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Variation in verbal fluency: A latent variable analysis of clustering, switching, and overall performance

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Verbal fluency tasks have long been used to assess and estimate group and individual differences in executive functioning in both cognitive and neuropsychological research domains. Despite their ubiquity, however, the specific component processes important for success in these tasks have remained elusive. The current work sought to reveal these various components and their respective roles in determining performance in fluency tasks using latent variable analysis. Two types of verbal fluency (semantic and letter) were compared along with several cognitive constructs of interest (working memory capacity, inhibition, vocabulary size, and processing speed) in order to determine which constructs are necessary for performance in these tasks. The results are discussed within the context of a two-stage cyclical search process in which participants first search for higher order categories and then search for specific items within these categories.

Keywords: Verbal fluency; Executive functions; Individual differences.

Verbal fluency tasks in which participants are required to generate words based on a given set of rules (e.g., generate as many animals as possible; generate as many words beginning with the letter S as possible) within a specified amount of time (usually 60 s) have long been used to examine group and individual differences in cognitive processes. In particular, these tasks have been used to examine group and individual differences in the integrity of lexical and semantic memory stores as well as strategic control differences in word retrieval (e.g., Baldo & Shimamura, 1998; Henry & Crawford, 2004a; Mayr & Kliegl, 2000; Rosen & Engle, 1997; Troyer, Moscovitch, & Winocur, 1997). For instance, deficits in verbal fluency have been found in older adults (e.g., Mayr & Kliegl, 2000; Troyer et al., 1997), patients with frontal lobe lesions (e.g., Henry & Crawford, 2004a; Perret, 1974), patients with temporal lobe lesions (e.g., Henry & Crawford, 2004a; Martin, Loring, Meador, & Lee, 1990; Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998a), patients with Alzheimer's disease (Troster et al., 1998), Parkinson's patients (e.g., Henry & Crawford 2004c; Troster et al., 1998), Huntington's patients (e.g., Henry, Crawford, & Phillips, 2005), individuals with schizophrenia (e.g., Henry & Crawford, 2005b), patients with traumatic brain injury (e.g., Henry & Crawford, 2004b), individuals with multiple sclerosis (e.g., Henry & Beatty, 2006; Troster et al., 1998), and individuals with depression (e.g., Fossati,

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Guillaume, Ergis, & Allialaire, 2003; Henry & Crawford, 2005a), as well as individuals low in certain cognitive abilities such as intelligence and working memory capacity (e.g., Rosen & Engle, 1997). Furthermore, individual differences analyses have suggested that fluency is related to individual differences in personality disorders such as schizotypal personality disorder, avoidant personality disorder, and obsessive compulsive personality disorder (e.g., Unsworth et al., 2009).

Given the importance of these tasks in multiple research domains, the goal of the present study was to better examine the processes that are needed for successful fluency performance in a sample of healthy, younger adults. Specifically, we wished to examine the component processes in various fluency tasks (i.e., semantic and letter fluency) as well as to examine the cognitive correlates of verbal fluency in order to better understand the processes that are needed for successful performance and why individuals and groups differ in their performance.

Component retrieval processes involved in verbal fluency

Largely beginning with the work of Bousfield and Sedgewick (1944), researchers have suggested that in verbal fluency tasks (particularly semantic fluency), retrieval from long-term memory is dictated by a two-stage cyclical search process (Gruenewald & Lockhead, 1980; Herrmann & Pearle, 1981; Wixted & Rohrer, 1994). In the first stage, it is assumed that participants search for overall categories, and then in the second stage participants search for specific items within the categories. For example, if participants are told to generate as many animals as possible in 60 s, this type of model assumes that first participants search for subcategories of animals (e.g., pets) and then search for items from within the subcategory (dog, cat, fish, etc.; Gruenewald & Lockhead, 1980; Herrmann & Pearle, 1981; Wixted & Rohrer, 1994). Once items within the chosen subcategory have been exhausted, participants revert back to searching for and recalling items from a new subcategory (e.g., farm animals). Thus, this two-stage search model predicts that participants should not only generate clusters or bursts of items that are highly similar but that there should be distinct breaks (i.e., pauses) between bursts. In fact, this is exactly what Bousfield and Sedgewick (1944), and subsequently many other researchers, have consistently found. During fluency tasks, participants tend to recall semantically related items in quick succession with distinct pauses between clusters of semantically related items. Thus, there seems to be good support for two-stage search models in terms of accounting for performance in verbal fluency tasks.

Recent work has added other components to the two-stage search framework in order to account for various experimental and individual differences effects. For instance, Rosen and Engle (1997) suggested that four components were important for retrieval in verbal fluency tasks (see also Azuma, 2004). According to Rosen and Engle, these components include (a) activation spreading automatically from the cue to related items, (b) monitoring of generated items to prevent errors (especially repetitions), (c) suppression of previously recalled items, and (d) self-generation of category cues to access new items. Rosen and Engle suggested that these retrieval components reflect the dynamic interplay between strategic and automatic search components as represented by frontal and medial temporal lobe structures, respectively. Importantly, this component framework suggests that not only are two stages (sampling of cues and then sampling of items) likely to be important for accounting for performance in verbal fluency tasks, but other components including monitoring and suppression (see also Perret, 1974) are also important. Like many cognitive tasks, this line of reasoning suggests that successful verbal fluency performance depends on a number of processes, each of which may rely on different neural substrates and individuals may differ on. In their study, Rosen and Engle suggested that individuals low in working memory capacity (WMC) were unable to perform as well as individuals high in WMC because they had deficits in accessing new items, monitoring their output, and suppressing already-recalled responses. Rosen and Engle suggested that successful verbal fluency performance was dependent on working memory processes that are needed to generate new category cues as well as to suppress already recalled items.

In order to better examine the components important for verbal fluency performance and possible variation within these components, Troyer et al. (1997) proposed a two-component model of verbal fluency and developed means to estimate these components. Similar to other two-stage models of verbal fluency, Troyer et al. (1997) suggested that verbal fluency performance relies on both clustering and switching. According to Troyer et al., clustering refers to the generation of words within particular subcategories as defined by the current task (i.e., clusters of semantically related words as in the case of semantic fluency, or clusters of phonemically related words as in the case of letter fluency). Switching, however, refers to the generation of new subcategories from which items are subsequently sampled. Troyer et al. suggested that clustering relies on medial temporal lobe structures thought to be important for word storage, whereas switching relies on frontal lobe structures thought to be important for strategic search (e.g., Moscovitch, 1992). Similar to other models, this view suggests that both relatively automatic components and more strategic components act in concert to determine performance on verbal fluency tasks. Importantly, Troyer et al. provided methodology to estimate both clustering and switching processes and examined the extent to which these different components affected performance and were differentially related to the effects of ageing and various neuropsychological disorders.

Specifically, Troyer et al. (1997) found that on semantic fluency tasks older adults produced fewer total number of correct items, and this seemed to be due to a deficit in switching given that older adults switched less often than younger adults, but there were no differences in clustering scores. Likewise, Kave, Kigel, and Kochva (2008) found that total number of items generated tended to increase with age from 8 years up to 17 years of age, and this was mainly due to an increase in switching scores with no age-related changes in clustering. Thus, age differences in overall fluency performance seem to be primarily due to differences in switching rather than clustering.

In terms of neuropsychological differences, patients with frontal lobe deficits have been shown to generate fewer total number of correct items than controls and have smaller switching scores, but are no different from controls in terms of clustering scores (e.g., Troyer et al., 1998a). Furthermore, other work has suggested that Alzheimer's patients have deficits in both clustering and switching (Epker, Lacritz, & Cullum, 1999; Troyer, Moscovitch, Winocur, Leach, & Freedman, 1998b), and this may differ as both a function of type of fluency task (semantic vs. letter) and stage of the disease. Similarly, Rosen et al. (2005) found that individuals who have a genetic risk for Alzheimer's based on the apolipoprotein E genotype tended to have deficits primarily in switching, but not clustering. Likewise, Parkinson's patients can have deficits in both clustering and switching (e.g., Troyer et al., 1998b), and this may vary as a function of the type of fluency task used (semantic vs. letter). Patients with other neurodegenerative disorders (e.g., Huntington's disease, multiple sclerosis) have also demonstrated deficits in switching compared to age-matched controls (e.g., Troster et al., 1998). Thus, it seems clear that verbal fluency performance is multiply determined and that two main components that seem to drive performance are the ability to generate items within a cluster (perhaps automatically based on stored knowledge in the temporal lobes) and the ability to generate new clusters (via strategic search processes based on frontally mediated control processes). Although related (Troyer et al., 1997), these two components are dissociable to the extent that various manipulations affect them differently (Troyer et al., 1997) and seem to be, at least partially, reliant on different neural substrates.

Although the work of Troyer and colleagues has provided a number of important pieces of evidence consistent with their overall model, there is at least one point of contention in terms of the extent to which the different components reflect automatic versus more strategic/controlled processes. According to Troyer and colleagues (Troyer et al., 1997; see also Moelter et al., 2001), clustering represents a fairly automatic process, whereas switching between clusters represents a more effortful strategic search process. However, Mayr (2002; see also Mayr & Kliegl, 2000) has suggested that each act of retrieval involves the strategic component (i.e., is frontally mediated). Thus, all items, regardless of whether they are recalled within a cluster or between clusters, are retrieved, in part, based on strategic search processes. This suggests that participants who have strategic search deficits (e.g., frontal patients, older adults, low WMC individuals) should have trouble accessing items both within and between clusters. According to Mayr (2002), Troyer et al.'s (1998a) clustering and switching scores do not provide unambiguous estimates of controlled and automatic processing; rather they provide reasonable estimates of a participant's propensity to cluster items together and the propensity to generate new items (both within and between clusters). Clearly, more work is needed to determine the extent to which clustering reflects a combination of automatic and strategic components or only automatic processes.

In addition to demonstrating differences between switching and clustering components in verbal fluency tasks, a number of researchers have also suggested that different types of fluency task (e.g., letter/phonemic and semantic/categorical fluency tasks) may draw on different processes (e.g., Azuma, 2004; Martin, Wiggs, Lalonde, & Mack, 1994; Rende, Ramsberger, & Miyake, 2002; Troyer et al., 1997). Specifically, prior work has suggested that letter fluency tasks rely more on frontally mediated strategic search processes, whereas semantic fluency tasks rely on both temporally mediated automatic associative processes and frontally mediated search processes. Intuitively these differences may result from the fact that our verbal memory system is not organized based on the first letters of words, and thus the ability to generate associative clusters will be difficult and will rely more on strategic search processes. For semantic fluency tasks, however, words can be generated to some extent based on associative links between words (i.e., clusters) as well as from more strategic search processes. This line of reasoning suggests that letter and semantic fluency tasks should be differentially sensitive to deficits in frontally mediated search processes and more automatic temporally mediated associative processes. Although initial evidence seemed to suggest that frontal deficits were more pronounced on letter fluency tasks than on semantic fluency tasks, more recent work suggests equal deficits on both letter and semantic fluency tasks (e.g., Baldo & Shimamura, 1998; Henry & Crawford, 2004a). Thus, Baldo and Shimamura concluded that frontally mediated strategic search processes are required on both letter and semantic fluency to a similar extent. In contrast, patients with temporal damage (thought to disrupt the semantic store and the ability to cluster) typically show larger deficits on semantic fluency than on letter fluency (e.g., Henry & Crawford, 2004a; Troyer et al., 1998a). Thus, it is unclear whether letter and semantic fluency tasks largely measure the same set of processes, or whether letter fluency draws on more strategic processes than does semantic fluency.

Cognitive correlates and individual differences in verbal fluency

Given the widespread use of fluency tasks in a number of domains, a number of studies have examined cognitive correlates of fluency in order to better understand what processes are needed for successful performance as well as to understand why individuals differ in performance. In particular, researchers have been interested in examining the extent to which certain cognitive constructs are related to fluency performance and may account for the relation between fluency performance and other variables (e.g., age). Most of the research has been concerned with examining relations between various cognitive constructs and overall fluency performance, rather than specifically examining components such as clustering and switching. For instance, several studies have found relations between measures of WMC and total scores on various verbal fluency tasks (e.g., Fisk & Sharp, 2004; Fournier-Vicente, Larigauderie, & Gaonac'h, 2008; Hedden, Lautenschlager, & Park, 2005; Rosen & Engle, 1997). Similarly total number of words generated on semantic fluency tasks is related to episodic memory abilities in some studies (e.g., Cohen, 1984; Fisk & Sharp, 2004; Hedden et al., 2005; Ruff, Light, Parker, & Levin, 1997). Total scores on verbal fluency tasks are related to vocabulary in a number of studies (e.g., Ardila, Galeano, & Rosselli, 1998; Ardila, Pineda, & Rosselli, 2000; Hedden et al., 2005; Hughes & Bryan, 2002; Ruff et al., 1997). Likewise, measures of processing speed are related to the total number of words generated on fluency tasks (e.g., Ardila et al., 1998; Fisk & Sharp, 2004; Hedden et al., 2005). Furthermore, although the evidence is somewhat mixed, there is evidence for a relation between measures of response inhibition and total number of words generated on verbal fluency tasks (e.g., Ardila et al., 2000; Fisk & Sharp, 2004; but see Fournier-Vicente et al., 2008; Hughes & Bryan, 2002). Finally, there also seems to be a fairly stable link between intelligence and total verbal fluency scores, and this relation seems to be especially true for verbal intelligence (e.g., Ardila et al., 1998; Ardila et al., 2000). Thus, total scores on verbal fluency tasks seem to be related to a number of important cognitive constructs at least at the zero-order correlation level. By far, less work has been done examining the extent to which various fluency tasks can be considered as measures of the same latent construct and the extent to which this latent construct is related to other important latent variables.

In two studies, Hedden and colleagues (Hedden et al., 2005; Hedden & Yoon, 2006) provided evidence that fluency tasks load on a common factor, which is related to other important cognitive constructs. Although not the point of their study, Hedden et al. found that three letter fluency tasks all loaded on the same factor, and this factor was moderately related to latent variables of processing speed, WMC, vocabulary, episodic free and cued recall, and episodic recognition. Hedden and Yoon found that two excluded letter fluency tasks and a semantic fluency task all loaded on the same latent factor, and this factor was moderately related to latent factors of updating/shifting, response inhibition, verbal and visual memory, and processing speed. Thus, total scores on various verbal fluency tasks seem to be related to one another and related to a number of other cognitive constructs at both the zero-order and the latent level.

Although a number of studies have examined the correlations between fluency tasks and other cognitive measures, most of these studies have only examined total number of items generated and have not examined other components such as clustering and switching. Given that these two components theoretically reflect somewhat different processes, they should be differentially related to other cognitive constructs. Specifically, if clustering scores reflect the relatively automatic spread of activation in the lexical–semantic store, then clustering should be related to things like overall vocabulary size. Likewise if switching reflects more strategic/controlled search processes then it should be related to other tasks thought to rely on controlled processing. Unfortunately, to date, very few studies have examined the construct validity of these components (e.g., Troyer & Moscovitch, 2006), although those studies that have examined clustering and switching components have found some initial evidence consistent with these hypotheses. For instance, Hughes and Bryan (2002) found that verbal abilities (i.e., vocabulary) was related to overall number of words generated as well as number of switches. Although not statistically significant for their sample size, there was also a weak correlation between verbal ability and clustering. Furthermore, and consistent with the arguments of Mayr (2002), Hughes and Bryan also found that processing speed was weakly related to switching. Neither clustering nor switching was related to any of the putative measures of executive functioning in that study, however. Clearly, more work is needed to better examine the relations between verbal fluency and other cognitive constructs thought to be important for performance, as well as the relation between specific components of verbal fluency (i.e., clustering and switching) and other cognitive constructs.

Present study

The primary goal of the current study was to examine the extent to which various fluency tasks measure the same or different processes and the extent to which various components of verbal fluency are differentially related to other cognitive constructs thought to be important determinants of performance. In particular, one question addressed in the current study is whether there are differences between semantic and letter fluency tasks in terms of total number of items generated, as well as differences in clustering and switching. If semantic fluency relies on temporally mediated automatic spread of activation in the semantic network then one may expect more clustering (and less switching) in semantic fluency tasks than in letter fluency tasks. If, however, both tasks rely similarly on automatic and strategic (i.e., frontally mediated) components then there should be no differences in clustering or switching. This question can also be addressed from an individual differences standpoint. In particular, if semantic and letter fluency tasks represent the same set of cognitive processes, then both should load on a single factor in a factor analysis. If, however, semantic and letter fluency represent somewhat distinct cognitive processes, then they should load on separate, perhaps correlated, factors.

Additional questions addressed in the current study are whether clustering and switching differentially account for total number of items generated. Specifically, as noted previously, the total number of items generated should be a function of the number of items within a cluster as well as the number of switches between clusters. Previous work has suggested that switching tends to correlate higher with total number of items generated than does clustering (e.g., Troyer et al., 1997). Yet it is not known whether these same results will hold when examining a large number of participants on multiple measures of semantic and letter fluency.

Finally, the current study addressed the extent to which total number of items generated, clustering, and switching were related to other theoretically important cognitive constructs. Specifically, a number of studies have suggested that WMC should be an important predicator of verbal fluency performance to the extent that WMC is needed to successfully generate new clusters of items during strategic search (e.g., Rosen & Engle, 1997). Similarly, previous work has suggested that inhibitory processes are needed in verbal fluency tasks in order to suppress previously generated responses (e.g., Azuma, 2004; Chiappe & Chiappe, 2007; Perret, 1974; Rosen & Engle, 1997). In particular, these theories suggest that one of the main reasons for differences found on verbal fluency tasks is due to differences in the ability to suppress habitual responses and prevent perseverations (i.e., repetitions). Indeed, Chiappe and Chiappe (2007) have recently suggested that in verbal fluency tasks "inhibitory processes serve a restraining function, by preventing strong responses from immediately seizing control of thought and action effectors so that other, less probable responses can be considered" (p. 180). According to these theories measures of inhibition should be an important predicator of not only overall total number of items generated, but also the number of repetitions (or perseveration errors) that are made. Furthermore, vocabulary measures not only should be related to overall performance, but should be especially related to clustering to the extent that clustering reflects the propensity to traverse through the lexical–semantic store via associative linkages. Finally, given that verbal fluency tasks usually have a strict time limit (i.e., 60 s) and hence are rate limited, speed of processing should be related to overall performance and, as suggested by Mayr (2002), may be especially related to switching.

In order to address these questions, a latent variable analysis was used. This was done because previous results may have been found due to the fact that only a single task was used and, thus, may not provide the best evidence for more general constructs. Furthermore, most individual differences studies that have been done typically examined only extreme groups of participants (i.e., older adults vs. younger adults), and thus it is not clear whether the relation holds across a full range of participants and a large number of tasks. In order to derive latent variables for the constructs of interest, multiple indicators of each construct were used. Specifically, each participant performed two semantic fluency tasks (i.e., animal and supermarket fluency), as well as two letter fluency tasks (i.e., F and S letter fluency). In addition, participants performed two WMC tasks (i.e., operation and reading span), two measures of vocabulary (i.e., synonym and antonym vocabulary), two measures of speed of processing (i.e., number and letter comparison), and two inhibitory measures (i.e., antisaccade and flankers).

Performance on these tasks was then used to build latent variables for the constructs of interest in order to address the questions of interest.

Method

Participants

Participants were 156 individuals recruited from the University of Georgia subject pool. Participants were between the ages of 18 and 35 years and received course credit for their participation. Participants were tested individually in a laboratory session lasting approximately two hours.

Procedure

All participants completed (in order) operation span, reading span, antisaccade, animal fluency, F letter fluency, arrow flanker, supermarket fluency, S letter fluency, letter comparison, number comparison, synonym vocabulary, and antonym vocabulary. As is typically done in individual differences studies of this type, all participants performed the tasks in the same fixed order in order to avoid the confounding of individuals with a particular task order that would complicate individual differences analyses due to an increase in error variance (e.g., Salthouse & Babcock, 1991).

Fluency

Semantic fluency. Participants performed two semantic fluency tasks (animal and supermarket fluency). For each, participants were given 1 minute to type as many exemplars from the specified category as possible. The dependent variables were: (a) the number of unique (i.e., not repeated) instances of a category, (b) the number of repetitions, (c) mean cluster size, and (d) number of switches based on the scoring procedures outlined in Troyer et al. (1997). Clusters were defined as successively generated words from the same subcategory (see Troyer et al., 1997, and Troyer & Moscovitch, 2006, for specific subcategories). Switches were defined as the number of transitions between clusters (including single words). Note that we decided to use the Troyer et al. scoring procedures given that much prior work has utilized these procedures, and thus we wanted to make contact with this other work. Thus, cluster size and switching were based on these exact procedures rather than on other procedures that might be used. For instance, future work might utilize more objective techniques based on association norms to determine cluster size and switching and to determine the extent to which these measures are similar to those used previously.

Letter fluency. Participants performed two letter fluency tasks (F and S letter fluency) Participants were given 1 min to type as many words that began with the specified letter as possible. The dependent variables were the same as those for the semantic fluency tasks. Specifically, clusters were defined as successively generated words that began with the same first two letters, differed only by a vowel sound, rhymed, or were homonyms (see Troyer et al., 1997, for specific scoring procedures). Switches were defined as the number of transitions between clusters (including single words).

WMC

Operation span (Ospan). Participants solved maths problems while trying to remember an unrelated set of letters. Participants received three trials of each set size, with the set sizes ranging from 3–7. This made for a total of 75 letters and 75 maths problems. Order of set sizes was random for each participant. The score was the number of correct items recalled in the correct position. See Unsworth, Heitz, Schrock, and Engle (2005) for full task details.

Reading span (Rspan). Participants read sentences while trying to remember an unrelated set of letters. Participants received three trials of each set size, with the set sizes ranging from 3–7. This made for a total of 75 letters and 75 sentences. Order of set sizes was random for each participant. The score was the number of correct items recalled in the correct position.

Inhibition

Antisaccade. In this task (Kane, Bleckley, Conway, & Engle, 2001) participants were instructed to stare at a fixation point, which was onscreen for a variable amount of time (200–2,200 ms). A flashing white " = " was then flashed to either the left or the right of fixation (11.33° of visual angle) for 100 ms. This was followed by the target stimulus (a B, P, or R) onscreen for 100 ms. This was followed by masking stimuli (an H for 50 ms and an 8, which remained onscreen until a response was given). The participants' task was to identify the target letter by pressing a key for B, P, or R (the keys 1, 2, or 3) as quickly and accurately as possible. In the prosaccade condition the flashing cue (=) and the target appeared in the same location. In the antisaccade condition the target appeared in the opposite location to the flashing cue. Participants received 10 practice trials to learn the response mapping, 15 trials of the prosaccade condition, and 60 trials of the antisaccade condition. The dependent variable was the number of errors made on the antisaccade trials.

Arrow flankers. Participants were presented with a fixation point for 400 ms. This was followed by an arrow directly above the fixation point for 1,700 ms. The participants' task was to indicate the direction the arrow was pointing (pressing the F for left-pointing arrows and pressing J for right-pointing arrows) as quickly and accurately as possible. On 50 neutral trials the arrow was flanked by two horizontal lines on each side. On 50 congruent trials the arrow was flanked by two arrows pointing in the same direction as the target arrow on each side. Finally, on 50 incongruent trials the target arrow was flanked by two arrows pointing in the opposite direction to the target arrow on each side. These trial types were intermixed. The dependent variable was the reaction time difference between incongruent and congruent trials.

Vocabulary

Synonym vocabulary. In this task participants were given 10 vocabulary words and were required to select the best synonym (out of five possible choices) that best matched the target vocabulary word (Hambrick, Salthouse, & Meinz, 1999). Participants were given 2 minutes to complete the 10 items. A participant's score was the total number of items solved correctly.

Antonym vocabulary. In this task participants were given 10 vocabulary words and were required to select the best antonym (out of five possible choices) that best matched the target vocabulary word (Hambrick et al., 1999). Participants were given 2 minutes to complete the 10 items. A participant's score was the total number of items solved correctly.

Processing speed

Letter comparison. In this task participants were given two pages with multiple pairs of letters. The pairs consisted of three, six, or nine letters, and the task for the participant was to write the letter *S* between the pair if the two members were the same and to write the letter *D* if the two members were different. Participants were given 60 s to complete both pages. A participant's score was the total number of correct responses.

Number comparison. In this task participants were given two pages with multiple pairs of numbers. The pairs consisted of three, six, or nine numbers, and the task for the participant was to write the letter *S* between the pair if the two members were the same and to write the letter *D* if the two members were different. Participants were given 60 s to complete both pages. A participant's score was the total number of correct responses.

Results

The results are divided into three primary sections. The first section examined differences between semantic and letter fluency tasks in terms of total number of items generated, number of repetitions, cluster size, and number of switches. The second section examined the extent to which semantic and letter fluency tasks can be considered as the same or different constructs. Additionally, the extent to which clustering and switching differentially relate to overall total number of items generated was also examined. The third section examined the extent to which the fluency variables were differentially related to the other cognitive constructs.

Experimental effects within fluency measures

In the first results section, the extent to which semantic and letter fluency tasks differ in terms of a number of dependent variables was examined. Specifically, if performance on semantic fluency tasks is due to more automatic processes reflected in clustering than in letter fluency tasks, one would expect the semantic fluency tasks to have more total numbers of items generated, fewer repetitions, larger clusters, and fewer switches than letter fluency tasks. However, if both types of fluency task largely measure the same set of processes one would not expect differences between them. In order to examine these issues, the two semantic fluency tasks were averaged together, the two letter fluency tasks were averaged together, and the variables of interest were examined as a function of type of fluency task. Shown in Table 1 are descriptive statistics for each of the fluency tasks separately and combined for semantic and letter fluency. As can be seen in Table 1, there was a marginal effect of type of task on total number generated, $F(1, 155) = 3.49$, $MSE = 5.38$, $p = .06$, $\eta_p^2 = .02$, with participants generating slightly more items in letter fluency than in semantic fluency. Examining repetitions, there was no effect of type of fluency task, $F < 1$. Examining cluster size suggested no difference between semantic and letter fluency, $F < 1$ (see also Troyer et al., 1997, Experiment 2). Finally, examining number switches also suggested no difference in terms of fluency task, $F(1, 155) = 2.21$, $MSE = 4.00$, $p > .13$, $\eta_p^2 = .01$. Collectively these results suggest that there are virtually no differences between semantic and letter fluency when examining various measures of performance. Thus, this suggests that semantic and letter fluency probably measure the same set of processes.

Correlations within fluency measures

Given that there seemed to be no differences between semantic and letter fluency in terms of various measures of performance, next the extent to which the semantic and letter fluency tasks represent the same underlying construct was examined via exploratory factor analysis. In particular, an exploratory factor analysis was done to (a) examine the communality estimate of each fluency task, which estimates the proportion of

Table 1. *Measures of verbal fluency for each task and for combined semantic and letter fluency*

					Combined	
	Animal	*Supermarket*	*F-letter*	*S-letter*	*Semantic*	*Letter*
Total generated	18.85 (0.31)	20.46 (0.34)	18.39 (0.31)	21.90 (0.34)	19.66 (0.28)	20.15 (0.29)
Repetitions	0.14 (0.03)	0.06 (0.02)	0.13 (0.03)	0.08 (0.03)	0.10 (0.02)	0.11 (0.02)
Cluster size	1.82 (0.05)	1.78 (0.04)	1.75 (0.04)	1.87 (0.05)	1.80 (0.04)	1.87 (0.04)
Switches	9.89 (0.22)	10.97 (0.23)	10.14 (0.22)	11.40 (0.25)	10.43 (0.18)	10.77 (0.19)

Note: Values in parentheses represent one standard error of the mean.

variance accounted for in a task by the other tasks in the factor analysis, and (b) examine whether one or two factors account for the fluency tasks. Therefore, a principal factor analysis with promax rotation (oblique rotation) was conducted on the total number of items generated for each of the four fluency tasks As shown in Table 2, the factor analysis yielded one factor (eigenvalue = 2.43) accounting for 60.69% of the variance. The scree plot also suggested the presence of only one factor.

As can be seen in Table 2, the communality estimate for each task was moderately high, suggesting that on average 48% of the variance in each task was shared with the other fluency tasks. Furthermore, as shown in Table 2, each task had a moderate to strong loading on the extracted factor, suggesting that a single common factor accounted for much of the shared variance among the tasks. Thus, similar to the experimental effects, these results are consistent with the notion that semantic and letter fluency tasks largely measure the same set of processes rather than representing distinct processes.

Next, we examined the extent to which overall performance based on the total number of items generated was related to the different fluency components (i.e., clustering and switching) as well the propensity to perseverate and repeat items. Given that the exploratory factor analysis suggested one common fluency factor, a composite fluency measure was formed by averaging the total number of items generated across the four fluency tasks. Similar composites were formed for clustering, switching, and repetitions. Shown in Table 3 are the resulting correlations among the composite measures.

Table 2. *Exploratory factor analysis for the fluency tasks*

Measure	h^2	*Factor loading*
Animal	.35	.60
Supermarket	.52	.72
F-letter	.47	.69
S-letter	.57	.76

Note: h^2 = communality estimate.

Table 3. *Correlations for the fluency composite measures*

Variable	*1*	*2*	*3*	*4*
1. Total generated	—			
2. Clustering	.32*	—		
3. Switching	.58*	−.49*	—	
4. Repetitions	.04	.02	.01	—

*Correlations are significant at the $p < .05$ level.

Consistent with prior research (e.g., Troyer et al., 1997), switching was more highly correlated with total number of words generated than was clustering, $t(153) = 2.37$, $p < .05$. Although switching may be more important than clustering, both components are important in determining the total number of words generated in verbal fluency tasks. Furthermore, this pattern of results holds at the more global composite fluency level, suggesting that both components are needed regardless of whether the task is a semantic or letter fluency task. Additionally, and consistent with prior research (e.g., Troyer et al., 1997), there was a moderate negative correlation between clustering and switching, suggesting that individuals with larger clusters tended to switch less. Given the strong time constraints on these tasks, this finding is perhaps not surprising. Finally, as shown in Table 3, the composite measure of repetitions was not related to total number of words generated, nor was it related to either clustering or switching. Thus, at least at an individual differences level, this suggests that perseveration rates are not related to overall performance on verbal fluency tasks. This finding is clearly at odds with prior work that suggests that fluency tasks rely on inhibitory processes to prevent repetitions (e.g., Azuma, 2004; Chiappe & Chiappe, 2007; Perret, 1974; Rosen & Engle, 1997).

Correlations between fluency measures and other cognitive constructs

For our final set of analyses we used confirmatory factor analysis and structural equation modelling to determine the extent to which the total number of words generated, cluster size, and number of switches are related to other cognitive constructs (WMC, vocabulary, processing speed, inhibition) that are thought to be important determinants of fluency performance. Descriptive statistics for the cognitive ability measures are shown in Table 4. As can be seen in Table 4, all measures had generally acceptable values of internal consistency and most were approximately normally distributed with values of skewness and kurtosis under the generally accepted values (i.e., skewness < 2 and kurtosis < 4). Finally, correlations for all of the measures (including the fluency measures) are shown in Table 5.

Confirmatory factor analysis (CFA) was used to further examine the underlying structure of the data and the relations among the fluency measures and the cognitive ability measures. Model fits were assessed via a combination of several fit statistics. The chi-square statistic reflects whether there is a significant difference between the observed and reproduced covariance matrices. Therefore, nonsignificant values are desirable. We also report the root mean square error of approximation (RMSEA), which is an index of model misfit due to model misspecification, and the standardized root mean square residual (SRMR), which reflects the average squared deviation between the observed and reproduced covariances. In addition, we report the non-normed fit index (NNFI) and the comparative fit index (CFI), both of which compare the fit of the specified model to a baseline null model. NNFI and CFI values greater than .90 and RMSEA and SRMR values less than .08 are indicative of acceptable fit.

Before examining the fluency to cognitive ability relations, we examined the relation among the cognitive ability measures via CFA. Four cognitive ability factors were specified with two tasks loading only on their respective factor of interest. Thus, the WMC factor was composed of operation and reading span, the vocabulary factor was composed of synonym and antonym vocabulary tests, the processing speed factor was composed of letter and number comparison tasks, and the inhibition factor was composed of antisaccade and flankers. These four latent variables were allowed to correlate. As shown in Table 6, the fit of the model was good (labelled cognitive ability CFA). Shown in Figure 1 is the resulting CFA model. As can be seen, each task loaded significantly on its factor of interest, and most of the factors had weak to moderate correlations with one another. Importantly, those constructs that are theoretically related (i.e., WMC and inhibition) were more strongly correlated than constructs that are theoretically unrelated (i.e., WMC and vocabulary). Thus, this provides both convergent and discriminant validity for the constructs of interest.

Next, in order to examine how the fluency components differentially related to the cognitive ability measures, we formed a single fluency latent variable

Table 4. *Descriptive statistics and reliability estimates for cognitive ability measures*

Measure	M	SD	*Skew*	*Kurtosis*	α
Ospan	62.03	10.04	−1.84	3.48	.78
Rspan	58.84	10.85	−1.14	2.24	.80
Syn	4.06	1.87	0.29	−0.06	.60
Ant	4.58	2.04	0.31	0.83	.61
LetCom	26.80	6.62	1.08	1.20	.91
NumCom	32.48	7.31	0.48	−0.19	.98
Anti	0.55	0.12	0.25	−0.68	.81
Flanker	108.5	2.13	1.59	5.80	NA

Note: Ospan = operation span; Rspan = reading span;
Syn = synonym vocabulary test; Ant = antonym vocabulary test; LetCom = letter comparison; NumCom = number comparison; Anti = antisaccade; Flanker = flanker interference score. NA = not applicable.

Table 5. *Correlations for fluency and cognitive ability measures*

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
1. Ospan	—																			
2. Rspan	.65	—																		
3. Syn	.13	.20	—																	
4. Ant	.14	.13	.46	—																
5. LetCom	.09	.10	.04	.10	—															
6. NumCom	.09	.04	.13	.11	.32	—														
7. Anti	.12	.13	.06	.05	.20	.09	—													
8. Flanker	−.27	−.23	−.19	−.07	.04	−.05	−.25	—												
9. Antot	.19	.24	.14	.17	.13	.04	.06	−.10	—											
10. Anclu	.02	.09	.19	.18	.06	−.04	−.02	−.09	.12	—										
11. Answ	.18	.14	.06	.04	.03	.10	.03	−.01	.62	−.52	—									
12. Sutot	.28	.27	.18	.20	.17	.12	.11	−.13	.51	.09	.35	—								
13. Suclu	.19	.22	.13	.15	.10	.01	.01	.01	.07	.40	−.11	.33	—							
14. Susw	.07	.01	.08	.07	.05	.11	.07	−.11	.31	−.16	.33	.49	−.60	—						
15. Ftot	.37	.32	.11	.17	.06	.08	.13	−.11	.37	.01	.27	.45	.22	.14	—					
16. Fclu	.11	.17	.19	.03	.02	.05	.03	−.12	.08	.00	.03	.25	.25	−.03	.28	—				
17. Fsw	.17	.08	−.07	.14	.03	.00	.10	.05	.21	.02	.16	.11	−.05	.14	.41	−.68	—			
18. Stot	.38	.34	.12	.25	.18	.04	.14	−.16	.42	.04	.27	.51	.15	.26	.58	.25	.24	—		
19. Sclu	.16	.16	.04	.13	−.06	−.05	−.01	−.17	.12	.02	.03	.04	.08	−.08	.19	.43	−.20	.35	—	
20. Ssw	.14	.09	.01	.04	.21	.08	.12	.03	.17	.04	.15	.33	.02	.28	.17	−.25	.35	.40	−.62	—

Note: Ospan = operation span; Rspan = reading span; Syn = synonym vocabulary test; Ant = antonym vocabulary test; LetCom = letter comparison; NumCom = number comparison; Anti = antisaccade; Flanker = flanker interference score; Antot = animal fluency total; Anclu = animal fluency clustering; Answ = animal fluency switching; Sutot = supermarket fluency total; Suclu = supermarket fluency clustering; Susw = supermarket fluency switching; Ftot = F letter fluency total; Fclu = F letter clustering; Fsw = F letter switching; Stot = S letter total; Sclu = S letter clustering; Ssw = S-letter switching.

Table 6. *Fit indices for all models*

Model	χ^2	df	*p*	χ^2/df	*RMSEA*	*NNFI*	*CFI*	*SRMR*
Cognitive ability CFA	14.11	14	.44	1.01	.01	1.0	1.0	.04
Total generated CFA	37.68	44	.74	0.87	.00	1.0	1.0	.04
Clustering CFA	72.09	44	.01	1.64	.06	.86	.90	.07
Switching CFA	49.70	44	.26	1.13	.03	.96	.98	.05
Total generated SEM	37.68	44	.74	0.87	.00	1.0	1.0	.04
Clustering SEM	72.09	44	.01	1.64	.06	.86	.90	.07
Switching SEM	49.70	44	.26	1.13	.03	.96	.98	.05

Note: RMSEA = root mean square error of approximation; NNFI = non-normed fit index; CFI = comparative fit index; SRMR = standardized root mean square residual. CFA = confirmatory factor analysis. SEM = structural equation modelling.

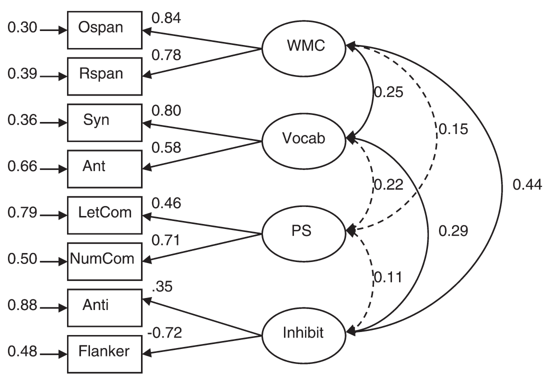

Figure 1. *Confirmatory factor analysis for working memory capacity (WMC), vocabulary (Vocab), processing speed (PS), and inhibition (Inhibit). Ospan = operation span; Rspan = reading span; Syn = synonym vocabulary test; Ant = antonym vocabulary test; LetCom = letter comparison; NumCom = number comparison; Anti = antisaccade; Flanker = flanker interference score. Paths connecting latent variables (circles) to each other represent the correlations between the constructs, the numbers from the latent variables to the manifest variables (squares) represent the loadings of each task onto the latent variable, and numbers appearing next to each manifest variable represent error variance associated with each task. Solid lines are significant at the* p < *.05 level, and dotted lines are not significant at the* p < *.05 level.*

and combined this with the latent variables from the cognitive ability CFA.[1] Specifically, in order to examine how total number of items generated on the fluency tasks related to the cognitive ability constructs, a fluency total latent variable was formed by having each of total scores from the four fluency tasks load onto a single latent variable, and this latent variable was allowed to correlate with the four cognitive ability latent variables. As shown in Table 6, the fit of the model was good (labelled total generated CFA). Consistent with the exploratory factor analysis, each of the four fluency tasks loaded significantly on the specified factor (i.e., animal = .58, supermarket = .69, F-letter = .70, S-letter = .77). As shown in Table 7, the total number of items generated was significantly correlated to each of the cognitive ability factors. Thus, overall fluency scores were related to WMC, vocabulary size, processing speed, and inhibition as suggested by prior work and prior theorizing. Furthermore, as shown in Table 7, WMC was more highly correlated with fluency than were any of the other cognitive ability constructs, all *t*s > 2.82, all *p*s < .01, suggesting an important role of WMC in word generation in fluency tasks (i.e., Rosen & Engle, 1997).

[1] Note, that separate CFAs were run for total number of items generated, cluster size, and switching due to issues of multicollinearity and dependency within the data. Specifically, given that the total number of items generated are a reflection of both the number switches and the number of items per cluster, simultaneously examining all three in the same model would result in a large amount of multicollinearity. Furthermore, as shown in Table 5, cluster size and switching were strongly negatively correlated within each task, suggesting a good of degree of within task dependency. Thus, including measures of cluster size and switching from the same task in the same model would result in a model with several task-specific factors rather than more general factors. Thus, for clarity and in order to better examine the correlations between the constructs, models were constructed for each fluency component separately.

Table 7. *Correlations of fluency factors with cognitive ability factors*

Measure	*WMC*	*Vocabulary*	*Processing speed*	*Inhibition*
Total generated	.55*	.36*	.27*	.29*
Clustering	.33*	.32*	.06	.07
Switching	.30*	.09	.29*	.05

*Correlations are significant at the $p < .05$ level. WMC = working memory capacity.

A similar CFA was done for clustering scores in which a clustering latent variable was formed and was allowed to correlate with the cognitive ability constructs. As shown in Table 6, the fit of the model was acceptable (labelled clustering CFA). As expected, each of the four clustering scores loaded significantly on the overall clustering latent variable (i.e., animal = .49, supermarket = .77, F-letter = .36, S-letter = .22). As shown in Table 7, and unlike the total number of words generated factor, the clustering factor was only significantly related to the WMC factor and the vocabulary factor. Consistent with prior work (e.g., Rosen & Engle, 1997) WMC was related to individual differences in cluster size, and cluster size was related to overall differences in vocabulary.

The final CFA examined how switching abilities would be related to the cognitive ability constructs. As with the previous models, the four switching scores formed a single latent switching variable, and this variable was allowed to correlate with the four cognitive ability latent variables. As shown in Table 6, the fit of the model was good (labelled switching CFA). As expected, each of the four switching scores loaded significantly on the overall switching latent variable (i.e., animal = .41, supermarket = .47, F-letter = .47, S-letter = .60). As shown in Table 7, switching was only related to WMC and processing speed. Consistent with prior work (e.g., Rosen & Engle, 1997), WMC was related to individual differences in switching abilities, and switching was related to individual differences in processing speed (e.g., Hughes & Bryan, 2002).

Structural equation modelling (SEM) was used next to examine how the cognitive ability constructs differentially related to the fluency measures. Thus, not only is the underlying structure of the data taken into account, but also models can be tested to examine how the different constructs are related to one another and account for separate and unique sources of variance in another construct like verbal fluency. Thus, although each of the cognitive ability constructs were related to the total number of items generated, it is possible that only some of the constructs actually predict unique variance in fluency, whereas the relation between the other constructs and fluency is largely due to shared variance. In order to examine whether the cognitive ability constructs account for unique variance in the total number of items generated, a SEM was specified in which each of the four cognitive ability factors was allowed to predict the total number of items generated, and each of the four cognitive ability factors was allowed to correlate with one another based on the prior CFA. As shown in Table 6, the fit of the model was good. Shown in Figure 2 is the resulting model. As can be seen, although the prior CFA suggested that each of the four cognitive ability constructs was related to the total number of items generated in fluency tasks, the SEM suggests that only WMC and vocabulary accounted for significant unique variance in the total number of items generated. This suggests that individual differences in WMC and vocabulary abilities are two of the primary reasons for individual differences in the total number of items generated in fluency tasks. This also suggests that WMC and vocabulary abilities account for partially independent variance in fluency, and, hence, both are important for accounting for variation in overall fluency scores. Furthermore, these results suggest that WMC probably mediates the relation between inhibition and total number of items generated. That is, although inhibition was related to fluency in the CFA, it did not account for unique variance in the SEM, but WMC did, suggesting that the relation between inhibition and total number of items generated is due to shared variance with

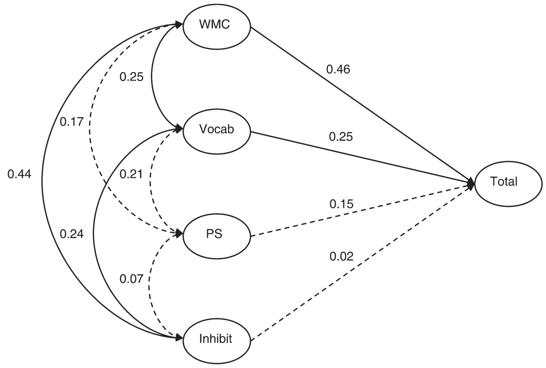

Figure 2. *Structural equation model predicting total number of items generated on verbal fluency tasks (Total) with working memory capacity (WMC), vocabulary (Vocab), processing speed (PS), and inhibition (Inhibit). Single-headed arrows connecting latent variables (circles) to each other represent standardized path coefficients indicating the unique contribution of the latent variable. Double-headed arrows connecting the memory factors represent the correlations among the factors. Solid lines are significant at the* p $<$ *.05 level, and dotted lines are not significant at the* p $<$ *.05 level.*

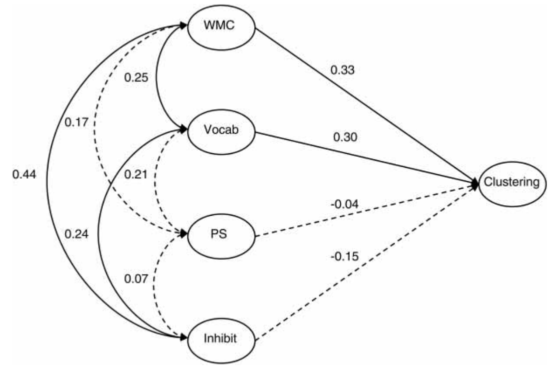

Figure 3. *Structural equation model predicting clustering on the verbal fluency tasks with working memory capacity (WMC), vocabulary (Vocab), processing speed (PS), and inhibition (Inhibit). Single-headed arrows connecting latent variables (circles) to each other represent standardized path coefficients indicating the unique contribution of the latent variable. Double-headed arrows connecting the memory factors represent the correlations among the factors. Solid lines are significant at the* p $<$ *.05 level, and dotted lines are not significant at the* p $<$ *.05 level.*

WMC. Indeed, examining only WMC and inhibition suggests that the correlation between inhibition and total number of items generated (.29) drops to near zero (.06) once WMC is partialled out. Thus, variation in WMC fully mediated the relation between inhibition and total number of items generated.

A similar SEM was specified in order to examine how each cognitive ability construct would predict unique variance in clustering. Like the SEM for total number of items generated, in this SEM each cognitive ability factor was allowed to correlate with another, and each was allowed to predict the clustering factor. As shown in Table 6, the fit of the model was acceptable. Shown in Figure 3 is the resulting model. Similar to the clustering CFA, the resulting model suggests that only WMC and vocabulary predicted significant unique variance in clustering scores. Importantly, these two sources of variance are partially independent, suggesting that both WMC and vocabulary are necessary to account for variation in clustering. Thus, it is not the case that the WMC correlates with clustering because of differences in vocabulary (e.g., Rosen & Engle, 1997); rather WMC is related to clustering independently of variation in vocabulary abilities.

In the final SEM we examined how each cognitive ability construct would predict variance

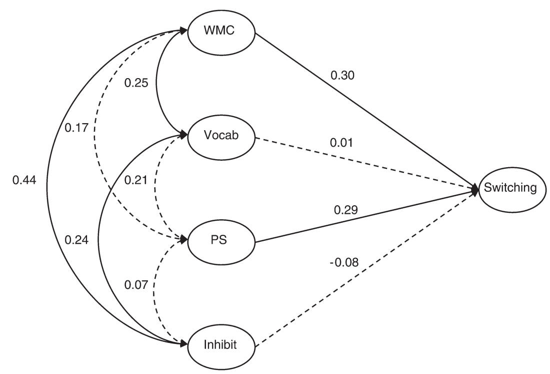

Figure 4. *Structural equation model predicting switching on the verbal fluency tasks with working memory capacity (WMC), vocabulary (Vocab), processing speed (PS), and inhibition (Inhibit). Single-headed arrows connecting latent variables (circles) to each other represent standardized path coefficients indicating the unique contribution of the latent variable. Double-headed arrows connecting the memory factors represent the correlations among the factors. Solid lines are significant at the* p $<$ *.05 level, and dotted lines are not significant at the* p $<$ *.05 level.*

in switching similar to the two prior SEMs. As shown in Table 6, the fit of the model was good. Shown in Figure 4 is the resulting model. As can be seen, only WMC and processing speed predicted significant unique variance in switching. Thus, consistent with the CFA, and with prior work, WMC significantly predicted individual differences in switching (Rosen & Engle, 1997), and processing speed predicted variation in switching (e.g., Hughes & Bryan, 2002; Mayr, 2002). Importantly, these two sources of variance were independent, suggesting that both WMC and processing speed account for unique variance in switching abilities.

Discussion

In the current study we examined the components of verbal fluency from both experimental and individual differences perspectives in order to better understand the component processes involved generating items from long-term memory in a sample of young, healthy adults. In particular, we addressed three primary questions of interest. First, we examined whether there are differences between semantic and letter fluency tasks in terms of total number of items generated, as well as clustering and switching. It was found that there were no systematic differences between semantic and letter fluency tasks in terms of total number of items generated, cluster size, or frequency of switches. Furthermore, an exploratory factor analysis suggested that all four fluency tasks shared a good deal of common variance and could be accounted for by a single factor. Thus, this suggests that semantic and letter fluency tasks largely measure the same set of processes, rather than relying on fundamentally different processes. As such, this result suggests that both semantic and letter fluency rely on both strategic (frontally mediated) and automatic (temporally mediated) components, and thus differences between the two tasks that have been found previously may have more to do with the relative sensitivity of the tasks rather than differences in component processes (see also Baldo & Shimamura, 1998; Henry & Crawford, 2004a).

Our second question of interest was how clustering and switching relate to the total number of items generated. Previous work (e.g., Troyer et al., 1997) has suggested that switching is more important for the total number of items generated than is clustering. Consistent with this work, the current results suggested that although both components were related to the total number of items generated at a latent level, switching was more highly related to the total number of items generated than was clustering. These results held regardless of whether the task was a semantic fluency task or a letter fluency task. Thus, both clustering and switching are important for overall performance, but it seems that switching is more important. This suggests that the ability to self-generate category cues (switching) is more important than the number of items subsumed under the cue (clustering) for overall performance and individual differences in overall performance.

Our final question was aimed at determining how total number of items generated, clustering, and switching would be related to other important cognitive constructs like WMC, vocabulary, processing speed, and inhibition. To this end several different confirmatory factor analyses and structural equation models were examined in order to determine the relations between the components of fluency performance and the cognitive constructs. For WMC, the results suggested that WMC had the strongest relation with total number of items generated, and much of this relation represented unique variance shared between WMC and total number of items generated independently of the other constructs. WMC also predicted unique variance in clustering and switching, suggesting that variation in WMC was an important contributor to both components of verbal fluency and, hence, a major reason why WMC seems to be so important for overall performance. These results are consistent with prior work by Rosen and Engle (1997), suggesting that WMC is important for verbal fluency performance due to the need to self-generate category cues and monitor the products of retrieval based on frontally mediated strategic control processes.

In terms of vocabulary, the results suggested that vocabulary was related to both overall number of items generated as well as clustering, but was not related to switching. Importantly, the structural equation modelling results suggested that only WMC and vocabulary predicted significant unique variance in the total number of items generated and clustering. Thus, both WMC and vocabulary contribute to overall performance and clustering, but these contributions are largely independent. These results are consistent with the notion that performance on verbal fluency tasks is driven by both strategic search components (e.g., WMC) and automatic associative links between the words (e.g., vocabulary). Thus both strategic and automatic components are needed for each act of retrieval (e.g., Mayr, 2002).

For processing speed, the results suggested that processing speed was related to both overall number of items generated and switching, but predicted significant unique variance in switching only. Similar to clustering, these results suggest that both WMC and processing speed predict unique variance in switching, and these two contributions are independent. Given that these fluency tasks are rate limited, these results are consistent with the idea that switching frequency is partially determined by speed of processing differences. Importantly, these speed of processing differences do not account for the substantial relation between WMC and overall performance, given that WMC and processing speed were unrelated. Again, these results point to the multifaceted nature of verbal fluency tasks and suggest that overall performance is due to a combination of processes.

Finally, in terms of inhibition the results suggested that although inhibition was related to overall levels of performance, it was not related to either clustering or switching. Furthermore, the results suggested that the relation between inhibition and total number of items generated was fully mediated by variation in WMC. Thus, inhibition by itself was not related to verbal fluency performance, but rather this relation was due to shared variance with WMC. These results are inconsistent with prior claims that fluency tasks are good indicators of inhibition control given the need to suppress previously generated responses (e.g., Azuma, 2004; Chiappe & Chiappe, 2007; Perret, 1974; Rosen & Engle, 1997). That is, Rosen and Engle specifically suggested that one of their four components involved in retrieval in verbal fluency tasks was suppression (i.e., their Component 3). However, the current results suggest that inhibition by itself may not be needed to account for verbal fluency. Indeed, suppression views of verbal fluency would seem to predict a correlation between preservation errors (repetitions) and overall fluency performance. However, no such relation was found. Thus, although one could make the argument that the relation between WMC and fluency is due to inhibitory control processes in WMC, a simpler interpretation seems to be that inhibition is not needed in verbal fluency tasks, and the shared variance between WMC and verbal fluency is due primarily to self-generation of category cues (i.e., Rosen & Engle's Component 4).

The current results suggest that a number of component processes support overall performance on verbal fluency tasks and account for the large amount of individual variation in performance. In particular, as suggested by previous work (Gruenewald & Lockhead, 1980; Herrmann & Pearle, 1981; Rosen & Engle, 1997; Troyer et al., 1997; Wixted & Rohrer, 1994) verbal fluency tasks can be broken down into clustering and switching components, and these components are differentially related to other important cognitive abilities. As such, this work provides important evidence for contributors to verbal fluency. In the current study, the two main contributors were WMC and vocabulary. As suggested previously these two components are theoretically important for verbal fluency because they index both frontally mediated strategic (WMC) and temporally mediated associative (vocabulary) retrieval processes that drive the generation of items on verbal fluency tasks. WMC is important for self-generating category cues and for generating individual items within a category and relies on intact frontal functioning. Vocabulary size seems to be important for determining associative links between items within a category and probably relies on intact temporal functioning. That is, cluster size is determined in part by word knowledge that individuals bring to the task. The more prior knowledge an individual has in a given domain, the larger the cluster should be. Importantly, these two contributors seem to act in concert such that those individuals who self-generate category cues and associative links between individual items will perform the best. Deficits in either component, however, will lead to lower levels of performance. Thus, individuals may perform poorly because of strategic search deficits or because of an overall smaller knowledge base to pull from.

Overall, these results are consistent with Rosen and Engle's (1997) component processes model of verbal fluency, with one major exception; suppression of previously retrieved responses is not needed to account for the results. That is, Rosen and Engle suggested that performance was determined by associative links between items, monitoring of generated items to prevent repetitions, and suppression of previously retrieved items, as well as the self-generation of category cues to access new items. The current results suggest that associative links and overall vocabulary size are important determinants of performance as well as the self-generation of category cues thought to be reliant on WMC. However, inhibitory processes were not uniquely related to any of the fluency measures. Thus, it seems that a revision to their model is in order in which inhibition is not directly tied to performance nor to individual differences in performance. Clearly, more work is needed to better specify how participants rely on associative links to transition between items, and more work is needed to understand how participants generate their own category cues in order to access items in verbal fluency tasks.

Clearly, when examining individual and group differences in verbal fluency performance, knowing which of these components is responsible for the differences will go a long way toward understanding verbal fluency. That is, given that fluency tasks are used extensively to assess neuropsychological differences, it is clearly an important endeavour for future research to better examine the extent to which these conclusions extend to other populations such as individuals with frontal deficits and individuals with temporal deficits, as well as other neuropsychological disorders. Understanding the linkages between the underlying cognitive processes, individual and group differences in those processes, and their neural substrates should provide a better understanding of how strategic search and associative processes work in concert in order to generate items from long-term memory (e.g., Moscovitch, 1992).

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REFERENCES

Ardila, A., Galeano, L. M., & Rosselli, M. (1998). Toward a model of neuropsychological activity. *Neuropsychology Review*, *8,* 171–190.

Ardila, A., Pineda, D., & Rosselli, M. (2000). Correlations between intelligence test scores and executive function measures. *Archives of Clinical Neuropsychology*, *15,* 31–36.

Azuma, T. (2004). Working memory and perseveration in verbal fluency. *Neuropsychology*, *18,* 69–77.

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

Bousfield, W. A., & Sedgewick, C. H. (1944). An analysis of restricted associative responses. *Journal of General Psychology*, *30,* 149–165.

Chiappe, D. L., & Chiappe, P. (2007). The role of working memory in metaphor production and comprehension. *Journal of Memory and Language*, *56,* 172–188.

Cohen, R. L. (1984). Individual differences in event memory: A case for nonstrategic factors. *Memory & Cognition*, *12,* 633–641.

Epker, M. O., Lacritz, L. H., & Cullum, C. M. (1999). Comparative analysis of qualitative verbal fluency performance in normal elderly and demented populations. *Journal of Clinical and Experimental Neuropsychology*, *21,* 425–434.

Fisk, J. E., & Sharp, C. A. (2004). Age-related impairment in executive functioning: Updating, inhibition, shifting, and access. *Journal of Clinical and Experimental Neuropsychology*, *26,* 874–890.

Fossati, P., Guillaume, Le, B., Ergis, A. M., & Allialaire, J. F. (2003). Qualitative analysis of verbal fluency in depression. *Psychiatry Research*, *117,* 17–24.

Fournier-Vicente, S., Larigauderie, P., & Gaonac'h, D. (2008). More dissociations and interactions within central executive functioning: A comprehensive latent variable analysis. *Acta Psychologica*, *129,* 32–48.

Gruenewald, P. J., & Lockhead, G. R. (1980). The free recall of category examples. *Journal of Experimental Psychology: Human Learning and Memory*, *6,* 225–240.

Hambrick, D. Z., Salthouse, T. A., & Meinz, E. J. (1999). Predictors of crossword puzzle proficiency and moderators of age−cognition relations. *Journal of Experimental Psychology: General*, *128,* 131–164.

Hedden, T., Lautenschlager, G., & Park, D. C. (2005). Contributions of processing ability and knowledge to verbal memory tasks across the adult life-span. *The Quarterly Journal of Experimental Psychology*, *58A,* 169–190.

Hedden, T., & Yoon, C. (2006). Individual differences in executive processing predicts susceptibility to interference in verbal working memory. *Neuropsychology*, *20,* 511–528.

Henry, J. D. & Beatty, W. W. (2006). Verbal fluency deficits in multiple sclerosis. *Neuropsychologia*, *44*, 1166−1174.

Henry, J. D., & Crawford, J. R. (2004a). A meta-analytic review of verbal fluency performance following focal cortical lesions. *Neuropsychology*, *18,* 284–295.

Henry, J. D., & Crawford, J. R. (2004b). A meta-analytic review of verbal fluency performance following traumatic brain injury. *Neuropsychology*, *18,* 621–628.

Henry, J. D., & Crawford, J. R. (2004c). Verbal fluency deficits in Parkinson's disease: A meta-analysis. *Journal of the International Neuropsychological Society*, *10,* 608–622.

Henry, J. D., & Crawford, J. R. (2005a). A meta-analytic review of verbal fluency deficits in depression. *Journal of Clinical and Experimental Neuropsychology*, *27,* 1–24.

Henry, J. D., & Crawford, J. R. (2005b). A meta-analytic review of verbal fluency deficits in schizophrenia relative to other neurocognitive deficits. *Cognitive Neuropsychiatry*, *10,* 1–33.

Henry, J. D., Crawford, J. R., & Phillips, L. H. (2005). A meta-analytic review of verbal fluency deficits in Huntington's disease. *Neuropsychology*, *19,* 243–252.

Herrmann, D. J., & Pearle, P. M. (1981). The proper role of clusters in mathematical models of continuous recall. *Journal of Mathematical Psychology*, *24,* 139–162.

Hughes, D. L., & Bryan, J. (2002). Adult age differences in strategy use during verbal fluency performance. *Journal of Clinical and Experimental Neuropsychology*, *24,* 642–654.

Kane, M. J., Bleckley, M. K., Conway, A. R. A., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General*, *130,* 169–183.

Kave, G., Kigel, S., & Kochva, R. (2008). Switching and clustering in verbal fluency tasks throughout childhood. *Journal of Clinical and Experimental Neuropsychology*, *30,* 349–359.

Martin, R. C., Loring, D. W., Meador, K. J., & Lee, G. P. (1990). The effects of lateralized temporal lobe dysfunction on formal and semantic word fluency. *Neuropsychologia*, *28,* 823–829.

Martin, A., Wiggs, C. L., Lalonde, F., & Mack, C. (1994). Word retrieval to letter and semantic cues: A double dissociation in normal subjects using interference tasks. *Neuropsychologia*, *32,* 1487–1494.

Mayr, U. (2002). On the dissociation between clustering and switching in verbal fluency: Comment on Troyer, Moscovitch, Winocur, Alexander, and Stuss. *Neuropsychologia*, *40,* 562–566.

Mayr, U., & Kliegl, R. (2000). Complex semantic processing in old age: Does it stay or does it go? *Psychology & Aging*, *15,* 29–43.

Moelter, S. T., Hill, S. K., Ragland, D., Lunardelli, A., Gur, R. C., Gur, R. E., et al. (2001). Controlled and automatic processing during animal word list generation in schizophrenia. *Neuropsychology*, *15,* 502–509.

Moscovitch, M. (1992). Memory and working with memory: A component process model based on modules and central systems. *Journal of Cognitive Neuroscience*, *4,* 257–267.

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

Rende, B., Ramsberger, G., & Miyake, A. (2002). Commonalities and differences in the working memory components underlying letter and category fluency tasks: A dual-task investigation. *Neuropsychology*, *16,* 309–321.

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General*, *126,* 211–227.

Rosen, V. M., Sunderland, T., Levy, J., Harwell, A., McGee, L., Hammond, C., et al. (2005). Apolipoprotein E and category fluency: Evidence for reduced semantic access in healthy normal controls at risk for developing Alzheimer's disease. *Neuropsychologia*, *43,* 647–658.

Ruff, R. M., Light, R. H., Parker, S. B., & Levin, H. S. (1997). The psychological construct of word fluency. *Brain and Language*, *57,* 394–405.

Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology*, *27,* 763–776.

Troster, A. I., Fields, J. A., Testa, J. A., Paul, R. H., Blanco, C. R., Hames, K. A., et al. (1998). Cortical and subcortical influences on clustering and switching in the performance on verbal fluency tasks. *Neuropsychologia*, *36,* 295–304.

Troyer, A. K., & Moscovitch, M. (2006). Cognitive processes of verbal fluency tasks. In A. M. Poreh (Ed.), *The quantified process approach to neuropsychological assessment*. New York: Taylor & Francis.

Troyer, A. K., Moscovitch, M., & Winocur, G. (1997). Clustering and switching as two components of verbal fluency: Evidence from younger and older healthy adults. *Neuropsychology*, *11,* 138–146.

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

Troyer, A. K., Moscovitch, M., Winocur, G., Leach, L., & Freedman, M. (1998b). Clustering and switching on verbal fluency tests in Alzheimer's and Parkinson's disease. *Journal of the International Neuropsychological Society*, *4,* 137–143.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, *37,* 498–505.

Unsworth, N., Miller, J. D., Lakey, C. E., Young, D. L., Meeks, J. T., Campbell, W. K., et al. (2009). Exploring the relations among executive functions, fluid intelligence, and personality. *Journal of Individual Differences*, *30,* 194–200.

Wixted, J. T., & Rohrer, D. (1994). Analyzing the dynamics of free recall: An integrative review of the empirical literature. *Psychonomic Bulletin & Review*, *1,* 89–106.