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Relations Between Cognitive Abilities and Measures of Executive Functioning

Timothy A. Salthouse
University of Virginia

Although frequently mentioned in contemporary neuropsychology, the term *executive functioning* has been a source of considerable confusion. One way in which the meaning of a variable can be investigated involves examining its pattern of relations with established cognitive abilities. This method was applied to a variety of variables hypothesized to assess executive functioning in 2 data sets, 1 consisting of 328 adults between 18 and 93 years of age and a 2nd composite data set based on nearly 7,000 healthy adults between 18 and 95 years of age. Most of the hypothesized executive functioning variables were strongly related to reasoning and perceptual speed abilities, and very few had any unique relations with age after taking into consideration the relations of age through the cognitive abilities. These results raise questions about the extent to which neuropsychological tests of executive functioning measure a distinct dimension of variation in normal adults.

Keywords: executive functioning, aging, cognitive ability, reasoning, perceptual speed

Executive functioning is hypothesized to involve the control and coordination of cognitive operations and has become an important concept in contemporary neuropsychology. However, there is still little consensus on what executive functioning actually means. Consider the following sample of variables that have been used to assess executive functioning in recent articles: Verbal Fluency (Bastin & van der Linden, 2003; Mungas, Reed, & Kramer, 2003), Trail Making (e.g., Barnes, Yaffe, Satariano, & Tager, 2003; Bigler et al., 2003), Stroop Color Word (e.g., Barnes et al., 2003; Bastin & van der Linden, 2003), and Digit Symbol or Symbol Digit (e.g., Barnes et al., 2003; Bigler et al., 2003; Verghese et al., 2003). Moreover, two recent neuropsychological test batteries designed to assess executive functioning only have tests of verbal fluency and sorting or categorization in common, with one battery also including tests of proverb interpretation, inferring word meaning from context, and 20 questions (Delis, Kaplan, & Kramer, 2001) and the other battery also including tests of judgment and maze solution (Stern & White, 2003). The diversity of variables used to assess executive functioning suggests that there is not yet much agreement about the nature of this construct and even less about how it is best assessed.

The uncertainty about the nature of executive functioning is also apparent in the following characterizations from recent articles and books. “Executive functions cover a variety of skills that allow one to organize behavior in a purposeful, coordinated manner, and to reflect on or analyze the success of the strategies employed” (Banich, 2004, p. 391). “Executive functions are those involved in complex cognitions, such as solving novel problems, modifying behavior in the light of new information, generating strategies or sequencing complex actions” (Elliott, 2003, p. 50). “Executive functions include processes such as goal selection, planning, monitoring, sequencing, and other supervisory processes which permit the individual to impose organization and structure upon his or her environment” (Foster, Black, Buck, & Bronskill, 1997, p. 117). “The executive functions consist of those capacities that enable a person to engage successfully in independent, purposive, self-serving behavior” (Lezak, 1995, p. 42). “Executive functions include the following abilities: 1. Formulating goals with regard for long-term consequences. 2. Generating multiple response alternatives. 3. Choosing and initiating goal-directed behaviors. 4. Self-monitoring the adequacy and correctness of the behavior. 5. Correcting and modifying behaviors when conditions change. 6. Persisting in the face of distraction” (Malloy, Cohen & Jenkins, 1998, p. 574).

Perry and Hodges (1999) “refer to executive functions as those higher-order cognitive capabilities that are called upon in order to formulate new plans of action and to select, schedule, and monitor appropriate sequences of action” (p. 389). “The ‘executive functions’ broadly encompass a set of cognitive skills that are responsible for the planning, initiation, sequencing, and monitoring of complex goal-directed behavior” (Royall et al., 2002, p. 378). According to Tranel, Anderson, and Benton (1994), “the term executive functions . . . [is] . . . used to refer to higher-order cognitive capacities, for example, judgment, decision-making, planning, and social conduct” (p. 126). “Executive functioning involves problem solving abilities such as abstraction, planning, strategic thinking, behavioral initiation and termination, and self-monitoring” (Troyer, Graves, & Cullum, 1994, p. 45). “Executive functions are often referred to as the most complex of human behaviors being primarily concerned with planning and organization of purposeful behavior” (Tuokko & Hadjistavropoulos, 1998, p. 143).

Many of these descriptions are quite broad, and several seem to refer to rather general aspects of thinking. It is thus not surprising that a number of researchers have speculated that a close relation might exist between executive functioning and the concept of fluid intelligence (e.g., Denchla, 1995; Duncan, 1994; Duncan, Emslie, Williams, Johnson, & Freer, 1996; Duncan, Johnson, Swales, &

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Correspondence concerning this article should be addressed to Timothy A. Salthouse, Department of Psychology, University of Virginia, Charlottesville, VA 22904. E-mail: salthouse@virginia.edu

Freer, 1997; Mittenberg, Seidenberg, O'Leary, & DiGiulio, 1989; Phillips, 1997; Rabbitt, 1997; Salthouse, Atkinson, & Berish, 2003).

In light of the apparent uncertainty regarding the nature of executive functioning, it is worth considering how the validity of potential executive functioning measures might be evaluated. At the current time, the primary basis for deciding that a test assesses executive functioning is a decision that the test has face validity, but judgments of this type are inherently subjective. A more objective type of validity is predictive validity, but that is not feasible with executive functioning because there is no external criterion against which to compare measures of executive functioning (e.g., Burgess, 1997; Royall et al., 2002; Tranel et al., 1994). Many purported executive functions are impaired in certain patients with frontal lobe damage, and hence these functions are sometimes linked to activity of the frontal lobes. Results from functional neuroimaging studies might also be used to provide evidence that tasks hypothesized to reflect executive functioning represent something distinct from what is involved in other types of tasks (e.g., Collette & van der Linden, 2002). However, because the correspondence between brain region and function is not one to one, tests cannot be validated as methods of assessing a particular theoretical construct simply by finding that they are associated with damage in a particular region of the brain (e.g., Duncan et al., 1996; Foster et al., 1997; Perry & Hodges, 1999; Reitan & Wolfson, 1994; Robbins et al., 1997; Tranel et al., 1994).

One well-accepted method of investigating the meaning of a variable from the psychometric tradition is based on the examination of construct validity. That is, a variable can be inferred to be similar to other variables to which it is moderately related (indicating that it has convergent validity) and to be dissimilar to variables to which it is only weakly related (indicating that it has discriminant validity). Unfortunately, many of the studies in which multiple measures of executive functioning were examined have found weak or mixed results (e.g., see citations in Royall et al., 2002, and in Salthouse et al., 2003). Results from a recent project by Salthouse et al. (2003) are fairly typical. These researchers investigated the construct validity of several commonly used measures of executive functioning including the Wisconsin Card Sorting Test (Heaton, Chelune, Talley, Kay, & Curtis, 1993), the Tower of Hanoi (Salthouse et al., 2003), a variant of the Trail Making Test, and tests of verbal and figural fluency. Although the variables had moderate correlations with one another, this type of convergent validity evidence was not considered very compelling because most reliably assessed cognitive variables are positively correlated with one another. Because the variance common to the purported executive functioning variables was very strongly related to other cognitive ability constructs and particularly to a fluid intelligence construct, it was concluded that, at least when assessed with these variables, the construct of executive functioning had little discriminant validity.

An alternative method of investigating the meaning of an individual variable involves examining relations of the variable with established cognitive abilities and with an individual-difference characteristic such as age. Consider the analytical model portrayed in Figure 1. The boxes in this type of structural equation model correspond to observed variables, and the circles represent latent variables, or theoretical constructs, that are assumed to be responsible for at least some of the variation in the observed variables. Unidirectional arrows portray an influence from one variable to another, and bidirectional arrows represent a correlation without any assumption about the causal direction between the variables.

When the coefficients for the relations from the cognitive ability latent constructs to the target variable are standardized, they can be interpreted as indicating the relative contribution of each ability to the variance in the variable. That is, these coefficients provide an objective estimate of the degree to which the variables are pure with respect to particular cognitive abilities. The direct relation from age to the target variable in this type of model is also of interest because it indicates the unique contribution of age on the variable, independent of any indirect age-related influences operating through the abilities.

The model portrayed in Figure 1 can therefore be used to investigate the meaning of variables postulated to represent executive functioning by determining the degree to which the variables are related to other cognitive abilities and the magnitude of any unique relations to age. The rationale is that if a variable represents a construct, such as executive functioning, that is distinct from the other cognitive ability constructs included in the analysis, then the coefficients from the ability constructs to the variable should be relatively small. Furthermore, if the hypothesized construct is assumed to have significant relations with age and if at least some of the age-related influences on that construct are statistically independent of the age-related influences on the other cognitive ability constructs included in the analysis, then the coefficient for the direct relation from age to the variable should be significantly different from zero.

The primary goal of the current project was to use the analytical model represented in Figure 1 to investigate relations of cognitive abilities to variables often assumed to reflect executive functioning. The model was applied to two separate data sets. The first data set was based on a new study involving 328 adults who performed all of the 16 reference cognitive tasks as well as several tasks often hypothesized to represent executive functioning, that is, the Wisconsin Card Sorting Test, verbal fluency tasks, and a variant of the Trail Making Test. The second data set was based on data combined across multiple samples rather than on data from a single study. This aggregate data set has several advantages over data from a single study, including a much larger and more diverse sample than is typically feasible in a single study and a broader variety of target variables (cf. Salthouse, 2004).

Data Set 1

Summary characteristics of the sample for the first data set are presented in Table 1. The participants were recruited from posted flyers and newspaper advertisements, and there were 89 individuals between 18 and 39 years of age, 133 individuals between 40 and 59 years of age, and 106 individuals between 60 and 93 years of age. Inspection of the table indicates that, on average, these individuals were highly educated and in good health. The sample was functioning at a relatively high cognitive level because the scaled scores for the vocabulary and digit symbol variables were 12.8 and 11.0, respectively. (Note that the scaled scores have means of 10 and standard deviations of 3 in the nationally representative sample used to establish the test norms; cf. Wechsler, 1997a.)

Further examination of Table 1 reveals that all of the reference variables for the cognitive abilities had acceptable levels of reliability and that with the exception of the vocabulary variables, they

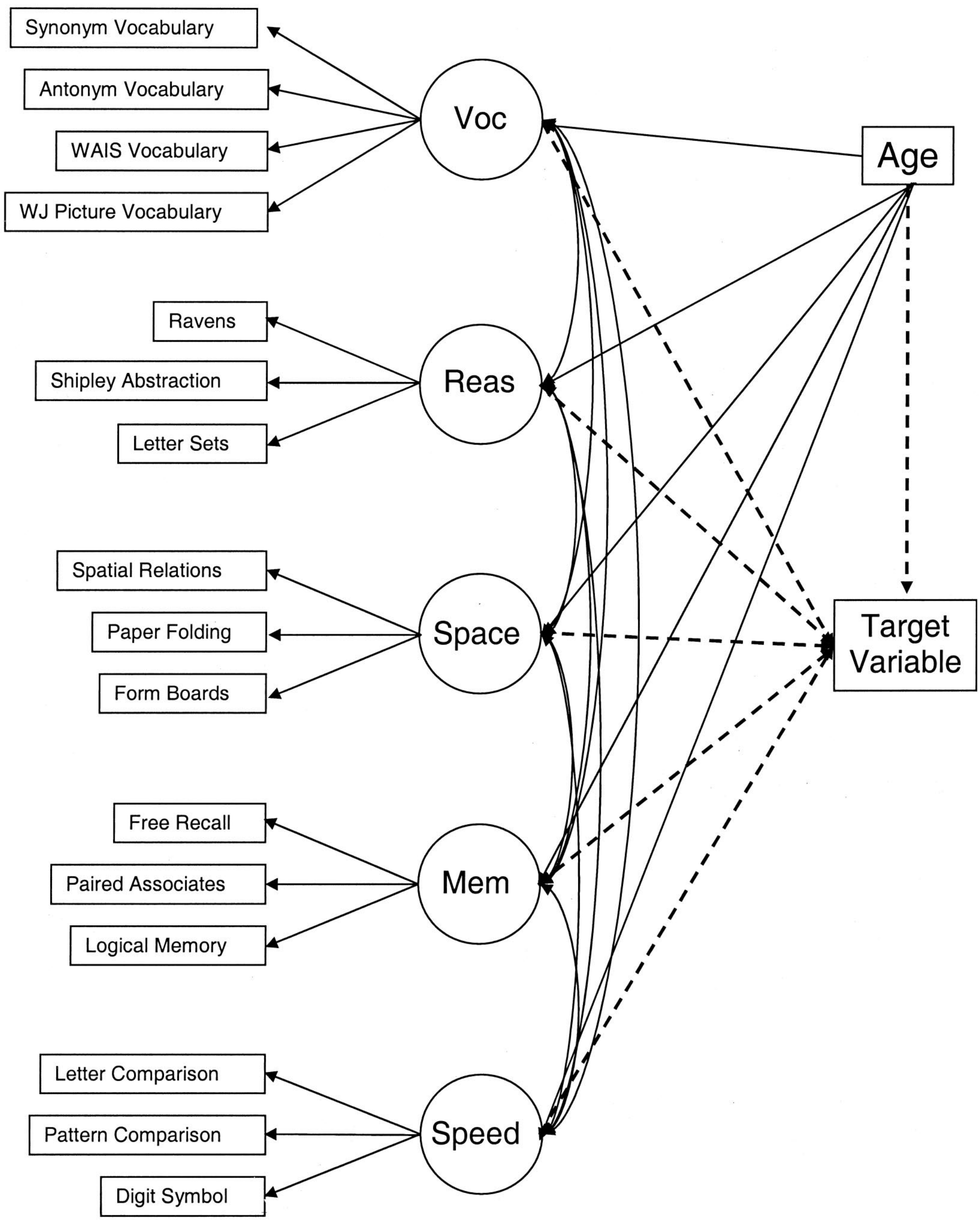

Figure 1. Schematic illustration of an analytical model used to investigate relations of cognitive abilities on a target cognitive variable and the direct and indirect (mediated through the abilities) influences of age on the target cognitive variable. Voc = vocabulary; WAIS = Wechsler Adult Intelligence Scale—Third Edition; WJ = Woodcock–Johnson Psycho-Educational Battery—Revised (Woodcock & Johnson, 1990); Reas = reasoning; Space = spatial visualization; Mem = episodic memory; Ravens = Advanced Progressive Matrices: Set II (Raven, 1962); Shipley = Shipley Institute of Living Scale—Revised (Zachary, 1986).

all had significant negative correlations with age. The structural equation models were analyzed with the AMOS (Arbuckle, 2003) computer program. Fit statistics for the model portrayed in Figure 1 with five correlated factors are presented in the bottom of Table 1. Although the chi-square statistic provides a direct test of differences between the predicted and observed variances and covariances, it is usually significant with moderate sample sizes and thus is not considered very diagnostic. Two more informative statistics are the comparative fit index (CFI), which represents the improvement relative to an alternative model, and the root-mean-square error of approximation (RMSEA), which represents the deviation between the predicted and observed variances and covariances. Models with reasonable fit should have CFI values greater than .9 and RMSEA values less than .1, with the fit

Table 1
Means, Standard Deviations, Standardized Factor Loadings, and Factor Correlations for the 16 Reference Variables in Data Set 1 (N = 328)

					Factor				
Variable	Reliability	*M*	*SD*	Age correlation	Reasoning	Spatial visualization	Episodic memory	Perceptual speed	Vocabulary
Age		50.8	17.6						
Gender (% female)		64.0		−.05					
Education[a]		15.6	2.6	.13					
Health[b]		2.1	0.9	.21*					
MMSE		28.8	1.5	−.18*					
Ravens			0.78	7.4	3.5	−.47*	.83+		
Shipley Abstraction	.84	12.9	3.6	−.37*	.84*				
Letter Sets[c]	.74	11.0	2.8	−.32*	.74*				
Spatial Relations[d]	.88	8.8	5.2	−.37*		.90+			
Paper Folding[c]	.77	6.4	2.8	−.30*		.84*			
Form Boards[c]	.85	7.2	4.4	−.45*		.73*			
Free Recall[e]	.88	0.7	0.1	−.36*			.75*		
Paired Associates[e]	.76	2.9	1.7	−.36*			.76*		
Logical Memory[f]	.80	45.6	9.9	−.23*			.65+		
Letter Comparison[g]	.87	10.5	2.5	−.46*				.81*	
Pattern Comparison[g]	.90	16.6	3.7	−.59*				.84*	
Digit Symbol[h]	.93	70.9	17.5	−.57*				.82+	
Synonym Vocabulary[i]	.83	6.7	3.0	.29*					.87*
Antonym Vocabulary[i]	.82	6.1	3.0	.17*					.81*
WAIS Vocabulary	.90	51.5	10.3	.12					.89*
WJ Picture Vocabulary	.86	18.6	5.0	.30*					.80+
Factor correlations									
Reasoning					—	.84*	.70*	.69*	.57*
Spatial visualization						—	.51*	.57*	.43*
Episodic memory							—	.57*	.38*
Perceptual speed								—	.22*
Vocabulary					−.48*	−.42*	−.44*	−.66*	.26*

Note. The plus symbol (+) indicates that the unstandardized coefficient was fixed to one to identify the factor. The reliability of the digit symbol variable was based on the correlation with a parallel form in another sample of 143 adults (Salthouse, Nesselroade, & Berish, 2004). All other reliability estimates were based on coefficient alpha. The fit statistics were as follows: $\chi^2(279, N = 328) = 94$; comparative fit index = .94; root-mean-square error of approximation = .08. MMSE = Mini-Mental Status Examination; Ravens = Advanced Progressive Matrices: Set II (Raven, 1962); Shipley = Shipley Institute of Living Scale—Revised (Zachary, 1986); WAIS = Wechsler Adult Intelligence Scale—Third Edition; WJ = Woodcock–Johnson Psycho-Educational Battery—Revised.
[a] Number of years of education completed. [b] Self-rating of health on a scale ranging from 1 (*excellent*) to 5 (*poor*). [c] Ekstrom et al. (1976). [d] Bennett, Seashore, and Wesman (1997). [e] Salthouse, Fristoe, and Rhee (1996). [f] Wechsler (1997b). [g] Salthouse and Babcock (1991). [h] Wechsler (1997a). [i] Salthouse (1993b).
* $p < .01$.

improving as the CFI approaches 1.0 and the RMSEA approaches 0.0. The fit statistics indicate that the five-factor model provided a relatively good fit to the data, particularly considering the simple nature of a model in which none of the variables was related to more than one factor. It should also be noted that all of the factors had at least moderate correlations with one another, and each was significantly related to age.

The analyses conducted to investigate the model in Figure 1 added age and the target variable to the correlated cognitive abilities model. Although the factor loadings and covariances could have been constrained to the original values when introducing the new variables, they were allowed to vary to evaluate the robustness of the structure. The rationale is that the structure may not be very stable if the addition of another variable changes the pattern of relations among variables and factors. However, in all cases the addition of age and the target variable to the model resulted in only minor changes in the structural coefficients relating variables to abilities, and abilities to one another, and thus the structures can be considered fairly robust.

Parameter estimates for the model in Figure 1 are presented in Table 2. The second column in the table, labeled *Only age*, contains the correlation between age and the target variable that represents both the direct and indirect influences of age, and the third column, labeled *Unique age*, contains the standardized coefficient corresponding to only the direct relation of age on the variable. Entries in the remaining columns are standardized regres-

Table 2
Standardized Coefficients of Relations Between Variables and Age When Considered Alone and Age When Considered in the Context of Other Cognitive Abilities for Data Set 1

			Cognitive ability				
Variable	Only age	Unique age	Reas	Space	Mem	Speed	Voc
Mini-Mental Status Examination	−.18*	.11	.95*	−.28	−.05	−.06	−.01
	−.18*	.10	.67*	—	.00	−.06	.01
CLOX1	−.14*	−.01	.84*	−.37	.05	−.21	.00
	−.14*	−.01	.49*	—	.11	−.21	.01
CLOX2	−.03	.16	.35	−.03	.02	.04	.01
	−.03	.15	.32	—	.03	.04	.01
WCST number categories	−.33*	−.03	.53*	−.04	.05	.07	.01
	−.33*	−.05	.47*	—	.06	.06	.02
WCST proportion correct responses	−.38*	−.11	.40	.07	.09	.05	.08
	−.38*	−.13	.45*	—	.08	.04	.09
Letter Fluency[a]	.05	.29*	.38	−.32	.06	.36*	.25
	.05	.31*	.09	—	.11	.36*	.26
Category Fluency[a]	−.19*	.09	.17	−.13	.18	.35*	.22
	−.19*	.10	.09	—	.20*	.35*	.22*
Alternating Fluency[a]	−.18*	.26	.34	−.35	.18	.53*	.01
	−.18*	.27	.00	—	.24*	.53*	.03
Connections—Same sequence	−.51*	−.10	.99*	−.42*	−.06	.44*	−.22
	−.51*	−.11	.58*	—	.01	.44*	−.20
Connections—Alternating sequence	−.17*	.21	.78*	−.26	.01	.10	.16
	−.17*	.21	.54*	—	.05	.09	.16
Connections—Difference	−.09	.20	.65	−.20	.02	.03	−.14
	−.09	.21	.47*	—	.05	.02	−.14

Note. The second row for each variable represents the coefficients when the space construct was not used as a predictor in order to minimize collinearity with the reasoning construct. Dashes indicate that the predictor variable was not used in the analysis. The cognitive ability factors were based on the variables described in Table 1 and Figure 1. Reas = reasoning; Space = spatial visualization; Mem = episodic memory; Speed = perceptual speed; Voc = vocabulary; CLOX1 = first part of the CLOX Test (Royall, Corde, & Polk, 1998); CLOX2 = second part of the CLOX Test; WCST = Wisconsin Card Sorting Test.
[a] Delis et al. (2001).
* $p < .01$.

sion coefficients relating the cognitive ability to the target variable. Because of the high correlation between the reasoning and spatial visualization constructs (i.e., .84), some of the estimates could have been distorted because of collinearity. The analyses were therefore repeated without the space construct to examine this possibility. Results from these analyses are presented immediately below those from the original analyses in Table 2.

The initial target variable was the score on a frequently used dementia screening instrument, the Mini-Mental Status Examination (Folstein, Folstein, & McHugh, 1975). Entries in the two rows of Table 2 indicate that this variable was strongly related to reasoning ability in the current sample of high-functioning adults. Although there was a small negative correlation between age and the Mini-Mental Status Examination score, it was eliminated when age relations through the cognitive abilities were taken into consideration.

The CLOX Test (Royall, Corde, & Polk, 1998) was designed to assess aspects of executive functioning in the context of a clock drawing task. In the first part of the test, CLOX1, the participant is asked to draw a clock set at a particular time, and in the second part, CLOX2, he or she simply copies a clock drawn by the examiner. Both participant drawings are scored in terms of a number of criteria such as spacing of the numbers, clock hands represented as arrows with the minute hand longer than the hour hand, and so forth. The CLOX1 scores had a slight negative relation with age in this sample, but there was no age relation on the CLOX2 scores. Only the CLOX1 score was significantly related to the cognitive abilities, and the influence was restricted to reasoning ability.

In part because of its widespread usage, the Wisconsin Card Sorting Test has been characterized as the gold standard for assessing executive functioning (Delis et al., 2001). The task for the examinee in this test is to assign cards to categories according to rules that are changed after every 10 correct responses. There are many possible measures of performance in this task, but most are highly correlated with one another in samples of healthy adults across a wide age range (e.g., Salthouse et al., 2003; Salthouse, Fristoe, & Rhee, 1996). To illustrate, the correlation between the number of categories measure and the proportion of correct responses measure in this sample was .87. As one would expect on the basis of this high correlation, the results of the analyses with these two measures were very similar. In both cases, the measure had a strong relation with the reasoning ability, and there were no unique age-related effects after considering influences of age through the cognitive abilities.

The Letter Fluency, Category Fluency, and Alternating Fluency tasks (Delis et al., 2001) all involve the examinee generating as many words as possible within a limited time that satisfy specified constraints. In the Letter Fluency task, the constraint is that the words should begin with a particular letter of the alphabet; in the Category Fluency task, the constraint is that the words should belong to a particular category; and in the Alternating Fluency task, the constraint is that every other word should belong to a different one of two designated categories. These types of tasks are often assumed to involve maintenance of a set and inhibition of past responses.

Each of the fluency measures had a significant relation with perceptual speed ability, and there were also a few significant relations with the vocabulary and memory abilities. It is interesting that the relations with age were reversed in direction after controlling the influences through the cognitive abilities, and the adjusted relation was statistically significant for the Letter Fluency measure.

The Connections Test (Salthouse et al., 2000) is a variant of the Trail Making Test in which the test pages consist of adjacent circles containing either numbers or letters, and the four conditions involve numeric, alphabetic, alternating numeric and alphabetic, and alternating alphabetic and numeric sequences. As in the Trail Making Test, the task for the participant is to draw a line connecting the items in the appropriate sequence as rapidly as possible. The times to connect all of the items in the two simple sequences (i.e., numbers only and letters only) are averaged to form a same sequence measure that is roughly equivalent to Version A of the Trail Making Test, and the two times in the alternating sequences are averaged to form an alternating sequence measure that is roughly equivalent to Version B of the Trail Making Test.

The results in Table 2 indicate that the pattern was somewhat different across the three connections measures. However, each had a strong relation to reasoning ability, and in none of them was there a significant direct relation to age after considering the influence through other cognitive abilities. Only the same sequence connections measure had a significant relation to perceptual speed ability.

There are two major findings from the results summarized in Table 2. First, although most of the measures were negatively related to age, very few of the direct age relations, which were statistically independent of age-related influences through the cognitive abilities, were significantly different from zero. Second, all of the measures had significant relations with one or more cognitive abilities, and most were influenced by either reasoning ability or perceptual speed ability. As noted in the introduction, this is not the pattern of results one would expect if the measures represented a distinct executive functioning construct that has unique relations to age.

Data Set 2

The major purpose of the analyses of the second data set was to replicate the analyses based on the model in Figure 1 with a more extensive set of target variables. The larger collection of variables hypothesized to reflect executive functioning was made possible by aggregating data across many previous studies. The aggregate data set has a great deal of missing data, but the missing values are due to the study to which the individual was assigned rather than to the level of the variable, and thus the data can be assumed to be missing at random. This property allows powerful analytical procedures to be used to deal with missing data, such as maximum-likelihood estimation (Arbuckle, 1996; Enders & Bandalos, 2001). Additional information about the aggregate data set and the analytical procedure is available in another report that focused on different research questions (Salthouse, 2004).

Method

The analyses were based on data from a total of 6,959 different individuals from 34 studies conducted in Timothy A. Salthouse's laboratory, excluding the study described above. All of the studies were similar in that the participants in a given study were administered the tasks in the same order, and the samples consisted of adults spanning a continuous distribution of ages between 18 and 95. Studies with only two extreme age groups (e.g., younger and older adults) and those in which the younger adults were primarily college students were excluded to avoid inflating the estimates of the age relations when the variance associated with middle-aged adults is omitted, and to minimize confounding age with student status.

Only a subset of the 16 reference cognitive variables was included in most of the studies, but each study contained at least two of the reference variables, in addition to information about age and other demographic characteristics of the participants. Furthermore, each reference variable was assessed in at least three studies with different combinations of other variables. Many of the studies also included measures that have been hypothesized to represent executive functioning, which allowed examination of their relations with the cognitive abilities according to the model portrayed in Figure 1. More details on the target variables and the characteristics of the samples are available in the specific studies, which are cited in Table 4.

As in Data Set 1, the model in Figure 1 was investigated with the AMOS (Arbuckle, 2003) structural equation program. This program incorporates a maximum-likelihood estimation algorithm to take advantage of all of the available information at the time of analysis and thus is an efficient method of dealing with incomplete or missing data (e.g., Arbuckle, 1996; Enders & Bandalos, 2001).

Results and Discussion

Table 3 contains summary statistics for the reference cognitive variables, including factor loadings and factor correlations, derived from a confirmatory factor analysis specifying five correlated factors. Comparison of the results in Tables 1 and 3 reveals that the variable means, the factor loadings, and the factor correlations were very similar in the two independent data sets.

Because of the large number of variables in the aggregate data set, several additional analyses were conducted to explore the generalizability of the analytical procedure based on the model in Figure 1. One analysis focused on a target variable consisting of the number of words answered correctly on a *New York Times* crossword puzzle with a time limit of 15 min. Results with this measure are summarized in the top row of Table 4. The pattern of standardized coefficients suggests that crossword puzzle proficiency is primarily influenced by vocabulary ability, with small and not statistically significant influences of reasoning and memory abilities. Furthermore, to account for the age-related effects observed on this measure of crossword puzzle performance, the results imply that one must account for effects operating through vocabulary ability and also for positive age-related effects on at least one additional factor that is associated with better crossword puzzle performance. The analysis does not indicate the nature of the other factor(s) responsible for any direct or unique age-related influences, but in this particular case it may be related to a greater accumulation of a specific type of knowledge required in these crossword puzzles.

A second set of analyses was conducted on new variables hypothesized to be primarily influenced by one of the five cognitive abilities. Results with these variables serve as a validity check on the analytical method because to the extent that the procedure

Table 3
Means, Standard Deviations, Age Correlations, and Standardized Factor Loadings for the Reference Variables

Variable	*N*	*M*	*SD*	Age correlation	Factor: Reasoning	Spatial visualization	Episodic memory	Perceptual speed	Vocabulary
Age	6,959	49.1	17.2	—					
Gender (% female)	6,959	58.0	4.9	.02					
Education[a]	5,208	15.3	2.6	−.01					
Health[b]	6,943	2.1	1.0	.13*					
Ravens	2,110	7.6	3.7	−.50*	.89+				
Shipley Abstraction	1,408	13.2	4.6	−.30*	.86*				
Letter Sets[c]	1,308	10.0	3.9	−.26*	.80*				
Spatial Relations[d]	1,290	9.3	5.1	−.36*		.91+			
Paper Folding[c]	1,129	6.5	2.9	−.44*		.83*			
Form Boards[c]	990	7.2	4.2	−.41*		.79*			
Free Recall[e]	1,895	0.7	0.2	−.41*			.79*		
Paired Associates[e]	1,897	2.8	1.7	−.37*			.73*		
Logical Memory[f]	923	45.1	10.2	−.25*			.74+		
Letter Comparison[g]	6,212	10.4	3.2	−.43*				.80*	
Pattern Comparison[g]	6,212	16.4	4.2	−.52*				.82*	
Digit Symbol[h]	2,177	77.1	19.1	−.57*				.78+	
Synonym Vocabulary[i]	3,640	6.9	2.9	.28*					.89*
Antonym Vocabulary[i]	3,637	6.3	3.2	.18*					.90*
WAIS Vocabulary	927	51.4	10.3	.09*					.85*
WJ Picture Vocabulary	930	19.1	5.4	.29*					.77+
Factor correlations									
Reasoning					—	.92*	.73*	.78*	.45*
Spatial visualization						—	.66*	.66*	.43*
Episodic memory							—	.70*	.47*
Perceptual speed								—	.29*
Vocabulary					−.47*	−.40*	−.47*	−.61*	.27*

Note. The plus symbol (+) indicates that the unstandardized coefficient was fixed to one to identify the factor. The fit statistics were as follows: $\chi^2(753) = 94$; comparative fit index = .96; root-mean-square error of approximation = .03. Ravens = Advanced Progressive Matrices: Set II (Raven, 1962); Shipley = Shipley Institute of Living Scale—Revised (Zachary, 1986); WAIS = Wechsler Adult Intelligence Scale—Third Edition; WJ = Woodcock–Johnson Psycho-Educational Battery—Revised.
[a] Number of years of education completed. [b] Self-rating of health on a scale ranging from 1 (*excellent*) to 5 (*poor*). [c] Ekstrom et al. (1976). [d] Bennett, Seashore, and Wesman (1997). [e] Salthouse, Fristoe, and Rhee (1996). [f] Wechsler (1997b). [g] Salthouse and Babcock (1991). [h] Wechsler (1997a). [i] Salthouse (1993b).
* $p < .01$.

is valid, these variables would be expected to have strong relations with the relevant ability but relatively weak relations with other abilities.

Examination of the relevant rows in Table 4 indicates that measures postulated to represent different cognitive abilities generally had their highest loadings on the hypothesized ability. The Surface Development (Ekstrom, French, Harman, & Dermen, 1976) and Word Recall (Wechsler, 1997b) measures still had some unique age-related influences after considering influences of age through other abilities, which implies that not all of the age-related effects on these particular measures were shared with age-related effects on the cognitive abilities represented in the analysis. However, for the most part, the pattern in the top of Table 4 is consistent with the interpretation that the measures are primarily influenced by the hypothesized abilities and that most of the age-related effects on the measures are shared with age-related effects on the hypothesized ability and on other cognitive abilities.

As noted earlier, the strong correlation between the reasoning and space ability constructs (i.e., .92 in Table 3) can distort estimates of the influences of these abilities because of collinearity when both predictors are considered simultaneously. The analyses of the reasoning and spatial visualization measures were therefore repeated after dropping either the space or the reasoning construct from the model. For the Series Completion (Salthouse & Prill, 1987) and Analysis Synthesis (Woodcock & Johnson, 1990) measures, deletion of the space construct resulted in significant loadings only on the reasoning construct (i.e., .56 for Series Completion and .76 for Analysis Synthesis). For the Block Design (Wechsler, 1997a) measure, deletion of the reasoning construct resulted in a loading of .78 on the space construct and no other significant loadings, and for the Surface Development measure, there were only significant loadings of .75 on the spatial visualization ability and .32 on the vocabulary ability after the reasoning construct was deleted.

The results just described suggest that the analytical procedure based on the model in Figure 1 is informative about the relative magnitude of relations between different cognitive abilities and the target variable and about the unique relation of age on the variable after controlling age-related influences on several cognitive abilities. The procedure was therefore applied to measures often hypothesized to reflect executive functioning or aspects of executive control.

The first set of variables under the *Executive functioning* heading in Table 4 are the same variables examined in Data Set 1. Comparison of the results in Tables 2 and 4 indicates that the pattern was very similar in the two independent data sets. Specifically, the results in Table 4 indicate that the number of categories measure of the Wisconsin Card Sorting Test performance was strongly related to reasoning ability (and significantly so when the space construct was deleted from the analysis) and that there were no unique age-related effects on the number of categories measure after considering age-related influences through the set of cognitive abilities. Moreover, the fluency measures were all influenced by speed ability, and in each of these measures, the age relation was reversed in direction from negative to positive when the influences through the cognitive abilities were taken into consideration. Finally, the same-sequence connections measure was again influenced by reasoning and speed abilities, with the other connections measures having a mixed pattern of influences, and there were no unique age-related effects on any of the measures after considering influences through the cognitive abilities.

The Ruff Figural Fluency Test (Ruff, 1996) involves the participant attempting to draw lines between dots to generate as many different figures as possible within a fixed period of time. It is therefore similar to the Verbal Fluency tests but without any involvement of words. It can be seen in Table 4 that this measure was significantly related to perceptual speed ability and that there were no unique age-related effects on the measure after considering influences through the cognitive abilities.

The Tower of Hanoi task requires the participant to change one arrangement of disks on three towers to a different arrangement in the fewest number of moves, with the constraints that only one disk can be moved at a time and that a larger disk can never be placed on top of a smaller disk. Performance on this task is sometimes postulated to assess planning and goal management aspects of executive functioning. The results in Table 4 indicate that the average number of moves required in the Tower of Hanoi task was related to reasoning and memory abilities, but only the memory relation was statistically significant because of the large standard error for the reasoning relation. Both the influences from reasoning and from memory were significant when the space construct was deleted from the analysis. It is important to note that there were no unique age-related effects on the number of moves in the Tower of Hanoi task when age-related influences through the cognitive abilities were taken into consideration. This pattern implies that at least with respect to individual differences associated with aging, the Tower of Hanoi task does not seem to measure anything distinct from what is measured with the variables used to represent the five cognitive abilities in the model portrayed in Figure 1.

The Sort Recognition Test is included in the Delis–Kaplan Executive Function System (Delis et al., 2001) to assess conceptual reasoning ability. The task for the participant is to identify the basis for grouping objects into two categories. The number of correct classifications in this test was weakly and nonsignificantly related to the reasoning, space, and memory abilities. After deletion of the space construct, the influence of reasoning ability was larger and statistically significant. There were no unique age-related effects on the Sort Recognition measure after considering indirect age-related effects through the cognitive abilities.

The Proverb Interpretation test is a subtest included in the Delis–Kaplan Executive Function System (Delis et al., 2001) to assess verbal abstraction skills. The version of the test used in this project required the participant to select the best interpretation of the proverb from a set of alternatives. Performance on this test was positively related to reasoning ability and vocabulary ability but was negatively related to space ability. When the space construct was deleted from the analysis, none of the relations with any of the cognitive abilities were significant.

The Trail Making Test requires the examinee to draw lines to connect circles in a specified sequence as rapidly as possible. In Version A of the test, the circles contain numbers that are to be connected in numerical sequence. In Version B, the circles contain both numbers and letters, and the task is to connect the items in alternating numeric and alphabetic sequence. Performance in B relative to A is often assumed to reflect planning, switching, and maintaining the current status in each of the two sequences. No spatial visualization variables were included in the samples in which the Trail Making Test was administered, and thus it was not possible to examine the influence of the space ability construct on these measures. The Trail Making A, B, and B – A measures were all primarily influenced by speed, although the B-minus-A difference was also influenced by reasoning. There were no unique age effects in any of the Trail Making measures when age-related influences through the cognitive abilities were controlled.

Switching tasks have become popular as a means of investigating the efficiency of controlling one’s attention. The versions used in the study included in the data set were reaction time tasks in which initially the participant was to respond with one rule (e.g., press the right key for an odd digit and press the left key for an even digit), but when a signal occurred he or she was to switch to a different rule (e.g., press the right key for a digit greater than five and press the left key for a digit less than five). The primary measure of performance in these tasks is the difference between reaction time in the preswitch trials and reaction time on the trial immediately after the switch signal. The values in Table 4 indicate that the pattern of relations with cognitive abilities was inconsistent across the three measures with different combinations of rules, but in none of the measures was there a significant unique relation from age.

One aspect of cognitive control that has frequently been mentioned as a component of executive functioning is inhibition of prepotent responses. A popular test of this type of inhibition is the Stroop Color–Word Test in which the task is to name the colors of letter strings when the strings are XX’s (neutral), when they are names of the colors in which they are written (congruent), and when they are names of colors different from those in which they are written (incongruent). Naming times in this type of situation are typically very slow in the incongruent condition, and it is often assumed that this occurs because two potential responses (i.e., word name and color name) are in conflict and some type of inhibition is needed to suppress the currently irrelevant response. All of the Stroop measures, including the incongruent-minus-congruent difference score, were primarily influenced by speed

Table 4
Standardized Coefficients of Relations Between Variables and Age When Considered Alone and Age When Considered in the Context of Other Cognitive Abilities

Variable	Studies	*n*	Only age	Unique age	Cognitive ability				
					Reas	Space	Mem	Speed	Voc
New York Times crossword puzzle	25, 26, 30	601	.43*	.47*	.21	.02	.15	−.06	.47*
Reasoning									
Series Completion[a]	31	150	−.37*	.12	.64	−.17	.11	.25	.09
WJ Analysis Synthesis	31	204	−.36*	.09	.72	−.07	.12	.01	.07
Space									
Block Design[b]	16, 31	463	−.39*	.00	−.73*	1.21*	.21	.18	.12
Surface Development[c]	1, 2, 30	639	−.32*	−.21*	−.88*	1.48*	.06	−.02	.08
Memory									
New Recall (List B)[d]	16, 31–34	1,203	−.36*	.09	−.15	.07	.94*	−.01	−.11
Word Recall[d]	33	329	−.50*	−.22*	.18	−.21	.74*	−.08	.02
Speed									
Cross Out[e]	31	204	−.71*	−.10	.03	.09	−.13	.85*	−.04
Digit Digit RT[f]	8–14, 17–22, 27	2,417	−.41*	−.03	−.08	.01	.34*	.41*	−.08
Vocabulary-Knowledge									
Multiple-Choice Knowledge[g]	23–26, 30	803	−.05	.10	−.20	.37	.23	.02	.60*
Short Answer Knowledge[g]	25, 30	401	.09	.19*	−.07	.22	.23	−.07	.60*
Executive functioning									
WCST Number Categories	16, 18, 32	711	−.28*	−.12	.62	−.09	−.17	.01	.12
Letter Fluency[h]	16, 19, 23, 24, 31–33	1,447	−.13*	.15*	.19	−.06	.14	.32*	.21*
Category Fluency[h]	19, 33	454	−.19*	.33*	−.08	.03	.50*	.51*	−.03
Alternating Fluency[h]	33	330	−.20*	.22	−.42	.19	.43*	.54*	−.11
Connections—Same sequence	27–34	1,520	−.41*	.03	.47*	−.15	.03	.40*	−.08
Connections—Alt. sequence	27–34	1,520	−.21*	.08	.07	−.05	.05	.21*	−.12
Connections—Difference	27–34	1,520	−.14*	.07	.02	.04	.05	.13	−.13
Ruff Figural Fluency[i]	32	261	−.44*	−.01	.31	.19	−.04	.40*	−.01
Tower of Hanoi[j]	32	254	−.29*	.08	.52	.05	.34*	−.17	−.27*
Sort Recognition[h]	33	330	−.45*	−.11	.28	.26	.21	−.02	.05
Proverb Interpretation[h]	33	330	−.21*	−.06	.72*	−.65*	.11	.12	.20
Trail Making A	16, 19	383	−.50*	−.28	.22	—	−.27	.78*	.25
Trail Making B	16, 19	383	−.55*	−.10	.18	—	−.01	.55*	−.01
Trail Making B − A difference	16, 19	383	−.47*	.00	.34	—	.11	.34*	−.13
Switch 1	20	159	−.37*	−.06	.13	—	.31	.25	−.22
Switch 2	20	159	−.37*	.02	.12	—	.32	.21	−.01
Switch 3	20	159	−.42*	−.22	−.23	—	.21	.42	.10
Inhibition									
Stroop congruent	14, 15, 32	681	−.41*	.00	.32	−.31	−.01	.57*	−.15
Stroop neutral (N)	14, 15, 32	681	−.44*	.06	.13	−.23	.02	.74*	−.04
Stroop incongruent (I)	14, 15, 32	681	−.57*	.01	.53	−.25	.11	.48*	−.12
Stroop I − N difference	14, 15, 32	681	−.48*	−.16	.26	−.03	.07	.25*	−.02
Reading time normal	32	260	−.19*	−.22	−.14	−.25	.05	.48*	.51*
Reading time distraction	32	261	−.18*	−.07	.33	−.28	−.02	.38*	.38*
Reading time difference	32	261	−.14	−.05	.32	−.24	−.03	.34*	.36*
Reading acc normal	32	261	−.23*	−.17	.35	−.19	.27*	−.30	−.08
Reading acc distraction	32	261	−.20*	−.02	.51	−.04	.38*	−.31*	.02
Reading acc difference	32	261	.05	−.07	−.29	−.06	−.22	.13	−.06
Anti-Cue time congruent	32	255	−.45*	−.24	.01	−.16	.04	.41*	.05
Anti-Cue time incongruent	32	255	−.49*	−.37*	−.01	−.12	−.12	.42*	.07
Anti-Cue time difference	32	255	−.25*	−.32*	−.04	.02	−.28*	.17	.20
Anti-Cue acc congruent	32	255	−.27*	−.06	.11	.06	−.01	.24	−.05
Anti-Cue acc incongruent	32	255	−.39*	−.15	.20	.10	−.18	.35*	.02
Anti-Cue acc difference	32	255	.18*	.13	−.13	−.07	.23	−.18	−.08
Working Memory									
WAIS Letter-Number Sequence	31	204	−.40*	−.03	.40	−.16	.23	.15	.07
Computation Span[k]	3–6, 12, 14, 18	1,461	−.29*	.07	.95*	—	—	−.22*	−.18
Reading Span[k]	3–6, 12, 14, 18	1,461	−.36*	−.23	.00	—	—	.34*	.33*
NBack-0[j]	32	261	−.24*	−.04	.22	−.13	.26	−.00	−.15
NBack-1[j]	32	261	−.36*	−.02	.69*	−.38	.20	.25	−.14
NBack-2[i]	32	261	−.38*	−.02	.72*	−.07	.09	.09	−.09
Keeping Track[j]	32	257	−.23*	−.10	.83*	−.31	.07	−.19	.04
Matrix Monitoring 1[j]	32	258	−.17*	.12	.48	−.05	.06	.08	−.14

Table 4 (*continued*)

Variable	Studies	n	Only age	Unique age	Cognitive ability				
					Reas	Space	Mem	Speed	Voc
Working Memory (*continued*)									
Matrix Monitoring 2[j]	32	257	−.26*	.20	.95*	−.17	.07	.08	−.18
Running Memory[l] 1-back	33	330	−.34*	.01	−.11	.17	.24	.19	.12
Running Memory 2-back	33	330	−.27*	.19	.60*	−.22	.14	.30*	.00
Running Memory 3-back	33	330	−.20*	−.05	.10	.12	.22	.17	.08

Note. All target variables expressed in time or errors were recoded such that a higher score represented better performance, and a negative correlation with age reflected poorer performance with increased age. Dashes indicate that data were not obtained. Reas = reasoning; Space = spatial visualization; Mem = episodic memory; Speed = perceptual speed; Voc = vocabulary; 23, 24, 25, 26 = Hambrick, Salthouse, and Meinz (1999); 30 = Salthouse (2001b); 31 = Salthouse and Ferrer-Caja (2003); 16 = Salthouse, Fristoe, and Rhee (1996); 1 = Salthouse and Mitchell (1990); 2 = Salthouse, Babcock, Skovronek, Mitchell, and Palmon (1990); 32 = Salthouse, Atkinson, and Berish (2003); 33 = Salthouse, Berish, and Siedlecki (2004); 34 = Salthouse, Nesselroade, and Berish (2004); 8, 9 = Salthouse (1994b); 10, 11 = Salthouse (1994a); 12 = Salthouse (1995); 13 = Salthouse, Fristoe, Lineweaver, and Coon (1995); 14 = Salthouse and Meinz (1995); 17 = Salthouse, Hambrick, Lukas, and Dell (1996); 18 = Salthouse, Hancock, Meinz, and Hambrick (1996); 19 = Salthouse, Toth, Hancock, and Woodard (1997); 20 = Salthouse, Fristoe, McGuthry, and Hambrick (1998); 21 = Meinz and Salthouse (1998); 22 = Salthouse, McGuthry, and Hambrick (1999); 27 = Salthouse et al. (2000); 28, 29 = Salthouse (2001a); 15 = Salthouse (1996); 3 = Salthouse and Babcock (1991); 4, 5 = Salthouse (1992); 6 = Salthouse (1993a); WJ = Woodcock–Johnson Psycho-Educational Battery—Revised; RT = reaction time; WCST = Wisconsin Card Sorting Test; Alt. = alternating; Trail Making A = Trail Making Test, Version A (Barnes et al., 2003); Trail Making B = Trail Making Test, Version B; Stroop = Stroop Color Word Test (Barnes et al., 2003); acc = accuracy; WAIS = Wechsler Adult Intelligence Scale—Third Edition.
[a] Salthouse and Prill (1987). [b] Wechsler (1997a). [c] Ekstrom et al. (1976). [d] Wechsler (1997b). [e] Woodcock and Johnson (1990). [f] Salthouse (1992). [g] Hambrick, Salthouse, and Meinz (1999). [h] Delis et al. (2001). [i] Ruff (1996). [j] Salthouse et al. (2003). [k] Salthouse and Babcock (1991). [l] Siedlecki, Salthouse, and Berish (2005).
* $p < .01$.

ability, with the incongruent measure also significantly related to reasoning ability. After controlling for the age-related influences on the cognitive abilities, it was found that none of the Stroop measures had unique age-related effects.

Several of the tasks used to evaluate inhibition assessed performance both in terms of time and accuracy, and thus both measures are considered separately in these analyses. (Relations of cognitive abilities on composite measures of time and accuracy were examined with data from a single study in Salthouse et al., 2003.)

The Reading With Distraction task (Salthouse et al., 2003) resembles the Stroop task in that in order to be successful the participant must inhibit the tendency to make an irrelevant response. The task involves the participant reading short passages and answering questions about them in two conditions. In one condition, the to-be-read text is normal, and in the other condition, distracting words in a different font are interleaved within the normal text. The primary performance measures in this task are the reading time in the normal condition, the reading time in the distraction condition, and the difference between normal reading time and reading time with distraction. It can be seen in Table 4 that all of the reading time measures were primarily influenced by the speed and vocabulary abilities. There were no significant unique age effects on the reading time measures after adjusting for influences through the cognitive abilities.

Comprehension accuracy in the Reading With Distraction task was assessed in terms of accuracy of answering questions about the passage immediately after reading it. The reading accuracy measures were mostly influenced by memory ability, but they also had a negative relation to speed ability. There were no unique age-related effects on the reading accuracy measures after controlling age-related effects on the cognitive abilities.

The Anti-Cue task (Salthouse et al., 2003) was based on the Antisaccade task (de Jong, 2001) that has been used to investigate reflexive shifts of attention. In the version used in the study included in the aggregate data set, the respondent fixates in the middle of the computer screen, a flash (cue) is briefly presented on the left or right side of the display, and then a target letter (X or O) is presented either on the same side as the cue (congruent) or on the opposite side (incongruent). Both time and accuracy of the decisions are monitored in each condition. The decision time measures in this task were influenced by speed ability, but there were also strong unique age-related effects which indicate that the age-associated influences on these measures were not fully captured by the age-related influences on the cognitive abilities. The accuracy measures in the Anti-Cue task had weak and inconsistent relations to the cognitive abilities, but there were no unique age-related effects after controlling the influences of age on those abilities.

Several target variables were designed to assess simultaneous processing and storage aspects of working memory, but the results from the analyses were quite complex. In the Letter-Number Sequencing task from the Wechsler Adult Intelligence Scale—Third Edition (Wechsler, 1997a), the participants listened to an intermixed sequence of letters and digits and then reported the numbers in numerical order followed by the letters in alphabetical order. This measure did not have significant relations to any of the cognitive abilities, but it also had no unique age-related effects.

The Computation Span and Listening Span tasks (Salthouse & Babcock, 1991) were similar to the letter sequencing task in that the examinee attempted to carry out specified processing while keeping other information in memory. In the Computation Span task, the participant viewed a series of simple arithmetic problems that were to be solved by selecting the correct answer from a set of alternatives and also tried to remember the last digit in each problem for later recall. In the Listening Span task, the participant heard a series of sentences and then answered a question about the sentence while trying to remember the last word in each sentence for later recall. Although these two tasks were designed to be very similar and were administered to the same individuals, the measures had different patterns of relations with the cognitive abilities. For example, the Computation Span measure was positively related to reasoning and negatively related to speed, whereas the Listening Span measure was positively related to speed and to vocabulary. However, there was no unique age-related influence on either measure after considering age-related influences through the cognitive abilities. The inconsistency in the patterns may be at least partially attributable to the weak representation of different cognitive abilities in the studies in which these tasks were administered and in particular to the absence of any samples in which reference variables from space or memory abilities were assessed.

The N-back task (Salthouse et al., 2003) involves the research participant listening to or viewing a sequence of digits and reporting the items that occurred *N* items back in the sequence. Versions of this task have been popular in neuroimaging studies because the stimuli and responses can remain the same while the processing load is increased by requiring items farther back in the sequence to be reported. Inspection of Table 4 indicates that performance in this task was related to reasoning ability, with a stronger influence when the presumed mental demands increased from the 0-back to either the 1-back or 2-back condition. In none of the measures were there significant unique age-related effects after controlling age-related effects on the cognitive abilities.

The Keeping Track task (Salthouse et al., 2003) involves the presentation of a sequence of words from different categories, with the sequence periodically interrupted by queries in which the research participant was to determine whether the displayed word was the most recent member of the designated category. Performance on this task was strongly related to reasoning ability, and there were no significant unique age-related effects after considering effects through other cognitive abilities.

The Matrix Monitoring task (Salthouse et al., 2003) consisted of a series of four displays. The first contained a matrix with a dot in one cell, and the next two contained arrows indicating the direction in which the dot should be moved. The final display portrayed a dot in a new position in the matrix, with the research participant asked to decide whether this was the correct position for the dot on the basis of the initial position and the sequence of movements indicated by the arrows. There were two conditions in this task, the one-matrix condition just described and a two-matrix condition in which the same type of monitoring had to be carried out simultaneously with two matrices. Matrix monitoring performance was related to reasoning ability, with a stronger relation in the more demanding two-matrix condition. Deletion of the space construct from the analysis with the two-matrix measure resulted in the relation with reasoning remaining strong (i.e., .94), but deletion of the reasoning construct resulted in a much smaller relation with the space construct (i.e., .37). In none of the analyses with the Matrix Monitoring measures were the direct age-related effects significantly different from zero after controlling the influences of age on the cognitive abilities.

The Running Memory task (Siedlecki, Salthouse, & Berish, 2005) involved the examinee viewing a sequence of words and then occasionally being asked to recall the last three words in the sequence. Performance was assessed as the percentage of words correctly recalled in each serial position. Examination of Table 4 indicates that there was an inconsistent mixture of influences across the three serial positions, as the influence of reasoning ability was greater in the second position than in the first (most recent) position but was smaller in the third position. After controlling for age-related influences on the cognitive abilities, it was discovered that there were no unique age relations on the Running Memory measures.

General Discussion

The research reported in this article used the analytical model portrayed in Figure 1 to investigate the meaning of variables frequently hypothesized to reflect executive functioning. The rationale was that if the target variables represent something different from the cognitive abilities included in the model, then the variables not only should have relatively weak relations to those abilities but also should have significant unique (direct) relations with an individual-difference variable such as age if they are reliably influenced by another construct, such as executive functioning, that is related to age.

Evidence for the plausibility of the analytical method is available from the findings that measures hypothesized to reflect different cognitive abilities had expected patterns of loadings on their respective abilities and had few unique age-related influences. Moreover, the method is capable of identifying variables in which there are strong direct relations from age because the crossword puzzle performance measure had a substantial unique relation with age after considering age-related influences through the cognitive abilities. This pattern is consistent with the possibility that crossword puzzle performance is influenced by a construct not represented by the cognitive abilities in the model, which in this case probably corresponds to a specialized type of knowledge that increases with age among these individuals.

The similar pattern of results with two quite different data sets also indicates that the analytical method yields replicable results. One data set was based on a modest-sized sample of 328 adults with complete data on all reference variables but only a few variables postulated to reflect executive functioning, and the other was based on data from nearly 7,000 adults aggregated across 34 different studies with a large proportion of missing values for the reference variables but a substantial number of candidate executive variables.

Application of the analytical method to variables hypothesized to reflect the neuropsychological construct of executive functioning revealed that many of the target variables are closely related to the cognitive abilities of reasoning and perceptual speed. Furthermore, this was equally true for measures derived from traditional neuropsychological tests as for measures intended to assess specific aspects of cognitive control such as inhibition or working memory. Another pattern apparent in Tables 2 and 4 was that very few of the executive functioning variables had age-related influences that were statistically independent of the age-related influences on the cognitive abilities. Because this indicates that most of the variance shared between the target variable and age overlapped with the variance in established cognitive abilities, it is inconsistent with the interpretation that the target variable represents a distinct construct. The outcomes of these analyses therefore suggest that measures currently used by neuropsychologists to assess executive functioning may not represent novel aspects of functioning in normal adults. Instead they appear to reflect the same dimensions of differences assessed by more traditional cognitive tests that may have superior psychometric properties (in terms of reliability and sensitivity).

Although the results summarized in Tables 2 and 4 appear convincing, as with any project there are several limitations. One is that only five cognitive abilities were represented in the analyses, and the number of conceptually distinct cognitive abilities could be as many as 40 or more (Carroll, 1993). Furthermore, the representation of even these five abilities was not complete for all of the target variables because reference variables for some abilities were not included in several studies in the second data set, which precluded analyses of the relations between the ability and the target variable.

A second limitation of the analyses is that it is not clear whether the different pattern of results across ostensibly similar measures reflects weaknesses of the analytic method or unexpected complexity of the measures. The inconsistent pattern is particularly apparent with the switching measures used to assess efficiency of redirecting attention and with the working memory span measures used to assess working memory. In both cases, very similar target measures were obtained from the same participants and with the same combinations of reference cognitive variables, and yet the measures differed in their patterns of relations with cognitive abilities. These inconsistencies may reflect the involvement of construct-irrelevant characteristics such as the type of stimulus material (i.e., words vs. numbers) or the particular processing requirements (e.g., listening or reading vs. performing simple arithmetic). Until the reasons for the different patterns of relations with cognitive abilities are understood, however, researchers should be cautious in concluding that measures represent the same construct and in inferring that they would have the same patterns of relations with other constructs merely because they appear to involve similar processes.

Finally, although Figure 1 represents cognitive abilities as influencing the target variables, it is important to recognize that the direction of the relation between abilities and the target variable depends on one's theoretical perspective and cannot be distinguished on the basis of the current analyses. That is, latent constructs in the analyses conducted here correspond to variance that is common across variables, but the analyses are not necessarily informative about the reasons for that commonality. The latent constructs could correspond to abilities that affect the efficiency or effectiveness of the processes required in the tasks (as is assumed in the representation in Figure 1), or they could reflect the operation of critical processes that are involved in each of the measures postulated to assess different cognitive abilities (in which case the arrows in Figure 1 might be from the target variable to the ability constructs). Miyake and colleagues (e.g., Friedman & Miyake, 2004; Miyake et al., 2000) have adopted this latter type of process interpretation as they have tried to identify latent constructs that represent different theoretical processes and have then examined the relations of these constructs to performance on various cognitive or neuropsychological tests. Although the two approaches differ in how the constructs are conceptualized and in which theoretical concepts are assumed to be most fundamental, both acknowledge that there are strong relations among neuropsychological and cognitive variables and even stronger relations among latent constructs representing the variance shared among variables. Another common theme in the two approaches is the assumption that there are seldom one-to-one relations between variables and theoretical constructs and hence that few variables can be considered to be pure, either with respect to processes or to abilities.

In conclusion, this article raised the question of the type of evidence needed to establish that measures postulated to assess executive functioning actually do represent that construct. It was proposed that a potentially informative method of investigating the meaning of a variable is to examine the pattern of relations it has with established cognitive abilities and the degree to which the variable has unique relations with an individual-difference variable such as age. The results of the analyses suggest that many variables postulated to assess executive functioning in healthy adults are closely related to cognitive abilities of reasoning and perceptual speed. Furthermore, although nearly all of the purported executive functioning variables were negatively related to age, only a small proportion of the age-related influences were statistically independent of the age-related influences on the cognitive abilities. Taken together with the recent findings of Salthouse et al. (2003), these results raise questions about the extent to which executive functioning represents a distinct dimension of individual differences in healthy adults.

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