

## 11

## DIMENSIONS OF COGNITIVE AGING

### *Executive Function and Verbal Fluency*

SUSAN KEMPER AND JOAN M. McDOWD

A persistent issue in cognitive aging is whether all aspects of cognition are equivalently affected by developmental processes or whether some are differentially spared from developmental decline (Zelinski & Lewis, 2003). This argument has been nowhere more contentious than in debates concerning the effects of aging and age-associated diseases such as Alzheimer's disease (AD) and Parkinson's disease (PD) on language use. Linguistic tasks are commonly used to assess cognitive status and neuropsychological impairments; they include tests of verbal fluency, vocabulary, and prose comprehension and recall. A related concern has been whether these tests measure discrete, autonomous linguistic abilities (Fodor, 1982; Waters & Caplan, 1996) or composite abilities that draw on multiple cognitive domains, including working memory and executive function (Just & Carpenter, 1992). In particular, impairments of executive function (EF)

have been implicated as contributing to a wide range of linguistic and cognitive abilities; for example, verbal fluency involves not only semantic knowledge of lexical items and the ability to search semantic memory using phonological or categorical rules but also "executive" skills required to track prior responses and block intrusions from other semantic categories. Complicating this question has been the problem of defining and measuring EF.

Measures of EF have proliferated over the past half-century. In their review of executive function, Royall et al. (2002, Table 11.3) listed 46 studies conducted between 1983 and 2001 that involve factor analyses of EF. These studies employed 34 different measures of EF and report factor structures ranging from one to four independent EF factors. This summary indicates that there is little consensus regarding appropriate measures of EF or about the underlying structure of EF. Some of this heterogeneity

---

**AUTHORS' NOTE:** We thank Laura Berman, Pat Laubinger, Kelly Lyons, Alicia MacKay, and Kim Metcalf for their assistance with data collection. This research was supported in part by grants from the National Institutes of Health to the University of Kansas through the Mental Retardation and Developmental Disabilities Research Center (Grant P30 HD-002528); and the Center for Biobehavioral Neurosciences in Communication Disorders (Grant P30 DC-005803); as well as by Grants RO1 AG06319, K04 AG000443, P30 AG10182, RO1 AG09952, RO1 AG18892, and RO1 AG025906 from the National Institute on Aging. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the National Institutes of Health.

## 182 • DIMENSIONS OF COGNITIVE AGING

comes from the use of different populations (e.g., people with schizophrenia, children, college students, older adults, individuals with AD) both within and between studies. For example, Kanne, Balota, and Storandt (1998) found that people with AD had a different EF factor structure than did the elderly control participants. In that study, the normal older adults showed a single-factor structure for EF, whereas the patients with AD showed a three-factor structure with mental control, verbal memory, and visuospatial factors. In contrast, a study involving only people with AD produced a single factor structure (Loewenstein et al., 2001). Likely relevant is the fact that Loewenstein et al. (2001) administered only three measures of EF, and Kanne et al. administered five; only two tasks overlapped in the two studies. A further contrast is provided by a study healthy aging adults by Royall, Chiodo, and Polk (2003); they reported a three-factor structure: (1) Procedural Control, (2) Abstraction, and (3) Attention Switching. Together, these studies point to important questions that remain to be answered: What is the cognitive structure underlying the construct of EF? Does the structure vary with age or clinical population? What are the best measures of EF?

Two recent studies highlight the continuing need to resolve these issues. Salthouse, Atkinson, and Berish (2003), noting the complexity and breadth of notions of EF, undertook an examination of the construct validity of EF in a sample of 261 adults ranging in age from 18 to 84 years. Their approach was to examine convergent and discriminant validity among a set of neuropsychological and cognitive tasks typically associated with EF and a set of psychometric tasks. The neuropsychological tasks in their battery included the Wisconsin Card Sorting Test; the Connections test (based on the Trail-Making Test), the Tower of Hanoi, verbal fluency, and figural fluency. Three additional sets of tasks designed to assess component (cognitive) processes of EF included measures of time sharing, updating, and inhibitory processes. Psychometric measures included indices of verbal ability, fluid intelligence, episodic memory, and perceptual speed. A series of structural equation analyses were then conducted to look at the relations among these sets of variables. Salthouse et al. identified verbal fluency as the

“best” neuropsychological measure of EF based on factor loadings and the Stroop task as the best measure of inhibition, a keeping track task as the best measure of updating, and a paired-associate learning task combined with keeping track task as the best measure of time sharing. However, their results indicated that the various neuropsychological measures were not very highly related to one another (i.e., had low convergent validity) and were fairly highly related to other variables, particularly fluid intelligence, indicating low discriminant validity. The same pattern of results was reported for the cognitive process variables: little convergent or discriminant validity for inhibition, updating, or time-sharing abilities. All were fairly highly correlated with fluid intelligence. The authors concluded that individual differences in measures of EF may in fact reflect differences in much broader abilities, such as fluid intelligence.

Miyake and colleagues (Friedman & Miyake, 2004; Miyake, Emerson, & Friedman, 2000; Miyake et al., 2000) have addressed similar questions but take a somewhat different approach and reach different conclusions. For example, Miyake, Friedman, et al. (2000) noted that descriptions of task requirements underlying the same EF measure may vary widely, and perhaps rightly so because such measures are typically complex and may require several cognitive processes to carry out successfully. At the same time, different EF measures may require different cognitive processes for good performance. To address these issues, Miyake, Friedman, et al. (2000) reported a study addressing “the unity and diversity of executive functions” (p. 49) using confirmatory factor analysis and structural equation modeling. Like the Salthouse et al. study, Miyake, Friedman, et al. identified a set of EF tasks used in neuropsychological studies: the Wisconsin Card Sorting Test, the Tower of Hanoi, a random number generation test, the operation span task, and a dual task. They also identified a set of tasks designed to measure three subtypes of EF: (1) shifting, (2) updating, and (3) inhibition. To address the question of unity and/or diversity of functions, they first conducted confirmatory factor analyses using data from 137 college students performing the EF subtype measures. They found that a three-factor solution fit the data better than any

of the one- or two-factor solutions, indicating that there are separable dimensions of EF. They identified their letter memory and keeping track tasks as the best measure of updating, the plus/minus and number/letter tasks as the best measures of shifting, and the antisaccade and Stroop tasks as the best measures of inhibition. In addition to these analyses, Miyake, Friedman, et al. (2000) also tested a series of structural equation models to examine the contribution of these separable factors to the more complex neuropsychological EF tasks. Using structural equation modeling, they reported that the shifting factor is most relevant for Wisconsin Card Sorting Test performance, the inhibition factor is most relevant for the Tower of Hanoi, and that both inhibition and updating are relevant for the random number generation task. The authors concluded from this study that the three EF functions they measured (updating, shifting, and inhibition) are “clearly distinguishable” and that each plays a different role in more complex EF measures, such as the Wisconsin Card Sorting Test and the Tower of Hanoi.

Given these conflicting conclusions, there is a clear need to resolve this controversy regarding the structure of EF. Furthermore, neither of these studies directly addresses how aging affects EF, and they leave unresolved how best to assess EF in clinical populations. The Miyake, Friedman, et al. (2000) study involved only young adults, and the question remains whether the same pattern of results would be obtained with a sample of older adults. Indeed, in a partial replication of Miyake, Friedman, et al.'s study with adults 20 to 81 years of age, Fisk and Sharp (2004) found support for four factors: three corresponding to Miyake, Friedman, et al.'s updating, inhibition, and shifting components and a fourth, word fluency factor. Salthouse et al.'s (2003) study involved both young and old adults, but the age groups were not analyzed separately, and, based on the arguments of Hofer and Sliwinski (2001) and Hofer, Flaherty, and Hoffman (2007), there is some reason to predict that the pattern of results might be different for the two groups. Finally, neither study examined EF in clinical populations. We can only echo Rabbitt's (1997) lament: “Life would be simpler if there were generally agreed paradigmatic ‘executive’ tasks available for rigorous empirical analysis” (p. 8).

A second issue concerns the task impurity problem (e.g., Miyake, Friedman, et al., 2000). Many measures of EF are relatively complex, involve a variety of component processes that may or may not be part of EF, and are sometimes also used to assess other cognitive processes. One example of such a task is verbal fluency. Verbal fluency tasks, sometimes termed *generative naming*, typically require the person to generate as many words as possible meeting a criteria in a set amount of time. Many variations of the standard letter fluency task have been developed including generating words beginning with a target letter, words belonging to a semantic category, items occurring in a supermarket, and so on. Counts of valid responses and various types of errors (e.g., perseverations and intrusions) are typically assessed.

First introduced by Borkowski, Benton, and Spreen (1967) and Benton (1968), measures of verbal fluency are frequently part of batteries designed to assess EF in adults and children and diagnosis mild cognitive impairment and dementia due to AD, PD, HIV/AIDS, or other disorders; verbal fluency measures are also used to assess semantic memory or word knowledge and the impact of strokes and other closed head injuries, developmental disorders, and clinical conditions on semantic processes.

Verbal fluency was traditionally assumed to correspond to more general notions of discourse fluency, although there is no widely agreed-on definition or measure of discourse fluency. *Discourse fluency* is commonly assumed to involve word retrieval, sentence formulation, and articulation processes and to be subject to lapses of attention, memory limitations, and motor and articulatory control problems. Discourse is marked by many types of dysfluencies: interjections, filled and unfilled pauses, and sentence fragments. *Fillers*, defined as speech serving to fill gaps in the speech flow, include both lexical and nonlexical fillers. Fillers may serve pragmatic and discourse functions (Fox Tree, 1995) or reflect word finding problems or other breakdowns in semantic retrieval, syntactic planning, or sentence production. Nonlexical fillers, such as “uh,” “umm,” “duh,” and so on, are also common (Bortfield, Leon, Bloom, Schober, & Brennan, 2000; Brennan & Schober, 2001; Ferber, 1991) and are generally considered

## 184 • DIMENSIONS OF COGNITIVE AGING

to reflect problems in sentence and discourse planning.

Some forms of dysfluency, such as unfilled pauses; circumlocutions; "empty speech," such as pronouns lacking clear referents; and substitution errors (substituting *he* for *she*) during spontaneous speech have also been noted in older adults and may reflect age-related impairments in accessing and retrieving lexical information (Obler, 1980; Ulatowska, Cannito, Hayashi, & Fleming, 1985). Burke, Worthley, and Martin (1988) observed that word finding problems are common in the speech of older adults and often result in tip-of-the-tongue experiences. Burke and her colleagues (Burke & Laver, 1990; Burke, MacKay, Worthley, & Wade, 1991) suggest that aging affects the ability to retrieve complete phonological information about words, resulting in the retrieval of partial phonological information characteristic of tip-of-the-tongue experiences.

Kemper and Sumner (2001) compared measures of verbal ability, including initial letter and category fluency measures, obtained from a group of young adults, 18 to 27 years of age, and a group of older adults, 63 to 88 years of age. For older adults, Kemper and Sumner found that initial letter fluency and category fluency were related to other measures of processing efficiency, such as reading rate. Processing efficiency appeared to impose general limitations on task performance by older adults, affecting how efficiently they can search their mental lexicon for words with the appropriate initial letter and how efficiently they can search their memory for answers to comprehension questions. In contrast, young adults' performance on the fluency tasks appeared to be constrained by their knowledge of lexical items as measured by vocabulary tests. Hence, verbal fluency tasks may measure semantic knowledge in young adults but processing efficiency or EF in older adults.

Mayr and Kliegl (2000) recently developed an approach to disentangle the semantic and executive components of fluency performance. In their task, fluency performance is audio-recorded. Interword response intervals are computed and modeled as a function of retrieval position:  $t_n = c + s \times n$ , where  $t_n$  is the time between the recall of word  $n - 1$  and word  $n$ ,  $c$  is a constant representing EF, and  $s$  is the slope representing the time

increment with every additional word recalled. According to Mayr and Kliegl's reasoning, the constant (intercept) of this function represents executive functions that support or enable semantic retrieval processes—such as systematic searching and avoiding perseverations and non-category intrusions. The slope parameter represents semantic retrieval processes.

They tested their view with a fluency task that included a manipulation of semantic retrieval difficulty by varying the frequency and familiarity of the categories and a manipulation of demands on EF by including both normal and "switching" versions of fluency tasks. This switching manipulation was motivated by a suggestion (Troyer, Moscovitch, & Winocur, 1997) that executive processes are particularly relevant in memory retrieval tasks that require switching between semantic clusters. Thus, participants were asked to produce category exemplars, either blocked by category in the typical way (e.g., animal, animal, animal, etc.) or alternating between two categories (e.g., animal, tool, animal, tool, animal, tool, etc.). They hypothesized that the category difficulty manipulation should affect the slope parameter, and the switching manipulations should affect the constant parameter. They also hypothesized that age differences in the constant parameter would indicate age differences in EF in fluency tasks, whereas age differences in the slope parameter would indicate age differences in semantic processes.

Mayr and Kliegl (2000) observed no age differences for the no-switch condition in the slope parameter, although the difficulty manipulation did affect slope as expected, but equally so for young and old adults. In contrast, there was a significant age difference in the constant parameter, assumed to reflect EF. "This pattern [supports] the assumption of no age effects in semantic processing (i.e., the slope parameter), but age sensitivity in non-semantic, executive processes" (Mayr & Kliegl, 2000, p. 36). These findings illustrate the importance of separating component processes in order to identify the ones underlying group differences in task performance. In the case of older adults in Mayr and Kliegl's study, EF appears to be responsible for the group differences in fluency performance.

It is interesting that the switch condition did not produce larger age differences in the

constant parameter than the no-switch condition. Mayr and Kliegl (2000) concluded that EF impairment specific to switching is not the source of age differences in fluency performance. They suggested that updating and set maintenance may be more likely candidates for age-impaired EF functions.

In summary, Mayr and Kliegl's (2000) approach and findings illustrate two important points. First, there are significant interpretive problems when task components are poorly understood, and task performance could be affected by any of them. Second, separate analysis of task components is very useful in identifying specific deficits. In the case of normal aging, fluency task performance deficits appear to be due more to EF deficits than to semantic memory differences. A somewhat different approach to disentangling semantic function and EF in verbal fluency has been taken by Troyer and her colleagues (Troyer et al., 1997; Troyer, Moscovitch, Winocur, Alexander, & Suss, 1998; Troyer, Moscovitch, Winocur, Leach, & Freedman, 1998; but see Mayr, 2002; Troster et al., 1998).

To demonstrate the feasibility of Mayr and Kliegl's (2000) approach to the analysis of fluency tasks, we have conducted a series of small pilot studies using available participant pools from the Parkinson's Center and the Center for Brain Aging at the University of Kansas Medical Center. Our first study was a small pilot study with 10 healthy older adults (mean age: 73.4 years; mean education: 15.2 years) and 10 older adults with Parkinson's disease (mean age: 72.8 years; mean education: 16.1 years). All participants with PD were taking Carbidopa-Levodopa; all were 5 to 6 years postinitial diagnosis and had Hoehn and Yahr (1967) scores of 1 or 2. None of the participants had a history of heart disease, cancer, neurological disorders, or alcoholism. All were native speakers of English. None were taking anticholinergics, antidepressants, or anxiolytics. There were 7 women and 3 men in the group of healthy older adults and 6 women and 4 men in the group with PD.

All participants were given four versions of a category verbal fluency test, modeled after those of Mayr and Kliegl (2000). They were: (1) an easy version requiring participants to name exemplars of familiar categories (e.g., birds, clothes, body parts, and colors), (2) a hard version requiring

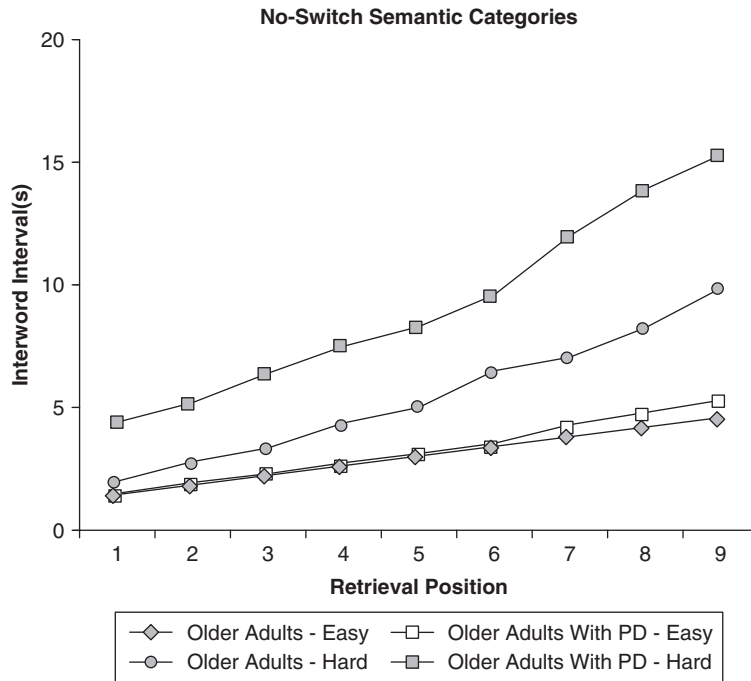
participants to name exemplars of unfamiliar categories (e.g., insects, writing utensils, fabrics, fluids), (3) an easy switching version requiring participants to name exemplars of two categories (e.g., birds alternating with body parts), and (4) a hard switching version requiring participants to name exemplars of two categories (e.g., writing utensils and fluids). Instructions and procedures followed those of Mayr and Kliegl with the exception that categories were presented on cue cards placed before the participants rather than on a computer monitor. All responses were digitally recorded for later analysis.

The results are summarized in Figures 11.1 and 11.2. The critical dependent measure is the interword response interval, timed from the offset of one response to the onset of the next response. Slopes and constant parameters from a linear regression analysis of these data are also presented.

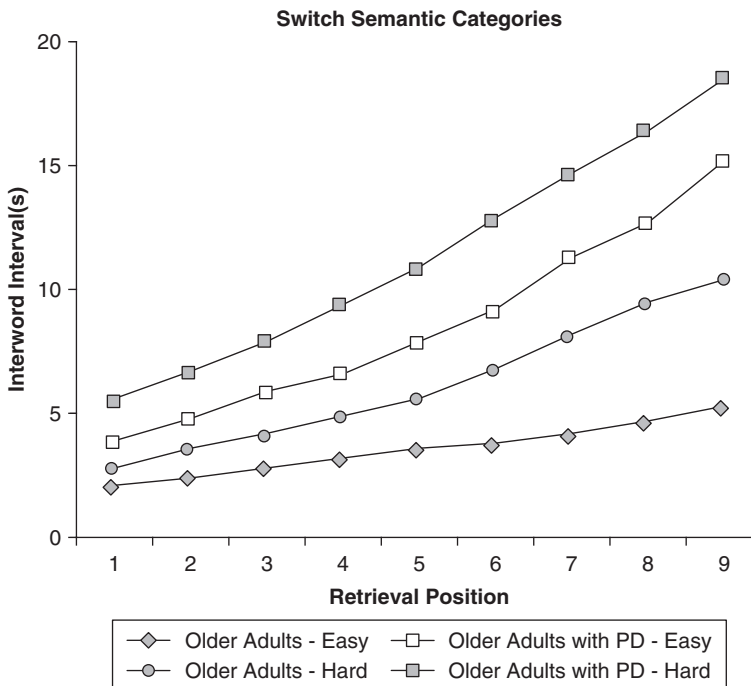
Mayr and Kliegl (2000) argued that the slope of these functions represents semantic search; we found that the slopes increased with task difficulty and that the slopes were greater for the participants with PD than for the healthy older adults, suggesting that PD does affect the efficiency of semantic processing. Mayr and Kliegl also argued that the constants represent nonsemantic EF; our results show that the constants increased with task difficulty and were greater for the participants with PD than the group of healthy older adults, suggesting executive functions also contribute to group differences in fluency performance.

To further explore this approach, we conducted a second pilot study with 30 healthy older adults and 30 older adults with PD. This study was designed to test the validity of Mayr and Kliegl's (2000) interpretation of slope and constant parameters. In this pilot, we regressed the participants' slopes and constants from the category fluency tests onto measures of EF and verbal ability. The selection of tests was dictated by individuals currently assessed by the Parkinson's Center; they do not provide an ideal test of our hypotheses. We hypothesized that the constant parameter should be associated with EF; that is, participants who score poorly on EF tests should have higher constants, if the constants reflect executive function. From the tests available, we selected the Wisconsin Card

186 • DIMENSIONS OF COGNITIVE AGING



**Figure 11.1** Interword Response Times for Easy and Hard Verbal Fluency Tests Administered to Healthy Older Adults and Older Adults With Parkinson’s Disease: No-Switch Condition



**Figure 11.2** Interword Response Times for Easy and Hard Verbal Fluency Tests Administered to Healthy Older Adults and Older Adults With Parkinson’s Disease: Switching Condition

Sorting test (Heaton et al., 1993) and the FAS fluency test (Spreen & Benton, 1977) as the measures of EF. In addition, the slope parameter might be expected to be related to vocabulary scores, which typically is indexed by verbal ability. Scores on the Shipley Institute of Living Scale vocabulary subtest (Shipley & Zachary, 1940), as well as years of formal education, were available for use as measures of verbal ability. In addition, a backward digit span test had been administered, and we considered this to be a measure of working memory. These hypotheses were tested in a group of 20 older adults and 8 older adults with PD. Mean performance levels on demographic, verbal ability, and EF variables are shown in Table 11.1.

Participants were tested on the easy and hard category fluency tests, described above, in both no-switching and switching conditions. The results are summarized in Table 11.2. Consistent with our previous findings, we found slope differences between easy and hard categories, reflecting ease of semantic retrieval; furthermore, slopes for healthy older adults were lower than those for individuals with PD, suggesting that PD does affect the efficiency of semantic retrieval.

We also found that the constants were greater for the switch conditions than for the no-switch conditions and greater for individuals with PD than for the healthy older adults, suggesting a breakdown of EF with PD.

We then defined a first-order factor for EF by loading scores for the FAS and Wisconsin Card Sorting tests onto a single factor. Two sets of regression analyses were then performed. In a test of our hypothesis that EF should be related to the constant parameter, we regressed the slopes and constants for the switching conditions onto the EF factor scores in Step 1 and then entered the verbal ability covariates (Shipley vocabulary score and years of education) in Step 2. In Step 3, we entered the working memory measure (backward digit span) and age.

The results are summarized in Table 11.3. The results of Step 1 indicate that individual variation in EF accounts for 6% to 18% (for healthy older adults) and 42% to 58% (for adults with PD) of the variance in the constants for the switching conditions but little ( $< .01$ – $.04$ ) of the variance in the slopes. Adding verbal ability to the regression models in Step 2 accounts for little additional variance in the constants (.02% – .05% increase in  $R^2$ ) but adds to the prediction of individual variation in the slopes; verbal ability accounts for a 10% to 60% increase in  $R^2$ . Adding the remaining covariates in Step 3 provided no additional increase in the fit of the regression equations. We also reversed the order of entry, entering the verbal ability measures in Step 1 and the EF measures in Step 2, with similar results: The verbal ability measures accounted for 25% to 35% of the variance in the slopes for the switching trials in Step 1 but only

**Table 11.1** Comparison of the Healthy Older Adults and Older Adults With Parkinson's Disease Who Participated in the First Pilot Study

	<i>Healthy older adults</i>		<i>Older adults with Parkinson's disease</i>	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<i>Variable</i>				
Age	75.7	4.3	73.3	5.7
Education	17.2	3.2	14.6	2.3
Shipley Vocabulary	32.9	5.2	29.6	6.8
Backward digit span	6.9	2.1	7.0	1.2
FAS Verbal Fluency	36.4	14.5	38.2	12.8
Wisconsin Card Sorting				
Categories	2.5	1.5	1.3	1.5
Total errors	21.2	10.4	29.5	13.1

## 188 • DIMENSIONS OF COGNITIVE AGING

**Table 11.2** Comparison of the Easy and Hard Verbal Fluency Tests Administered to Healthy Older Adults and Older Adults With Parkinson's Disease and Alzheimer's Disease

	<i>Slopes</i>				<i>Constants</i>			
	<i>No switch</i>		<i>Switch</i>		<i>No switch</i>		<i>Switch</i>	
	<i>Easy</i>	<i>Hard</i>	<i>Easy</i>	<i>Hard</i>	<i>Easy</i>	<i>Hard</i>	<i>Easy</i>	<i>Hard</i>
<i>Participant</i>								
Healthy older adults	0.69	1.95	0.43	1.36	-1.00	-0.16	0.46	0.74
Older adults with Parkinson's disease	1.16	2.39	0.17	2.56	-1.90	-0.41	0.43	2.74
Older adults with Alzheimer's disease	1.74	4.12	2.10	5.54	1.76	2.22	1.95	3.88

**Table 11.3** Results of the Regression Analysis (Total  $R^2$ ) of the Slopes and Constants Obtained From the Easy and Hard Switching Fluency Tests

	<i>Healthy older adults</i>		<i>Older adults with Parkinson's disease</i>	
	<i>Slope</i>	<i>Constant</i>	<i>Slope</i>	<i>Constant</i>
<i>Step</i>				
Step 1: Executive function				
Easy categories	.06	.06	.02	.42
Hard categories	.14	.18	0.8	.58
Step 2: Verbal ability				
Easy categories	.27	.10	.03	.52
Hard categories	.41	.22	.13	.61

0% to 8% of the variance in the constants, and the EF measures accounted for 15% to 46% additional variance in the constants in Step 2 but only 2% to 5% additional variance in the slopes.

We also conducted a third pilot study with 8 AD patients recruited from the Brain Aging Center. All participants with AD were taking Aricept, and 5 of the 8 were also taking Nemenda; all were judged to have mild to moderate AD. None of the participants had a history of heart disease, cancer, other neurological disorders, or alcoholism. All were native speakers of English. None were taking anticholinergics, antidepressants, or anxiolytics. We administered the same easy and hard category fluency tests

given in our second pilot study; however, we were constrained in our choice of covariates to those currently assessed by the Brain Aging Center. The Wisconsin Card Sorting task was not administered; however, the Trail Making Test (Reitan & Wolfson, 1995) was administered, so we used the proportional difference score (Test A - Test B/Test A) as a measure of EF ( $M = -0.68$ ,  $SD = 0.55$ ). The Boston Naming Test (Kaplan, Goodglass, & Weintraub, 2001;  $M = 11.63$ ,  $SD = 16.69$ ), rather than the Shipley vocabulary test, was available as a measure of verbal ability, along with education ( $M = 17.4$ ,  $SD = 3.2$ ). Backward digit span scores ( $M = 5.4$ ,  $SD = 1.5$ ) and age ( $M = 76.0$ ,  $SD = 6.7$ ), as well



as an overall rating of dementia severity (Mini-Mental Status Examination [Folstein, Folstein, & McHugh, 1975];  $M = 24.5$ ,  $SD = 5.3$ ) were also available and entered in Step 3.

The slopes and constants from the category fluency tests for the older adults with AD are also presented in Table 11.2. The slopes for older adults with AD were greater than those for healthy older adults as well as those for older adults with PD, confirming our hypothesis that AD affects the efficiency of semantic retrieval. We also found an effect of AD on the constants, indicating that AD also affects the efficiency of EF (see Ullman et al., 1997).

The results of the regression analysis are summarized in Table 11.4. In Step 1, we entered the EF measure, the proportional difference score from the Trail Making Test. In Step 2, we entered the verbal ability measures, the Boston Naming Test and education. In Step 3, we entered age, backward digit span, and Mini-Mental State Examination score. The results of Step 1 indicate that individual variation in EF accounts for much (48%–75%) of the variance in the constants for the switching conditions but less (24%–28%) of the variance in the slopes. Adding verbal ability to the regression models in Step 2 accounts for little additional variance in the constants but adds to the prediction of individual variation in the slopes; verbal ability accounts for a 10% to 60% increase in  $R^2$ . Adding the remaining covariates in Step 3 provided little additional increase in the fit of the regression equations. We also reversed

the order of entry, entering the verbal ability measures in Step 1 and the EF measures in Step 2, with similar results: The verbal ability measures accounted for much (49%–74%) of the variance in the slopes for the switching trials in Step 1 but only 10% to 15% of the variance in the constants, and the EF measures accounted for 38% to 54% additional variance in the constants in Step 2 but only 3% to 16% additional variance in the slopes.

In comparing the results of our regression analysis of fluency task performance by individuals with AD and PD we note that the EF and verbal abilities covariates account for considerably more variance in the performance of the older adults with AD on the switch trials than for the older adults with PD. Much of the variance in the constants for the older adults with PD remains unexplained. It is likely that unmeasured variance in the severity of PD may contribute to the variance in the slopes on the switch trials.

Together, this series of pilot studies supports the validity of Mayr and Kliegl's (2000) analysis of the components of fluency tasks; although very preliminary, our findings indicate a dissociation of verbal and executive functions in fluency task performance in terms of their relation to the slope and intercept parameters derived from the fluency task data. In addition, these results show that this approach of decomposing EF tasks, in this case fluency tasks, can lead to a better understanding of the component cognitive processes that affect performance in those tasks. These results also demonstrate how this approach will advance our understanding of AD and PD by revealing how these age-associated diseases affect semantic processes and EF.

## CONCLUSION

Decomposing fluency tasks into their component processes may provide an answer to Rabbitt's (1997) lament (see p. 183, this chapter): Life would be easier.

Life would be easier because verbal fluency tasks may be sensitive tests of EF for use in clinical contexts as well as for population-based assessments of cognition. Impairments of EF have been linked to functional impairments (Cahn-Weiner, Malloy, Boyle, Marran, & Salloway,

**Table 11.4** Results of the Regression Analysis (Total  $R^2$ ) of the Slopes and Constants Obtained From the Easy and Hard Switching Fluency Tests: Older Adults With Alzheimer's Disease

Step	Slope	Constant
Step 1: Executive function		
Easy categories	.28	.48
Hard categories	.24	.73
Step 2: Verbal ability		
Easy categories	.38	.59
Hard categories	.74	.75

## 190 • DIMENSIONS OF COGNITIVE AGING

2000; Carlson et al., 1999; Farias, Harrell, Neumann, & Houtz, 2003; Grigsby, Kaye, Baxter, Shetterly, & Hamman, 1998; Royall, Palmer, Chiodo, & Polk, 2004), although the lack of an easily administered “gold standard” for EF has hindered research on this issue.

The traditional FAS verbal fluency test is commonly included with the Wisconsin Card Sorting Task and the Trail Making Test in neuropsychological test batteries. Although the Wisconsin Card Sorting Task has been used extensively, it is time consuming to administer and score, although computerized versions are available. The Trail Making Test is also widely used, and it is easily administered. However, both Wisconsin Card Sorting Task and Trail Making Test lack convergent and discriminant validity. No-switching and switching fluency tests could be easily automated using existing voice recognition techniques, making these tests suitable for administration in clinical settings using only an audio- or video-recorder. Our pilot studies suggest that the decomposition of interword response times, particularly on switching trials, may discriminate among the effects of aging, PD, and AD on semantic and executive processes.

Life would also be easier because this approach provides a significant guidepost to the future of cognitive aging studies. For far too long we have relied on cognitive and neuropsychological tests of dubious construct validity. We have failed to bring to bear the vast armature of contemporary cognitive psychology to the task of decomposing these tasks into their component processes. Parameterizing task performance—into slopes and intercepts, time–accuracy functions, Rasch scaling, or other techniques—will yield a new generation of tests that can provide insights into the differential effects of aging and clinical conditions; clarify neuroimaging findings regarding brain–behavior linkages; and advance our understanding of functional status, care needs, and rehabilitation outcomes.

Life would be easier because parameterized verbal fluency tests could add a new level of sophistication to large, population-based studies of health and cognition. Currently, cognition is assessed by tests such as immediate and delayed word recall, counting backward, identifying words from definitions, and subtracting 7s. Switching and no-switching fluency tests

coupled with the automated analysis of interword response times could help identify how population demographics and health status affect verbal/semantic processes versus EF. Indeed, automatic speech recognition could add a new dimension to existing test batteries by permitting automatic scoring of verbal responses as well as the measurement of response times. The Center for Spoken Language Understanding makes available a toolkit of techniques to map speech input onto text output. Using these techniques, it is possible to approximate human speech recognition under ideal circumstances with around 90% accuracy; higher rates of accuracy can be obtained by training the systems on the acoustic characteristics of individual speakers, groups of speakers (e.g., elderly speakers) or models of accented speech. Further accuracy can be gained by limited word or response sequences and lexical inventories and limited environmental or system noise. These techniques are now capable of running in real time on desktop computers. It is further possible to develop add-ons that measure pause duration and interword response times (Hosom, Shriberg, & Green, 2004). Tools such as the Coh-Mex system of Graesser, McNamara, Louwerse, and Chai (2004) are now available to perform extensive text-based analyses, statistical analyses of word frequencies, extract measures of coherence, syntactic complexity, and semantic content. These technologies are now available, and their application could open up new approaches to clinical and population-based assessments of health and cognition.

## REFERENCES

- Benton, A. L. (1968). Differential behavioral effects of frontal lobe disease. *Neuropsychologia*, *6*, 53–60.
- Borkowski, J., Benton, A., & Spreen, O. (1967). Word fluency and brain damage. *Neuropsychologia*, *5*, 135–140.
- Bortfield, H., Leon, S. D., Bloom, J. E., Schober, M. F., & Brennan, S. E. (2000). Disfluency rates in spontaneous speech: Effects of age, relationship, topic, role, and gender. *Memory and Language*, *44*, 123–147.
- Brennan, S. E., & Schober, M. F. (2001). How listeners compensate for disfluencies in spontaneous speech. *Memory and Language*, *45*, 274–296.
- Burke, D. M., & Laver, G. D. (1990). Aging and word retrieval: Selective age deficits in language. In

- E. A. Lovelace (Ed.), *Aging and cognition: Mental processes, self-awareness, and interventions* (pp. 281–300). New York: Elsevier–North Holland.
- Burke, D. M., MacKay, D. G., Worthley, J. S., & Wade, E. (1991). On the tip of the tongue: What causes word finding failures in young and older adults. *Journal of Memory and Language, 30*, 542–579.
- Burke, D., Worthley, J., & Martin, J. (1988). I'll never forget what's-her-name: Aging and the tip of the tongue experience in everyday life. In M. M. Gruneberg, P. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory: Current research and theory* (Vol. 2, pp. 113–118). Chichester, UK: Wiley.
- Cahn-Weiner, D. A., Malloy, P. F., Boyle, P. A., Marran, M., & Salloway, S. (2000). Prediction of functional status from neuropsychological tests in community-dwelling elderly individuals. *The Clinical Neuropsychologist, 14*, 187–195.
- Carlson, M., Fried, L., Xue, Q., Bandeen-Roche, K., Zeger, S., & Brandt, J. (1999). Association between executive attention and physical functioning performance in community-dwelling older women. *Journal of Gerontology: Social Sciences, 54B*, 262–270.
- Farias, S., Harrell, E., Neumann, C., & Houtz, A. (2003). The relationship between neuropsychological performance and daily functioning in individuals with Alzheimer's disease: Ecological validity of neuropsychological tests. *Archives of Clinical Neuropsychology, 18*, 655–672.
- Ferber, R. (1991). Slip of the tongue or slip of the ear? On the perception and transcription of naturalistic slips of the tongue. *Journal of Psycholinguistic Research, 20*, 105–122.
- 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.
- Fodor, J. A. (1982). *Modularity of mind*. Cambridge: MIT Press.
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). *Mini-Mental State Examination*. Lutz, FL: Psychological Assessment Resources.
- Fox Tree, J. E. (1995). The effects of false starts and repetitions on the processing of subsequent words in spontaneous speech. *Journal of Memory and Language, 34*, 709–738.
- Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General, 133*, 101–135.
- Graesser, A. C., McNamara, D. S., Louwerse, M. M., & Chai, Z. (2004). Coh-Metrix: Analysis of text cohesion and language. *Behavior Research Methods, Instruments, and Computers, 36*, 193–202.
- Grigsby, J., Kaye, K., Baxter, J., Shetterly, S., & Hamman, R. (1998). Executive cognitive abilities and functional status among community-dwelling older persons in the San Luis Valley Health and Aging Study. *Journal of the American Geriatrics Society, 46*, 590–596.
- Heaton, R. K., Chelune, G. J., Talley, J. L., Kay, G. G., & Curtis, G. (1993). *Wisconsin Card Sorting Test (WCST) manual, revised and expanded*. Odessa, FL: Psychological Assessment Resources.
- Hoehn, M., & Yahr, M. (1967) Parkinsonism, onset, progression and mortality. *Neurology, 17*, 427–442.
- Hofer, S. M., Flaherty, B. P., & Hoffman, L. A. (2007). Cross-sectional analysis of time-dependent data: Mean-induced association in age-heterogeneous samples and an alternative method based on sequential narrow age-cohort samples. *Multivariate Behavioral Research, 41*, 165–187.
- Hofer, S. M., & Sliwinski, M. J. (2001). Understanding ageing: An evaluation of research designs for assessing the interdependence of ageing-related changes. *Gerontology, 47*, 341–352.
- Hosom, J. P., Shriberg, L., & Green, J. R. (2004). Diagnostic assessment of childhood apraxia of speech using automatic speech recognition (ASR) methods. *Journal of Medical Speech-Language Pathology, 12*, 167–171.
- Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99*, 122–149.
- Kanne, S. M., Balota, D. A., & Storandt, M. (1998). Relating anatomy to function in Alzheimer's disease: Neuropsychological profiles predicting regional neuropathology 5 years later. *Neurology, 50*, 979–985.
- Kaplan, E. F. Goodglass, H., & Weintraub, S. (2001). *The Boston Naming Test* (2nd ed.). Philadelphia: Lippincott Williams, & Wilkins.
- Kemper, S., & Sumner, A. (2001). The structure of verbal abilities in young and older adults. *Psychology and Aging, 16*, 312–322.
- Loewenstein, D. A., Ownby, R., Schram, L., Acevedo, A., Rubert, M., & Argueelles, T. (2001). An evaluation of the NINCDA–ADRDA

## 192 • DIMENSIONS OF COGNITIVE AGING

- neuropsychological criteria for the assessment of Alzheimer's disease: A confirmatory factor analysis of single versus multi-factor models. *Journal of Clinical and Experimental Neuropsychology*, 23, 274–284.
- 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 and Aging*, 15, 29–43.
- Miyake, A., Emerson, M. J., & Friedman, N. P. (2000). Assessment of executive functions in clinical settings: Problems and recommendations. *Seminars in Speech and Language*, 21, 169–183.
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, 41, 49–100.
- Obler, L. K. (1980). Narrative discourse style in the elderly. In L. K. Obler & M. L. Albert (Eds.), *Language and communication in the elderly* (pp. 75–90). Lexington, MA: Heath.
- Rabbitt, P. (1997). Introduction: Methodologies and models in the study of executive function. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 1–38). Hove, UK: Psychology Press.
- Reitan, R. M., & Wolfson, D. (1995). Category Test and Trail Making Test as measures of frontal lobe functions. *Clinical Neuropsychologist*, 9, 50–56.
- Royall, D. R., Chiodo, L. K., & Polk, M. J. (2003). Executive dyscontrol in normal aging: Normative data, factor structure, and clinical correlates. *Current Neurology and Neuroscience Reports*, 3, 487–493.
- Royall, D. R., Lauterbach, E. C., Cummings, J. L., Reeve, A., Rummans, T. A., Kaufer, D. I., et al. (2002). Executive control function: A review of its promise and challenges for clinical research. *Journal of Neuropsychiatry and Clinical Neuroscience*, 14, 377–405.
- Royall, D. R., Palmer, R., Chiodo, L., & Polk, M. (2004). Declining executive control in normal aging predicts change in functional status: The Freedom House study. *Journal of the American Geriatrics Society*, 52, 346–352.
- Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology: General*, 132, 566–594.
- Shipley, W. C., & Zachary, R. A. (1940). *Shipley Institute of Living Scale*. Los Angeles: Western Psychological Services.
- Spreeen, O., & Benton, A. L. (1977). *Neurosensory Center Comprehensive Examination for Aphasia*. Victoria, BC: Neuropsychology Laboratory, University of Victoria.
- Troster, A., Fields, J. A., Testa, J. A., Paul, R. H., Blanko, C. R., Hames, K. A., et al. (1998). Cortical and subcortical influences on clustering and switching in the performance of verbal fluency tasks. *Neuropsychologia*, 36, 295–304.
- 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., & Suss, D. (1998). 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. (1998). Clustering and switching on verbal fluency tests in Alzheimer's and Parkinson's disease. *Journal of the International Neuropsychological Society*, 4, 137–143.
- Ulatowska, H. K., Cannito, M. P., Hayashi, M. M., & Fleming, S. G. (1985). Language abilities in the elderly. In H. K. Ulatowska (Ed.), *The aging brain: Communication in the elderly* (pp. 125–139). San Diego, CA: College-Hill.
- Ullman, M. T., Corkin, S., Coppola, M., Hickok, G., Growdon, J. H., Koroshetz, W. J., et al. (1997). A neural dissociation within language: Evidence that the mental dictionary is part of declarative memory, and that grammatical rules are processed by the procedural system. *Journal of Cognitive Neuroscience*, 9, 266–276.
- Waters, G. S., & Caplan, D. (1996). The capacity theory of sentence comprehension: Critique of Just and Carpenter (1992). *Psychological Review*, 103, 761–772.
- Zelinski, E. M., & Lewis, K. L. (2003). Adult age differences in multiple cognitive functions: Differentiation, dedifferentiation, or process-specific change? *Psychology and Aging*, 18, 727–745.