PRODUCTION TIME DIFFERENCES AS EVIDENCE FOR AUTOMATIC VS. CONTROLLED WORD SELECTION PROCESSES

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INTRODUCTION

Human cognition is often conceptualized as consisting of automatic and controlled processes that are associated with posterior and prefrontal brain regions, respectively. Patterns of phonemic and semantic association among words reported during verbal fluency tasks have been cited as evidence of this distinction. We sought to investigate automatic and controlled processing by extracting information from the precise timing of word list production. We hypothesized that retrieving clusters of related words would use faster, more automatic processes, and searching between clusters to find a new category of related words would use slower, more controlled processes. This would be reflected in shorter intervals between related words and longer intervals between unrelated words.

We also sought to determine whether or not the grouping of words by phonemic and semantic association using a rational scoring system, such as that developed by Troyer et al. (1997), would be supported by objective measures of the time intervals between words (Gruenewald & Lockhead, 1980).

PARTICIPANTS AND METHODS

Forty-seven healthy adults (Table 1) completed two phonemic and two semantic verbal fluency tasks. The participants were asked to name as many words as possible in 60 seconds that either began with a particular letter (S or P – Phonemic fluency) or belonged to a specific category (Animals or Supermarket Items – Semantic fluency). The participants wore a head-mounted microphone that recorded their productions directly into a laptop computer using Audacity audio editing software.

Age	36.5 $\pm$ 14.1 years (range 18-60)
Sex	23 men (49%), 24 women (51%)
Ethnicity	72.3% White, 21.3% Black, 6.4% Other
Education	Minimum of a high school diploma

Table 1. Participant demographics (N = 47) .

The words lists generated by each participant were transcribed and then scored by two raters according to the system developed by Troyer and colleagues (1997). This involved grouping successive words into clusters based on their phonemic or semantic relatedness. Five scores were generated for each protocol, as follows:

- Total Correct Words: Sum of all words produced, minus repetitions and rule breaks.
- Number of Clusters: Number of single word clusters and multi-word clusters, including repetitions and rule breaks.
- Number of Switches: Number of transitions between clusters.
- Total Cluster Size: Number of words, starting with the second word, in multi-word clusters.
- Mean Cluster Size: The size of multi-word clusters, calculated by dividing Total Cluster Size by Number of Clusters.

Twenty percent of the verbal fluency protocols were scored by both raters and compared for inter-rater reliability (Table 2).

	Phonemic		Semantic	
	α	ICC	α	ICC
Total Words	1.0	.999	1.0	.999
Clusters	.999	.999	.975	.943
Switches	.999	.999	.975	.943
Total Cluster Size	.998	.996	.993	.987
Mean Cluster Size	.994	.988	.956	.905

Table 2. Reliability analysis on 2 raters using the Troyer et al. (1997) scoring system. Values shown are Cronbach's alpha (α) and single measures intraclass correlations (ICC).

The time intervals between words, or switches, were measured using spectrographs of the audio recordings (Computerized Speech Lab Model 4150 software, KayPENTAX). The switches were then classified as being between-cluster or embedded in multi-word clusters (within-cluster). Figure 1 illustrates clusters, within-cluster switches, and between-cluster switches.

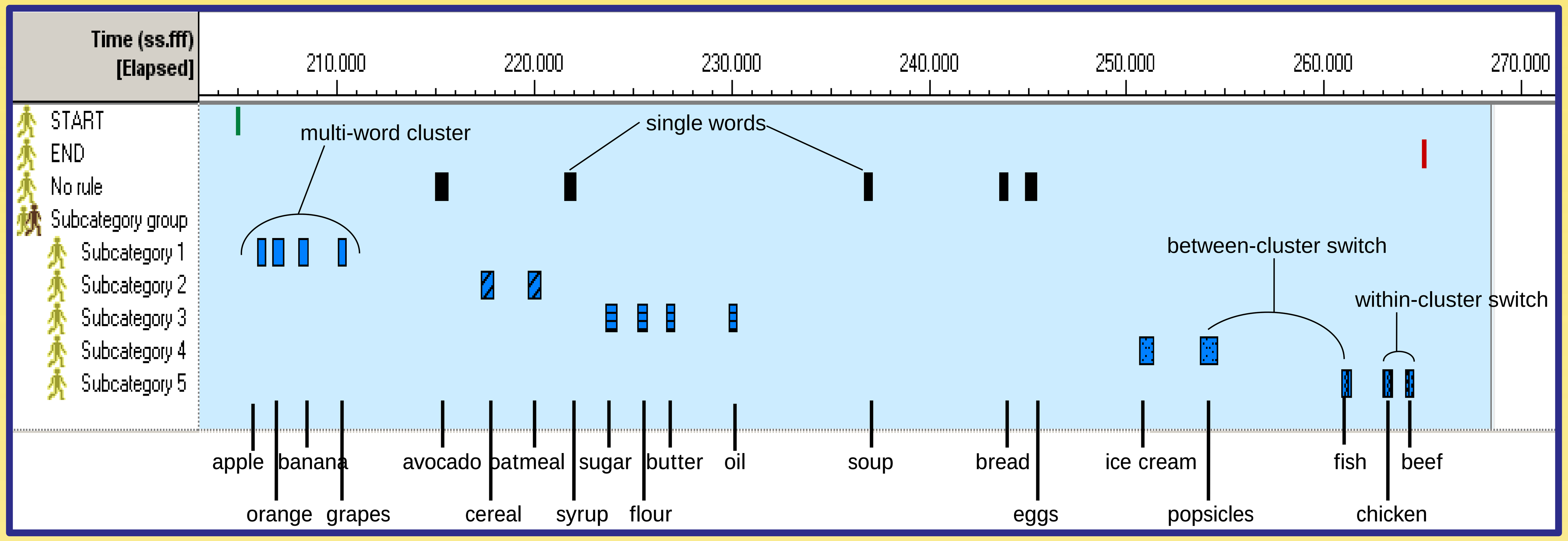

Figure 1. Illustration of one Supermarket fluency protocol. The start and end of the 60-sec task are indicated by the green and red lines, respectively. Each rectangular block represents one word. The width of each block shows how long it took the participant to say that word. Black blocks are single words (i.e., not clustered with any adjacent words). Blue blocks signify multi-word clusters, where adjacent blocks with the same pattern belong to the same cluster.

RESULTS

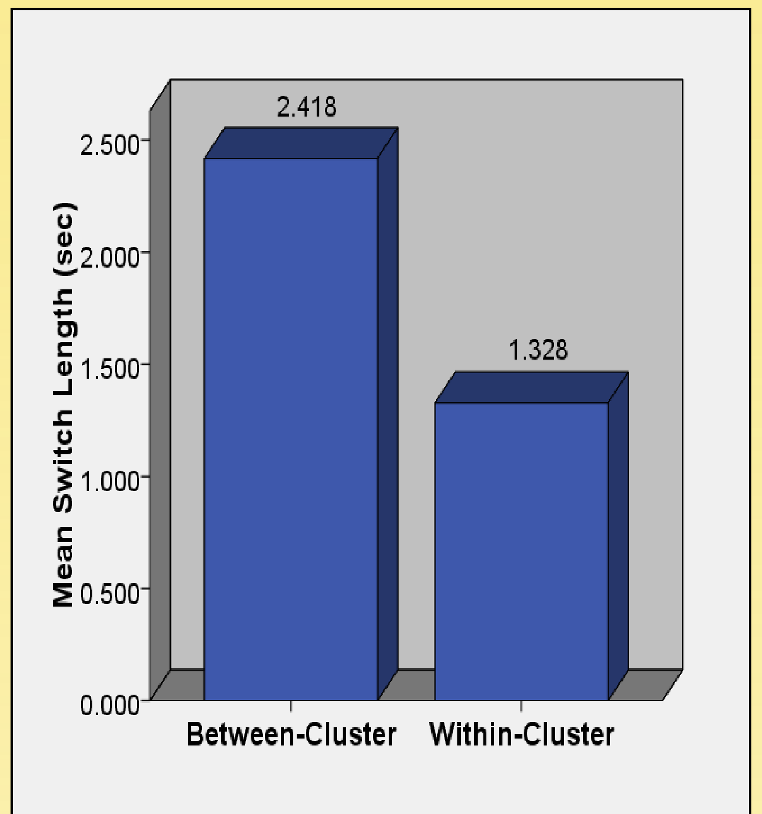

Figure 2

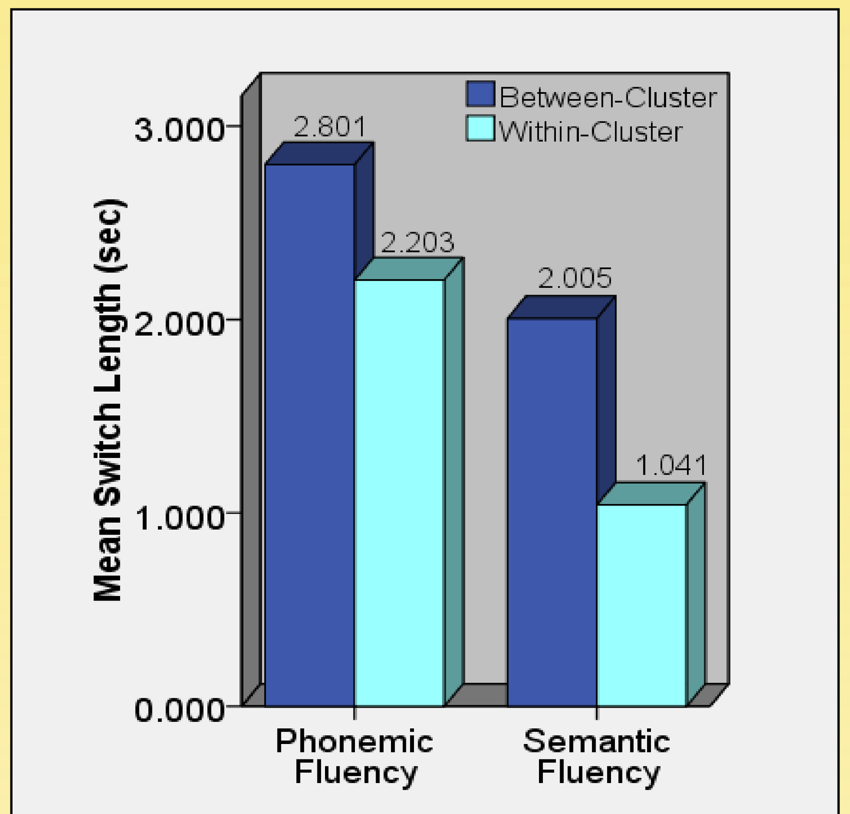

Figure 3

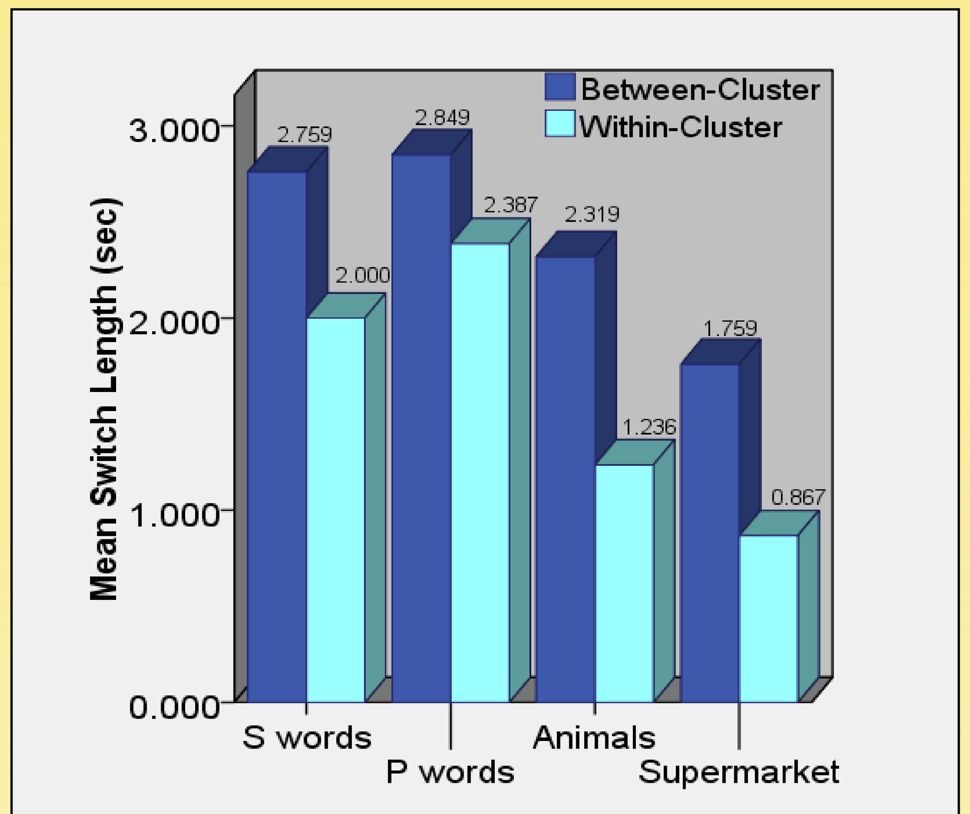

Figure 4

Figures 2-4. These panels compare the mean lengths of between-cluster switches to the mean lengths of within-cluster switches at three levels of analysis: all four tasks combined for an overall comparison (Fig. 2), Phonemic and Semantic Fluency (Fig. 3), and all four tasks individually (Fig. 4).

Level of Analysis	Difference (sec)
OVERALL (Fig. 2)	
Four tasks combined	1.090
PHONEMIC & SEMANTIC TASKS (Fig. 3)	
Phonemic (letters S + P)	0.598
Semantic (Animals + Supermarket Items)	0.964
INDIVIDUAL TASKS (Fig. 4)	
S Words	0.759
P Words	0.462
Animals	1.083
Supermarket Items	0.891

Table 3. The difference between the mean between-cluster switch length and the mean within-cluster switch length in seconds at different levels of analysis: Overall (4 tasks combined), Phonemic and Semantic, and the individual tasks. All differences are significant at the p < .001 level (equal variances not assumed) except P Words, which is significant at the p < .05 level (equal variances assumed).

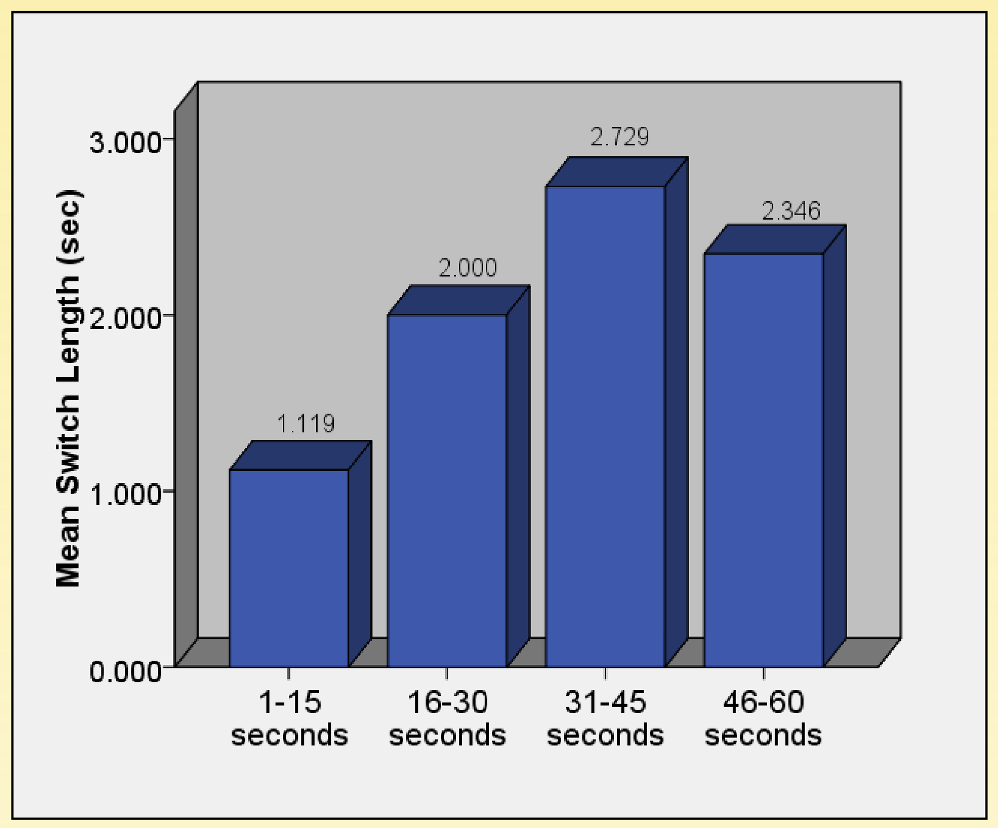

Figure 5. Mean switch lengths across quarters of the 60-sec interval, showing evolution of word retrieval times across the task. The means for all quarters are significantly different from each other at the p < .01 level (equal variances not assumed).

Switches between clusters were consistently longer than switches within clusters at all levels of analysis (Table 3), whether it was at the overall level with all four tasks combined (Fig. 2), the Phonemic/Semantic fluency level (Fig. 3), or the individual task level (Fig. 4). When looking at switches regardless of type (i.e., between- and within-cluster switches combined), the time between words increased from the first quarter of the task minute through the third quarter, and then decreased during the fourth quarter (Fig. 5).

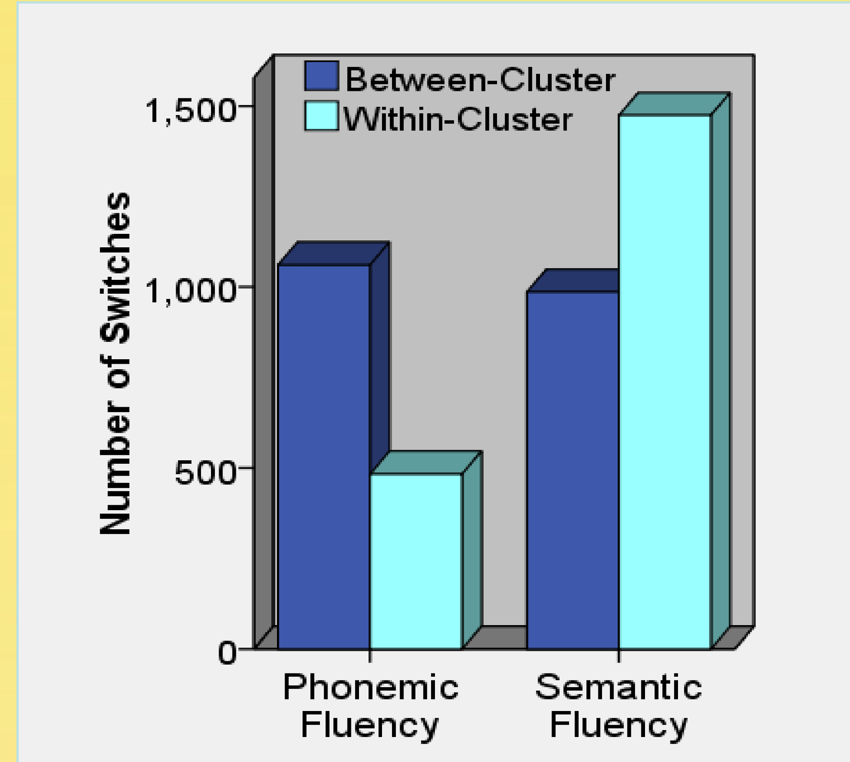

Figure 6. Numbers of between- and within-cluster switches produced during Phonemic and Semantic Fluency tasks. Participants reported more within-cluster switched on Semantic than Phonemic Fluency tasks (p < 0.0001). However, the overall frequency of between-cluster switches did not differ across tasks.

Participants produced more between-cluster switches than within-cluster switches during Phonemic fluency tasks, but showed the opposite pattern during Semantic fluency tasks (Fig. 6). Interestingly, participants produced the same number of between-cluster switches across Phonemic and Semantic fluency tasks, but produced significantly more within-cluster switches during Semantic fluency tasks than during Phonemic fluency tasks.

CONCLUSIONS

Overall, between-cluster switches took longer than within-cluster switches. This supports the hypothesis that searching within subcategories uses fast automatic word retrieval processes. Then, as a within-category search exhausts the available words, the person uses slower, more controlled processes to find a new subcategory from which to retrieve examplars.

As the task progresses, participants' productivity generally slows, as shown by increasing switch times. Our analyses also revealed differences in retrieval strategy between Phonemic and Semantic fluency tasks. This likely explains the fact that people typically report more words in response to category than letter cues on verbal fluency tests. While participants switch between clusters with equal frequency on Phonemic and Semantic fluency tasks, they report far more within-cluster words on Semantic fluency. Because retrieving related words is faster than switching among categories, people are more productive on Semantic fluency.

Our findings also demonstrate that precise measurement of timing can provide cross-validation of inferences about word retrieval search strategies based on the content analytic method developed by Troyer et al. (1997). Conversely, these findings suggest that it may be possible to use precise measurement of timing to elucidate unrecognized associations among verbal fluency productions that reveal the underlying architecture of semantic knowledge. For example, we are exploring the usefulness of examining the semantic relatedness of words produced in response to phonemic fluency tasks. In addition, timing measurements could be used to explore subtypes of switches, "hard" and "soft" switches, which others have distinguished (Abwender et al., 2001; Raboutet et al., 2009).

Finally, we currently are examining whether neuromodulatory brain stimulation can enhance either controlled or automatic processes that control word retrieval during verbal fluency.

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