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Mental Flexibility: Age Effects on Switching

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Mental flexibility is required to track and systematically alternate between 2 response sets. In this study, 719 individuals, 20 to 89 years old, engaged in 3 different tasks that required verbal and nonverbal cognitive switching. Of importance, each task allowed for independent measurement of component skills that are embedded in the higher level tasks. When gender, education, Full Scale IQ, and component skills were partialed out by multiple regression analyses, significant age effects were revealed for each task. This study provides evidence that executive functions—and verbal and nonverbal cognitive switching in particular—are affected by age independently from age-related changes in component skills. The results are discussed in terms of theories of executive control and neurologic correlates across the adult life span.

Keywords: executive function, aging, switching, mental flexibility

Executive functions are considered higher order mental operations involved with the maintenance, manipulation, planning, monitoring, and regulation of other cognitive processes, such as language, perception, and memory (Stuss & Benson, 1986). Although there is no consensus on how to best define executive functions, abilities such as self-regulation, sequencing of behavior, mental flexibility, response inhibition, planning, organization, and the ability to initiate, maintain, switch, and stop sequences of complex behavior are generally included (Eslinger, 1996; Lezak, 1995).

The ability to switch between different stimuli or response sets is a widely used exemplar of executive functioning (see discussion in Baddeley, Chincotta, & Adlam, 2001). Switching entails both the flexibility and control to disengage from a previous response in favor of a novel or alternate response. Dual-task and alternating response paradigms have been devised to attempt to capture these mental capacities. One of the most widely used clinical measures of executive functioning, the Trail Making Test (Reitan & Wolfson, 1985; Spreen & Strauss, 1998), uses an alternating response paradigm by requiring examinees to serially alternate between overlearned number and letter sequences.

The relationship between switching and age has been a matter of some dispute. Some investigators have noted age declines on switching tasks, whereas others have not (Hartley & Little, 1999; Salthouse et al., 2000; Wecker, Kramer, Wisniewski, Delis, & Kaplan, 2000); still others have had mixed results (Kray & Lindenberger, 2000). Some of the discrepancy in findings is likely due to differences in definitions, measurement, and method of analysis. Furthermore, the multifaceted nature of executive function tasks makes age comparisons challenging because performance on lower level skills required to perform the complex task may confound results, particularly when performance is collapsed into a single score. For example, the ability to draw lines quickly that serially alternate between number and letter sequences depends not only on executive ability but also on visual scanning, hand–eye coordination, ability to count, facility with the alphabet, sustained attention, motor speed, and other skills. A deficit in any of these more basic skills will lower performance on the executive function task, regardless of how preserved executive functioning might be. Thus, delineating and establishing scores reflecting component skills on complex tasks is imperative in order to interpret the target behavior (Levine, Stuss, & Milberg, 1995) and the source of between-groups differences (Baddeley, Bressi, Della Sala, Logie, & Spinnler, 1991; Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986).

Our main purpose in this study was to determine whether there are age effects on cognitive switching. We assessed the ability to switch under multiple conditions, including verbal fluency, design fluency, and serial alternation between automatized sequences. To more meaningfully evaluate the relationship between age and the executive function of cognitive flexibility, we first factored out component skills embedded in each task, such as perceptual speed, motor speed, and fluency. Our primary hypothesis was that the ability to engage in set-switching tasks declines with age, even after component skills are adequately controlled for.

Method

Participants

Data were obtained from adults participating in the standardization study of the Delis–Kaplan Executive Function System (D-KEFS; Delis, Kaplan,

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& Kramer, 2001). There were 719 participants (343 men and 376 women) between the ages of 20 and 89 years. The sample was recruited to be representative of the U.S. population according to the 2000 United States Census. The sample was divided into seven age groups by decade, with the following number of participants in each group: 20–29 (n = 155), 30–39 (n = 129), 40–49 (n = 74), 50–59 (n = 68), 60–69 (n = 104), 70–79 (n = 114), and 80–89 (n = 77). The mean age was 50.96 years (SD = 21.10 years). Gender, race or ethnicity, years of education, and geographic region were stratified by age group. The sample was 9.3% African American, 5.1% Hispanic, 84% White, and 1.5% other. In terms of education, 5.7% had less than or equal to 8 years, 10.8% had 9–11 years, 36.3% had 12 years, 26.6% had 13–15 years, and 20.6% had 16 or more years. Exclusionary criteria were lack of English fluency; self-report of at least one medical or psychiatric symptom or condition that may affect cognitive performance (e.g., uncorrected hearing loss or visual impairment, cerebral vascular disease, encephalitis, progressive neurologic conditions, epilepsy, history of loss of consciousness for 5 min or longer, head injury resulting in hospitalization); substance abuse (consumption of three alcoholic beverages on 2 or more days a week); history of cognitive or memory complaints, learning disabilities, schizophrenia, and bipolar disorder; and extant use of antidepressants, antianxiety medications, or antipsychotic medications.

Materials and Procedures

All participants completed the Wechsler Abbreviated Intelligence Scale (Wechsler, 1999) and the D-KEFS (Delis et al., 2001) in randomized order. Testing was typically completed in a single session.

Three tests from the D-KEFS incorporated conditions requiring set switching: Trail Making, Design Fluency, and Verbal Fluency. These tests, and assessment of the more fundamental component skills, are described below.

The D-KEFS Trail Making Test was modeled after the traditional Trail Making Test (see review of test history in Delis et al., 2001; Reitan & Wolfson, 1985), with some important modifications. The traditional Trail Making Test has two conditions: Part A, which requires the serial connection of the numbers 1 through 25, and Part B, which requires serial alternation between number and letter sequences. Interrater reliability has been reported as .94 on Part A and .90 on Part B (Spreen & Strauss, 1998). Test–retest reliability is influenced by time interval, population, and other factors and ranges from .36 to .98 on Part A to .63 to .86 on Part B (Spreen & Strauss, 1998).

Although Part A is designed to serve as a control condition for the set-switching demands of Part B, the ability of Part A to do so is limited by significant differences between the two stimuli besides the alternating aspect (Crowe, 1998; Gaudino, Geisler, & Squires, 1995). The stimulus page for Part B includes numbers and letters, and the task involves switching back and forth between the two sequences. The traditional Part A, however, has only numbers on the page, and there are fewer stimuli to scan, fewer lines to draw, and no controls for how well examinees process letter sequences. To address these limitations, the D-KEFS Trail Making Test contains both number sequencing and letter sequencing conditions that are completed prior to the switching condition. In addition, the stimulus pages for the number sequencing and letter sequencing conditions contain both numbers and letters, and taken together, the two conditions match the switching condition well in terms of the number of stimuli to visually scan and the number of lines that need drawing. Test administration is similar to the traditional Trail Making Test. Errors are brought to the attention of the examinee, and the examinee is instructed to return to the last correct placement and continue from there. Time to completion is the score for each condition.

The category naming sections of the D-KEFS Verbal Fluency Test used in the present study have their origins in similar tests dating back to 1969 (Spreen & Strauss, 1998). The interrater reliability for category fluency tasks is "nearly perfect" (Spreen & Strauss, 1998, p. 449). The retest coefficients vary between .70 and .88 depending on population and period of time elapsed (Spreen & Strauss, 1998).

The D-KEFS Verbal Fluency Test contains two category fluency trials and a single switching condition. The category fluency trials are administered first and require examinees to generate as many category exemplars (animals and boys' names) as possible. Test–retest reliability for category fluency is .79 (Delis et al., 2001). The switching condition evaluates the examinee's ability to generate exemplars while alternating between two different semantic categories (fruits and furniture). Selection of the categories was based on generation data collected on 154 nonimpaired participants. Because the category fluency and switching conditions have alternate forms, categories were selected so that the two forms were well matched on the mean number of exemplars generated. In each verbal fluency condition, the score is the total number of correct responses generated in 60 s.

The D-KEFS Design Fluency Test is a nonverbal analog to the Verbal Fluency Test. The component condition uses stimuli identical to that of the switching condition. There are rows of stimulus boxes that have an array of 10 dots in each, requiring the examinee to construct unique designs by connecting dots using only four straight lines. In each condition, the stimulus response box contains five filled dots and five empty dots (see Figure 1). In the control condition, examinees are asked to generate as many unique designs as possible in 60 s by drawing lines connecting unfilled dots. In the switching condition, examinees are asked to generate as many unique designs as possible in 60 s by drawing lines alternating between filled and unfilled dots. The score for each condition is the total number of correct designs created in 60 s. In both of these conditions, distinguishing between the two different types of dots and determining their integration into or omission from the design are required. In the switching condition, all 10 dots are available to be integrated into designs, presenting more options as well as the added challenge of making choices. Another component task of the Design Fluency Test available in the D-KEFS includes only 10 filled dots in each box. Although the visual presentation is obviously different between it and the switching condition, which comprises filled and empty dots, the choice availability is thus

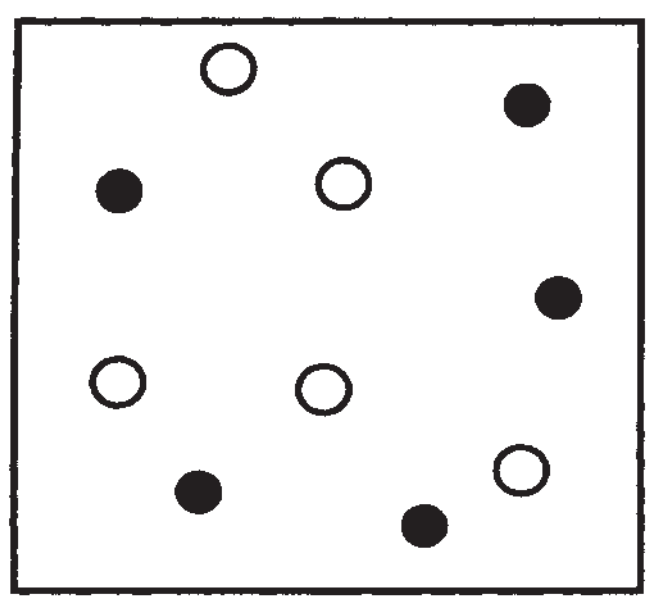

Figure 1. Example of a Design Fluency Test stimulus box (Delis et al., 2004). *Delis–Kaplan Executive Functioning Inventory.* Copyright © 2001 by Harcourt Assessment, Inc. Reproduced by permission. All rights reserved.

similar in that all the dots can be used in the creation of designs. Although aspects of both of the component tasks are embedded in the switching task, the uniqueness of the switching demand is best displayed in relation to the component task that has similarity of stimuli.

Results

The results for all component and switching test measures for the 719 participants grouped by decade are summarized in Table 1, including the means, standard deviations, and ranges of scores.

Our purpose in this study was to determine the age effect on set-switching tasks. First, we performed single-factor regression analyses to determine the amount of age-related variance in each switching task (without controlling for other variables). Next, to explain how much of the variance was uniquely explained by age, we used a multistage forced-entry linear regression approach. In each regression model, the dependent variable was performance on the switching condition. In an initial baseline model, we entered the demographic variables of gender, education, and Full Scale IQ. In the second step, we entered results of performance on the component conditions pertinent to that task. Age as a continuous variable was added as a predictor in the third and final step. Although linear regression was the primary focus, quadratic relationships were also inspected for comparison. The hypothesis that age adversely affects the ability to engage in set switching would be supported if age accounted for a significant increase in the explained variance after controlling for demographics and the component tasks.

Results of the D-KEFS Trail Making Test are summarized in Table 2. The first line of the table shows that age as the sole predictor of switching predicted a significant 32.7% ($p < .01$) of

Table 1
Means, Standard Deviations, and Ranges of Scores for Component and Switching Tasks by Age Group

Age group (years) and measure	Trail Making Test			Verbal Fluency Test		Design Fluency Test	
	Number seq.	Letter seq.	Switch	Animal naming	Switch	Unfilled dots	Switch
20–29 (n = 155)							
M	29.08	28.51	68.05	20.01	12.20	10.98	8.36
SD	9.93	10.21	26.80	4.52	3.31	3.71	3.00
Minimum	13.00	10.00	24.00	8.00	1.00	0.00	0.00
Maximum	59.00	65.00	181.00	31.00	19.00	22.00	15.00
30–39 (n = 129)							
M	31.04	30.55	75.32	20.46	12.79	10.87	7.98
SD	10.41	12.24	32.39	4.19	3.17	3.46	2.76
Minimum	13.00	14.00	30.00	8.00	2.00	4.00	0.00
Maximum	66.00	105.00	216.00	33.00	23.00	18.00	14.00
40–49 (n = 74)							
M	31.72	32.22	80.99	19.84	12.99	10.27	7.26
SD	12.12	12.01	33.72	4.26	3.75	4.13	3.50
Minimum	15.00	15.00	36.00	10.00	0.00	0.00	0.00
Maximum	73.00	74.00	203.00	30.00	21.00	18.00	15.00
50–59 (n = 68)							
M	37.90	38.84	90.88	18.32	12.01	10.72	7.37
SD	14.73	14.78	40.19	4.34	2.81	3.41	2.67
Minimum	15.00	16.00	42.00	10.00	4.00	2.00	0.00
Maximum	93.00	103.00	240.00	29.00	18.00	20.00	12.00
60–69 (n = 104)							
M	46.77	48.93	111.34	17.14	11.54	8.97	6.15
SD	17.79	20.56	44.15	4.24	3.08	2.96	2.60
Minimum	17.00	18.00	38.00	6.00	2.00	0.00	0.00
Maximum	100.00	150.00	240.00	25.00	18.00	16.00	12.00
70–79 (n = 112)							
M	55.05	56.92	123.21	16.25	10.90	8.21	5.44
SD	19.12	25.17	50.97	3.82	3.29	3.27	2.68
Minimum	23.00	23.00	50.00	7.00	0.00	0.00	0.00
Maximum	109.00	150.00	240.00	26.00	17.00	16.00	11.00
80–89 (n = 77)							
M	64.47	74.43	160.17	14.58	9.55	7.12	4.43
SD	25.25	31.12	53.54	3.80	3.55	2.68	2.24
Minimum	16.00	25.00	37.00	6.00	0.00	3.00	0.00
Maximum	150.00	202.00	240.00	23.00	17.00	15.00	9.00
Total (n = 719)							
M	40.93	42.53	97.56	18.33	11.79	9.73	6.89
SD	19.95	23.94	49.52	4.64	3.42	3.67	3.10
Minimum	13.00	10.00	24.00	6.00	0.00	0.00	0.00
Maximum	150.00	202.00	240.00	33.00	23.00	22.00	15.00

Note. Trail Making Test number sequencing, letter sequencing, and switching are shown as time to completion in seconds, Verbal Fluency Test animal naming and switching are shown as total number of correct responses, and Design Fluency Test unfilled dots and switching are shown as total number of correct designs. seq = sequencing; Switch = switching.

Table 2
Summary of Single- and Multiple-Variable Regression Analyses Predicting Trail Making Test Switching

Predictor	R^2	ΔR^2	ΔF	*df*s	*p*
Age[a]	.327	.327	348.36		<.01
Multiple regression					
Step 1: Education, gender, IQ	.132	.132	36.34	3, 715	<.01
Step 2: Education, gender, IQ, number sequencing, letter sequencing	.562	.430	349.55	2, 713	<.01
Step 3: Education, gender, IQ, number sequencing, letter sequencing, age	.592	.030	52.95	1, 712	<.01

[a] Age-related variance without controlling for demographic and component tasks.

the variance. Next, the multiple regression analyses in three steps are given. In the first step, gender, education, and Full Scale IQ accounted for 13.2% of the variance, $F(3, 715) = 36.34$, $p < .01$. In the second step, the two component tasks, sequencing and letter sequencing, accounted for an additional 43% of the variance, $\Delta F(2, 713) = 349.55$, $p < .01$. In the third step, age accounted for an additional 3% of the variance, $\Delta F(1, 712) = 52.95$, $p < .01$, with greater age associated with longer times required to complete the switching condition ($\beta = .24$). Quadratic analyses made no appreciable difference compared with linear analyses.

Data from the Verbal Fluency Test are summarized in Table 3. Age as the sole predictor of Verbal Fluency switching was significant, explaining 6% ($p < .01$) of the variance. In the first step of the multiple regression model, 10% of the variance in the switching condition was accounted for by demographic variables, $F(3, 714) = 26.40$, $p < .01$. In the second step, the component task, Category Fluency, accounted for an additional 7.5% of the variance, $\Delta F(2, 711) = 65.04$, $p < .01$. In the third step, age accounted for an additional 2.1% of the variance, $\Delta F(1, 711) = 18.88$, $p < .01$, with greater age associated with fewer correct responses on the switching condition ($\beta = -.17$). Quadratic analyses for this switching task indicated 4.3% additional variance explained by age after controlling for the demographics and component tasks, compared with the 2.1% using linear analyses.

Results of the Design Fluency Test are summarized in Table 4. Age as the sole predictor accounted for 17.6% ($p < .01$) of Design Fluency switching. In the first step of the multiple regression analyses, gender, education, and Full Scale IQ accounted for 8.3% of the variance, $F(3, 714) = 21.52$, $p < .01$. In the second step, the component task, Connecting Unfilled Dots, accounted for an additional 19.3% of the variance, $\Delta F(1, 713) = 189.53$, $p < .01$. In the third step, age accounted for an additional 8.7% of the variance, $\Delta F(1, 712) = 96.86$, $p < .01$, with greater age associated with fewer correct responses on the switching condition ($\beta = -.33$). Quadratic relationships were not a better fit for this task.

Three scatter plots of the residuals after Steps 1 and 2 of the regression analyses are presented along with the best-fit regression lines. Figure 2 (top) is the linear regression line for the Trail Making Test; Figure 2 (middle) is the quadratic regression for the Verbal Fluency Test; and Figure 2 (bottom) is the linear regression for the Design Fluency Test.

Pearson's product–moment correlations revealed that the switching tasks were all significantly correlated ($p < .01$) with one another. Trail Making Test switching correlated $-.38$ with Verbal Fluency switching and $-.48$ with Design Fluency switching. The Design Fluency switching and Verbal Fluency switching correlated .25. The inverse relationships are due to a higher score on Design Fluency and Verbal Fluency, representing a better performance (more designs completed and more words generated, respectively); whereas on the Trail Making Test, a higher score is inferior (more time to complete the task). Furthermore, correlation analyses of the residuals after controlling for component skills revealed that the Trail Making Test residual correlated $-.120$ ($p < .01$) with the Verbal Fluency residual and $-.093$ with Design Fluency ($p < .012$). The Verbal Fluency residual correlated .099 ($p < .01$) with the Design Fluency residual.

Discussion

The relationship between age and executive functions has been a matter of considerable debate. Some authors contend that executive functions decline with age (Daigneault & Braun, 1993;

Table 3
Summary of Single- and Multiple-Variable Regression and Quadratic Analyses Predicting Verbal Fluency Switching

Predictor	R^2	ΔR^2	ΔF	*df*s	*p*
Age[a]	.060	.060	45.57		<.01
Multiple regression[b]					
Step 1: Education, gender, IQ	.100	.100	26.40	3, 714	<.01
Step 2: education, gender, IQ, animal naming	.175	.075	65.04	2, 712	<.01
Step 3: Education, gender, IQ, animal naming, age	.196	.021	18.88	1, 711	<.01
Quadratic	.218	.043			<.01
Step 3:[c] Education, IQ, animal naming, Age					

[a] Age-related variance without controlling for demographic and component tasks. [b] Age-related variance controlling for demographic and component tasks by multiple regression analyses. [c] Age-related variance controlling for demographic and component tasks by quadratic regression analyses.

Table 4
Summary of Single- and Multiple-Variable Regression Analyses Predicting Design Fluency Switching

Predictor	R^2	ΔR^2	ΔF	*df*s	*p*
Age[a]	.176	.176	153.10		<.01
Multiple regression					
Step 1: Education, gender, IQ	.083	.083	21.52	3, 714	<.01
Step 2: Education, gender, IQ, connecting unfilled dots	.276	.193	189.53	1, 713	<.01
Step 3: Education, gender, IQ, connecting unfilled dots, age	.362	.087	96.86	1, 712	<.01

[a] Age-related variance without controlling for demographic and component tasks.

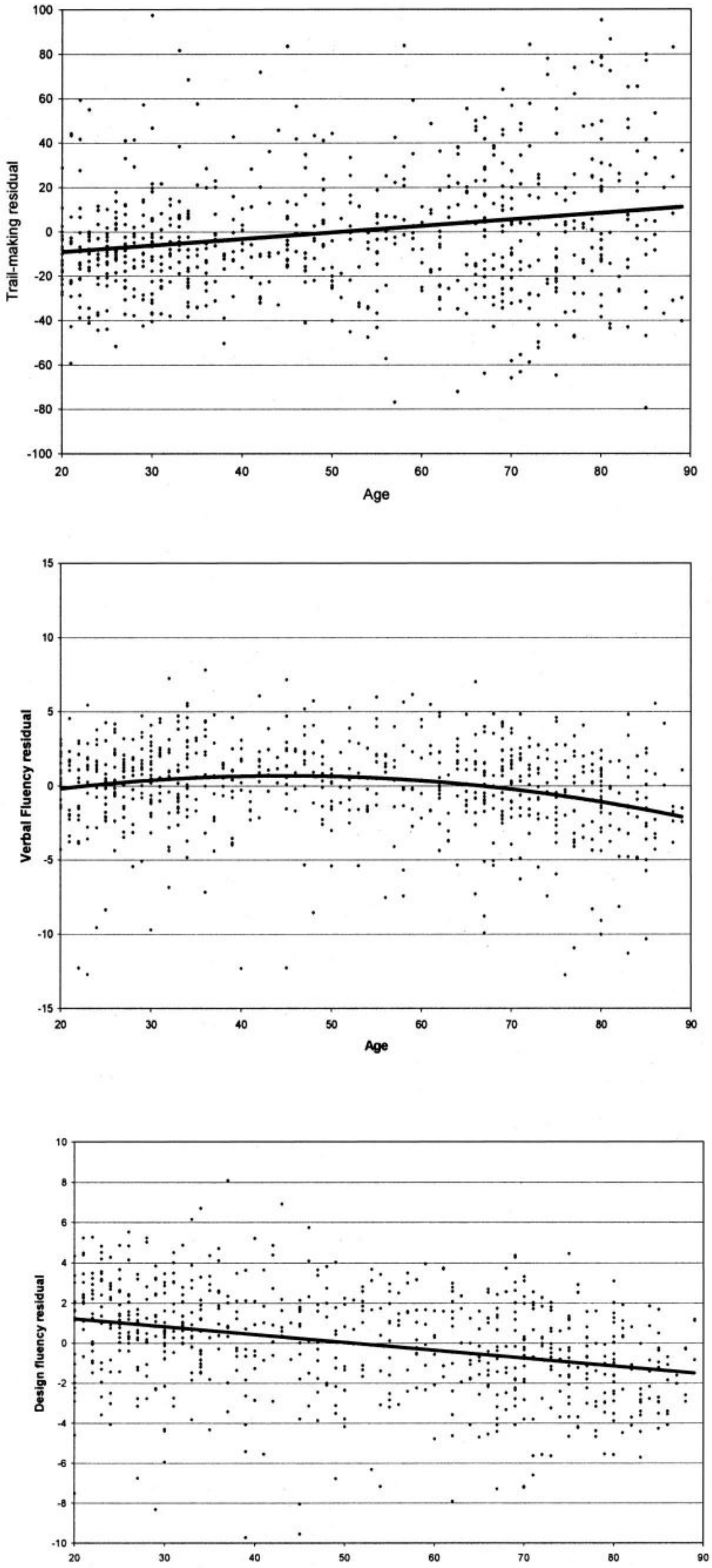

Figure 2. Scatter plots of shifting task residuals (controlling for component abilities) as a function of age. Top: Trail Making Test scatter plot of residuals with linear regression line. Middle: Verbal Fluency Test scatter plot of residuals with quadratic regression line. Bottom: Design Fluency Test scatter plot of residuals with linear regression line.

Malloy & Richardson, 1994), whereas others have not found significant age differences on all executive function tests (Boone, Miller, Lesser, Hill, & D'Elia, 1990; Kramer, Humphrey, Larish, Logan, & Strayer, 1994). Most tests that assess executive functions also tap several key fundamental cognitive skills (e.g., the switching condition of the Trail Making Test is also dependent on visual scanning, number sequencing, letter sequencing, and motor speed). The inconsistent findings that have been reported to date in this area may be related in part to differential effects of age on the component skills tapped by executive function tasks. Controlling for component skills on executive function tasks is essential, because older adults often perform more slowly on very basic perceptual and motor tasks that have minimal executive function demands (Baddeley, 1996; Salthouse, 1989; Schaie, 1989). This general slowing can affect performance on executive function tasks even if higher level cognitive skills are relatively preserved.

Our main finding in the present study is that advancing age is associated with poorer performance on tasks of cognitive switching, even after parsing out the key component skills tapped by those tasks (e.g., visual scanning, motor speed, fluency) and demographic factors (i.e., education, gender, and IQ). For example, on the D-KEFS Trail Making Test, participants are administered four baseline conditions that isolate component skills that contribute to performance on the higher level cognitive switching condition (i.e., visual scanning, motor speed, number sequencing, and letter sequencing). Our results suggest that a unique relationship exists between normal aging and cognitive flexibility on the Trail Making Test that cannot be accounted for by age-related decrements found on the more fundamental cognitive skills assessed by this task.

The present findings are consistent with several past studies that have also attempted to control for component skills when studying age-related declines in set-shifting performance. For example, Keys and White (2000) found age-related decrements in set-switching performance in older adults compared with younger adults beyond age-related psychomotor speed decrements. Similarly, Cepeda, Kramer, and Gonzalez de Sather (2001) reported that age accounted for a significant portion of switching (50%) for individuals ages 7 to 82 years old when controlling for other factors affecting performance, such as perceptual speed, working memory, and a nonswitch control condition. A limitation in these studies, however, was that the component skills were assessed on measures quite different from the target executive function tasks but assumed to be relevant or needed for successful performance on the executive function test. The executive function task investigated by Cepeda et al. (2001) involved shifting between two tasks: distinguishing between two numbers presented on a computer screen and deciding whether single or multiple numbers were on the screen. Working memory, which was specified as the component skill, was assessed with an oral digit span test.

In a well-designed study, Salthouse and colleagues (Salthouse, Fristoe, McGuthry, & Hambrick, 1998; Salthouse et al., 2000) used a carefully constructed version of the Trail Making Test to eliminate different spatial arrangement of targets and to formally assess several component skills of this task. These investigators used structural equation modeling to conclude that all age-related effects on this task were mediated through effects on perceptual speed. Differences between these findings and our results may be explained by several factors, such as participant characteristics, sample size, and statistical method. For example, Salthouse et al. (2000) suggested that their results may have been biased by high crystallized intelligence (estimated from vocabulary scores) in their older adult participants. In contrast, we controlled for IQ in our regression analysis, essentially factoring out the contribution of IQ to set-switching performance. Additionally, our large sample size may have allowed us to detect the small yet significant effect of aging on our executive function measures.

Our large sample size might be both an advantage and a limitation. That is, studies with large sample sizes are sometimes thought to have "oversensitivity to effects," or too much power (Levin, 1997). In the current study, we addressed this potential problem by requiring a highly conservative significance level ($p <$ .01) for all three conditions analyzed.

Cognitive flexibility has been linked consistently with frontal structures and subcortical basal ganglia (Eslinger & Grattan, 1993; Rogers, Andrews, Grasby, Brooks, & Robbins, 2000). Lesion studies have shown that patients with focal lesions in dorsolateral frontal regions were more impaired than patients without frontal lesions on shifting tasks such as the Trail Making Test, Part B (Eslinger & Grattan, 1993; Stuss et al., 2001). Functional neuroimaging has also been used to investigate the neural correlates of set switching (Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000; Garavan, Ross, Li, & Stein, 2000; Kimberg, Aguirre, & D'Esposito, 2000; Luks, Simpson, Feiwell, & Miller, 2002; Sohn, Ursu, Anderson, Stenger, & Carter, 2000; Sylvester et al., 2003). These studies suggest that most executive tasks use common selective attention processes mediated by the superior parietal cortices but that set switching preferentially engages the dorsolateral prefrontal cortex. Similarly, an EEG study of visual task switching suggested that frontal regions may act in an executive capacity in switching rule sets and updating working memory before initiating the involvement of motor and sensory cortices (Baddeley, 2002).

Given the importance of prefrontal structures for mediating cognitive set switching, performance on these tasks may be particularly vulnerable to decline in older adults. Atrophy of frontal brain regions is disproportionately larger than atrophy of posterior regions in older adults (Fabiani & Wee, 2001; Kray, Li, & Lindenberger, 2002; Prull, Gabrieli, & Bunge, 2000; Raz, 2000; West, 1996). Accordingly, it is reasonable to predict that frontal lobe functions may decline more rapidly than other cognitive domains in older adults, although our research was not directed at making these comparisons.

The ability to engage in cognitive set switching is anatomically and functionally related to other frontal-executive skills, such as working memory and inhibition. For example, a cognitive set-switching task requires the participant to maintain simultaneous (dual) attention, track progress, remember and apply various rules differentially, inhibit attention to extraneous stimuli, and constrain overlearned responses. Additionally, switching tasks require suppressing the impulse to maintain consistency, that is, to not switch. As such, our observed age effects in cognitive switching may be a result of age-related changes in other frontal-executive skills that are simultaneously activated dimensions or covariants of switching abilities, such as working memory, inhibition, controlled attention, and recollection.

The interrelationship between working memory, switching, and age is not entirely clear. Working memory, or the central executive aspect of working memory (Baddeley, 1990), is conceptualized as an attentional system that is activated when there is competing information, such as simultaneous processing or inhibition of interfering stimuli. Thus, cognitive switching is highly dependent on working memory. To extricate switching from working memory, some researchers have experimented with manipulating the working memory demands on executive function tasks, eliminating the age differences (Hartman, Bolton, & Fehnel, 2001; Kramer, Hahn, & Gopher, 1999; Ravizza & Ciranni, 2002). Others have found that age effects persist (Baddeley et al., 2001; Kray et al., 2002) or have had contradictory findings depending on the nature of the switching demands (Kray & Lindenberger, 2000). Eliminating the working memory demands of a task essentially alters the switching aspect, however.

Inhibition is also a distinct executive function, separable but moderately correlated with set switching (Miyake et al., 2000). Older adults appear to have greater difficulty inhibiting or deleting irrelevant information (Hedden & Park, 2001; Kramer et al., 1994; Lindfield & Wingfield, 1999; Persad, Abeles, Zacks, & Denburg, 2002). Accordingly, switching may be impeded by difficulty inhibiting the impulse to give a response that was appropriate to the last rule or in the last category, rather than generating a unique response. Hasher and Zacks (1979, 1988) integrated these concepts, explaining that less efficient working memory arises from greater difficulties in inhibition with increasing age. Whatever the constitutive aspects of switching, the age effect was unvarying in our study.

Cognitive switching was found across several types of executive function tasks, suggesting good generalizability. Other authors have reported similar cross-domain results with switching. For example, Kray and Lindenberger (2000) found comparable significance with the use of verbal, figural, and numeric stimuli. In our study, although age was significant across all domains, the amount of variance explained by age after controlling for demographics and component skills varied between tasks, ranging from 3.0% for Trail Making to 8.7% for Design Fluency. In addition, age had a fairly linear relationship with shifting on Trail Making and Design Fluency and a curvilinear relationship with Verbal Fluency. A downward trend in performance on Verbal Fluency was not evident until middle age. These data suggest that although age may be generally associated with a decline in shifting ability, the nature and size of this relationship may be different depending on the nature of the task. The reasons for these task differences are unclear. One possibility might be related to stimulus modality. The two tasks with linear relationships, Trail Making and Design Fluency, are both nonverbal, whereas Verbal Fluency relies directly on retrieval of semantic material. An alternate explanation relates to variability in the overall relationship between age and the set-shifting task prior to controlling for performance on the component tasks. The correlation between age and Verbal Fluency shifting was relatively small, sharing only 6% of their variance, whereas age and the shifting condition of Trail Making shared 32.7% of their variance. In addition, demographics, verbal fluency, and age combined to explain less than 20% of the total variance of the Verbal Fluency Test, which is only about a third of the total variance of the Trail Making Test. Clearly, other variables besides demographic and component skills are important for cognitive shifting, particularly for verbal fluency. Future studies should attempt to better control for factors such as working memory, inhibition, retroactive interference, and repetition effects (Hedden & Park, 2003; Jacoby, 1999).

In summary, in the present study we provide evidence that executive functions in general, and verbal and nonverbal cognitive switching in particular, are affected by age after carefully controlling for demographic factors and component cognitive skills. Our findings of declines in mental flexibility with age validate the cognitive complaints of many older individuals regarding problems in multitasking, and they point to the need to develop compensatory strategies to help aging adults in their everyday lives.

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