88)	32.82*** (10.73)	20.91 (5.08)	19.91 (5.35)
Switches	26.41 (8.42)	20.05*** (6.58)	12.32 (4.59)	10.43 (3.16)
Cluster size	0.48 (0.24)	0.42 (0.25)	0.66 (0.38)	0.76 (0.43)

Note. Standard deviations are shown in parentheses. Statistical analyses were conducted within each fluency task, across manipulations of attention.

*** $p < .001$.

on phonemic fluency is more highly correlated with switching than with clustering, whereas semantic fluency is correlated equally highly with switching and clustering. Thus, as expected, the manipulation of attention, which affected the switching component, had a greater effect on the total number of words generated on phonemic fluency than on semantic fluency.¹

General Discussion

The present findings indicate that switching and clustering are dissociable components of fluency performance. Switching was more important than clustering for optimal performance on phonemic fluency, whereas switching and clustering were equally important on semantic fluency. Furthermore, age was differentially associated with the two components. That is, age differences in switching on semantic fluency favored the young, whereas there were no age differences in clustering on semantic fluency, and age differences in clustering on phonemic fluency favored the old. Finally, conditions of divided attention specifically affected the switching component.

Two of our findings provide evidence to suggest that switching is a frontal-lobe related component of fluency. First, switching was the more important component on phonemic fluency, the fluency task thought to be relatively more sensitive to frontal-lobe lesions. In contrast, switching was no more important than clustering on semantic fluency, and this fluency task is thought to be relatively less sensitive to frontal lobe lesions. Second, switching, and not clustering, was decreased under conditions of divided attention, in which the secondary task, sequential finger tapping, is considered to interfere with frontal-lobe functions. Admittedly, these findings provide only indirect evidence of the specific brain regions involved. They are consistent, however, with ongoing research in our laboratory suggesting that patients with focal frontal-lobe lesions, as well as patients with dementia in which frontal lobe changes are prominent, are specifically impaired in switching (Troyer, Moscovitch, & Winocur, 1996).

Recent research has implicated switching as an important cognitive component on tests of attention (Meiran, 1996). Our findings suggest that switching is also an important process in fluency performance. The precise nature of switching on fluency tasks, however, is not clear. Switching may be related primarily to the participant's ability to disengage from a previous strategy or subcategory and would thus be impaired by perseverative behavior. Alternatively, switching may be related to the ability to initiate a search for a new strategy or subcategory. The present data do not allow us to discriminate these two, but it is possible that either or both of these components are involved.

It is apparent that the nature of switching and clustering is somewhat dependent on the specific fluency task. That is, rather than finding global effects of age or DA on either switching or clustering, there were age differences in switching on semantic fluency only, age differences in clustering on phonemic fluency only, and DA effects on switching in phonemic fluency only. As previously suggested, cluster size

on phonemic fluency may be related to the extent of the participant's vocabulary. The pattern of DA effects may imply that the subcategories involved in phonemic fluency are less salient than the subcategories in semantic fluency, thereby making switching on phonemic fluency a more demanding task. This would be consistent with the findings of Baddeley et al. (1984) that DA conditions have the greatest effect on tasks that make significant demands on cognitive resources.

In summary, the present study demonstrated that clustering and switching are dissociable components of fluency performance, at least in high-functioning older and younger healthy adults. Both components are highly related to the total number of words generated, indicating that they reflect important underlying cognitive processes. Thus, an examination of clustering and switching scores can provide information about why a particular participant performed well or poorly on these tasks. Furthermore, these scores are sensitive to the effects of age and to conditions of DA. Clustering and switching are quickly and easily calculated and have high interrater reliabilities. Our analyses expand upon previous models, as clustering and switching are applicable to both phonemic and semantic fluency and can be examined without changing the standard administration or recording procedures. To elucidate further the nature of switching and clustering on fluency tests, as well as their usefulness in clinical and experimental settings, we are currently collecting similar data on focal brain-lesion patients and patients with various types of dementia.

¹ We reanalyzed the data of Martin et al. (1994) using our clustering and switching procedures. We examined the percentage decrease in fluency performance from baseline as a result of the motor-sequencing (frontal lobe) task and the object-decision (temporal lobe) task. On phonemic fluency, the finger-tapping task decreased switching ($M = -.23$) slightly (but not significantly) more than clustering ($M = -.09$), $F(1, 23) = 1.80$, $p = .193$. On semantic fluency, the object-decision task decreased clustering ($M = -.27$) more than switching ($M = -.05$), $F(1, 23) = 9.68$, $p = .005$. The interaction was significant, $F(1, 23) = 11.02$, $p = .003$. This analysis extends our findings by demonstrating a dissociation, with switching more affected by the motor-sequencing task and clustering more affected by the object-decision task. We thank Martin and colleagues for providing these data to us.

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Appendix

Scoring Rules for Clustering and Switching

For each protocol, six scores were calculated, including the total number of correct words generated, mean cluster size, and number of switches for phonemic and semantic fluency, respectively. These scores are defined as follows:

Total number of correct words generated. This was calculated as the sum of all words produced, excluding errors and repetitions.

Mean cluster size. Cluster size was counted starting with the second word in a cluster. That is, a single word was given a cluster size of 0, two words had a cluster size of 1, three words had a cluster size of 2, and so forth. Errors and repetitions were included. The mean cluster size was computed for the three phonemic trials and for the one semantic trial.

Number of switches. This was calculated as the total number of transitions between clusters, including single words, for the three phonemic trials combined and for the one semantic trial. Errors and repetitions were included.

Phonemic Fluency

Clusters on phonemic fluency trials consisted of successively generated words that shared any of the following phonemic characteristics:

First letters: words beginning with same first two letters, such as *arm* and *art*

Rhymes: words that rhyme, such as *sand* and *stand*

First and last sounds: words differing only by a vowel sound, regardless of the actual spelling, such as *sat*, *seat*, *soot*, *sight*, and *sought*

Homonyms: Words with two or more different spellings, such as *some* and *sum*, as indicated by the participant

Semantic Fluency (Animals)

Clusters on semantic fluency trials consisted of successively generated words belonging to the same subcategories, as specified here. Subcategories are organized by living environment, human use, and zoological categories. Commonly generated examples are listed for each category, although listings are not exhaustive.

Living Environment

Africa: aardvark, antelope, buffalo, camel, chameleon, cheetah, chimpanzee, cobra, eland, elephant, gazelle, giraffe, gnu, gorilla, hippopotamus, hyena, impala, jackal, lemur, leopard, lion, manatee, mongoose, monkey, ostrich, panther, rhinoceros, tiger, wildebeest, warthog, zebra

Australia: emu, kangaroo, kiwi, opossum, platypus, Tasmanian devil, wallaby, wombat

Arctic/Far North: auk, caribou, musk ox, penguin, polar bear, reindeer, seal

Farm: chicken, cow, donkey, ferret, goat, horse, mule, pig, sheep, turkey

North America: badger, bear, beaver, bobcat, caribou, chipmunk, cougar, deer, elk, fox, moose, mountain lion, puma, rabbit, raccoon, skunk, squirrel, wolf

Water: alligator, auk, beaver, crocodile, dolphin, fish, frog, lobster, manatee, muskrat, newt, octopus, otter, oyster, penguin, platypus, salamander, sea lion, seal, shark, toad, turtle, whale

Human Use

Beasts of burden: camel, donkey, horse, llama, ox

Fur: beaver, chinchilla, fox, mink, rabbit

Pets: budgie, canary, cat, dog, gerbil, golden retriever, guinea pig, hamster, parrot, rabbit

Zoological Categories

Bird: budgie, condor, eagle, finch, kiwi, macaw, parrot, parakeet, pelican, penguin, robin, toucan, woodpecker

Bovine: bison, buffalo, cow, musk ox, yak

Canine: coyote, dog, fox, hyena, jackal, wolf

Deer: antelope, caribou, eland, elk, gazelle, gnu, impala, moose, reindeer, wildebeest

Feline: bobcat, cat, cheetah, cougar, jaguar, leopard, lion, lynx, mountain lion, ocelot, panther, puma, tiger

Fish: bass, guppy, salmon, trout

Insect: ant, beetle, cockroach, flea, fly, praying mantis

Insectivores: aardvark, anteater, hedgehog, mole, shrew

Primate: ape, baboon, chimpanzee, gibbon, gorilla, human, lemur, marmoset, monkey, orangutan, shrew

Rabbit: coney, hare, pika, rabbit

Reptile/Amphibian: alligator, chameleon, crocodile, frog, gecko, iguana, lizard, newt, salamander, snake, toad, tortoise, turtle

Rodent: beaver, chinchilla, chipmunk, gerbil, gopher, groundhog, guinea pig, hamster, hedgehog, marmot, mole, mouse, muskrat, porcupine, rat, squirrel, woodchuck

Weasel: badger, ferret, marten, mink, mongoose, otter, polecat, skunk

General Scoring Rules

In the case in which two categories overlapped, with some items belonging to both categories, some items belonging exclusively to the first category, and some items belonging exclusively to the

second category, the overlapping items were assigned to both categories. For example, for *dog*, *cat*, *tiger*, *lion*, the first two items were scored as pets, and the last three items were scored as feline. *Cat* was included in both the pet category and the feline category.

In the case where smaller clusters were embedded within larger ones, or two categories overlapped, but all items could correctly be assigned to a single category, only the larger, common category was used. For example, for *sly*, *slit*, *slim*, *slam* all begin with *sl*, but an additional cluster was not scored for the last two words, which differ only by a vowel sound.

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