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Age-Related Effects on Memory in the Context of Age-Related Effects on Cognition

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Negative age relations on measures of episodic memory are well-established because they have been found in literally hundreds of studies involving a wide variety of samples. Perhaps the most convincing illustration of this phenomenon is apparent in the results from the large nationally representative samples used to establish the norms for standardized tests of memory. For example, figure 1 portrays results from tests of immediate and delayed recall or recognition of stories, words, paired associates, and faces from the normative sample for the Wechsler Memory Scale III (Wechsler, 1997a). Notice that there is a performance difference of about 1 to 1.5 standard score units between age 20 and age 80. If this difference can be interpreted as reflecting changes occurring within an individual, then someone who at age 20 is at the 85th to 90th percentile of the population on a variable would be at the 50th percentile at age 70, and someone who is at the 50th percentile at age 20 would be between the 10th and 15th percentile at age 70. Expressed somewhat differently, because the range from −3 to +3 standard deviations encompasses over 99.7% of a normal distribution, a difference of 1 to 1.5 standard deviation units corresponds to between 1/6 and 1/4 of the effective range of scores in the population. Differences of this magnitude are likely to have a substantial impact on an individual's quality of life.

Most attempts to explain these types of age-related memory differences have focused on processes or components presumed to be involved in particular tasks. That is, because almost all memory and cognitive variables are hypothesized to reflect a mixture of different processes, many researchers have attempted to refine or purify the assessment to identify which specific processes are contributing to the age differences

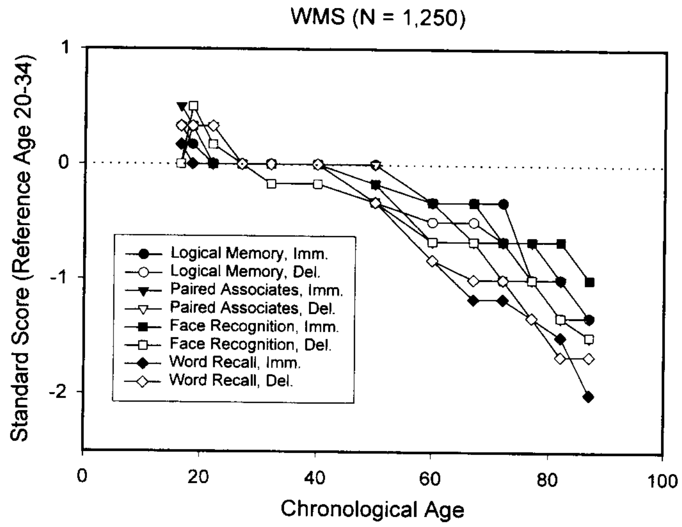

Figure 1
Performance in various episodic memory tasks (intermediate and delayed) as a function of age. (Data from Wechsler, 1997a.)

observed in a particular task. A primary motivation underlying this search for individual processes is the assumption that it is difficult, if not impossible, to understand the nature of age-related effects on a given task until the specific aspects responsible for the age differences in performance of the task can be identified and isolated. The decomposition or fractionation approach has had some success, as differential aging patterns have been observed on certain variables. For example, age-related effects are typically greater on conscious controlled processes than on automatic processes, and on processes related to encoding and retrieval than on processes related to storage.

However, large negative age relations are also evident on other types of cognitive variables besides those reflecting episodic memory. To illustrate, figure 2 portrays results on measures of working memory, perceptual speed, spatial visualization, and reasoning from the normative sample for the Wechsler Adult Intelligence Scale III (Wechsler, 1997b). Once again, it can be seen that the performance difference between age 20 and 80 is about 1 to 1.5 standard score units.

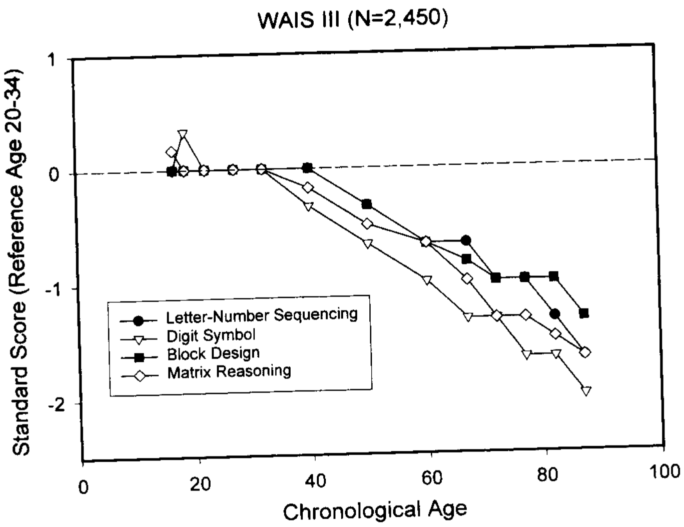

Figure 2
Performance in various cognitive tasks as a function of age. (Data from Wechsler, 1997b.)

The presence of age-related effects on so many different variables raises questions about the extent to which the age-related effects on memory variables are independent of the age-related effects on other types of variables. That is, regardless of the specific process suspected to be most age-sensitive in a particular task, the wide variety of variables exhibiting age-related differences suggests that it is meaningful to ask whether the age-related effects on a given variable are unique or are shared with the age-related effects found on other variables.

An implicit assumption among many cognitive researchers is that distinct causal factors are responsible for the age-related effects on different types of cognitive variables. That is, memory functioning might be impaired by age-related effects on processes such as encoding, on structures such as secondary memory, or on strategies such as organization that are specific to memory tasks, though qualitatively different mechanisms are presumed to be responsible for the age differences on variables reflecting other types of functioning.

If the age-related effects on memory are attributable to influences on processes, structures, or strategies specifically associated with the performance of memory tasks, then one might expect most of the age-related effects on memory variables to be independent of the age-related effects apparent on other types of cognitive variables. As a crude analogy to illustrate this point, consider the functioning of an automobile. A large number of distinct components are involved in the optimal functioning of an automobile, and the various components are often associated with separate and independent problems. For example, the failures that occur in the brake system are usually attributable to quite different factors than those that occur in the transmission system, the fuel system, or the steering system. It is possible that cognitive functioning is also somewhat modular with respect to age-related influences, so that age-related effects on memory are largely independent of age-related effects on reasoning, which in turn are independent of age-related effects on spatial abilities, etc.

However, an alternative possibility is that age-related effects on memory and other cognitive variables are not independent of one another but instead are shared to varying degrees. In terms of the automobile analogy, nonindependent influences might occur if there are cascading effects, as when weak steering leads to an increase in wear and tear on the brakes and the transmission, or if there are systemic effects, as when the materials in all components are subject to the same type of corrosive deterioration.

Distinguishing between these alternatives is important, because if only a small proportion of the age-related variance in memory variables is unique and independent of the age-related influences on other types of variables, then broad and general types of interpretations would presumably be needed to explain the shared age-related effects. Process interpretations restricted to specific tasks could still be viable for explaining how age-related effects are manifested in a particular task, but more inclusive explanations would also be necessary to account for the existence of age-related effects that are shared across different types of tasks.

How can the independence of age-related influences on different cognitive variables be investigated? Patrick Rabbitt (1993), in the title of an article published several years ago, asked, "Does it all go together when it goes?" The independence issue essentially concerns this question. Either cross-sectional or longitudinal data can be used to investigate the question, but it is important to recognize that the two types of data do not necessarily address the same issues. Longitudinal data are concerned with within-individual change, and thus are inherently developmental. Cross-sectional data can also be viewed as developmental if the between-individual differences are considered approximations to within-individual changes. However, it is also possible to consider the age variable in cross-sectional data as a static individual difference, such as sex, ethnic group, or socioeconomic status, in which case it is of interest to describe the nature and pattern of the observed differences, regardless of any relation those differences might have to longitudinal changes. It is important to emphasize that the issue of the independence of age-related effects on different variables is relevant to either conceptualization of cross-sectional comparisons, as well as to longitudinal contrasts.

If longitudinal data are available, then independence of age-related influences might be investigated by simply examining the correlations among change scores. That is, the magnitude of the correlations among the change scores can be interpreted as the degree to which the age-related effects on the variables are shared, or "go together."

Although conceptually straightforward, several complications have limited the investigation of correlations among change scores. First, the longitudinal retest interval needs to be large enough to allow moderate age-related effects to be manifested in each variable, because if there is little change in the variables, then the correlations among them may be low or nonexistent. For many variables, this may require intervals of 10 to 20 years, unless the individuals are in the period of very late adulthood, where more pronounced age-related effects might be expected.

And second, change or difference scores often have low levels of reliability that severely restrict the magnitude of possible correlations with other variables. That is, because only the reliable or systematic variance in a variable is available to be associated with other variables, correlations among difference scores may not be interpretable if their reliabilities are unknown.

At the current time, therefore, only weak conclusions regarding the degree of independence of age-related influences on memory and other cognitive variables are possible from longitudinal data. Only a few studies have reported relevant correlations, and in each case the variety of variables was limited, and the retest interval was relatively short compared to the age range typically studied in cross-sectional comparisons.

Investigation of the independence of age-related influences is somewhat more complicated with cross-sectional data and is most easily accomplished with various types of statistical-control methods. For example, we can use mediation analysis if data from each individual are available on age, V_x (target variable), and V_1 (some other variable). That is, given information on these variables, it is possible to determine the relations between age and V_x, between age and V_1, and between V_x and V_1, and then the effects of V_1 (the hypothesized mediator) on V_x can be controlled when examining the age-related effects on V_x. The relation of age to V_x indicates the total age-related effects on that variable. Because control of V_1 removes all effects shared between V_1 and V_x, the effects of age on the residual V_x measure can be inferred to be unique and independent of any age-related effects on V_1. By comparing the age-related variance before and after statistical control of another variable, this analytical method provides estimates of the amount of age-related variance that is unique (i.e., of age-related effects on the residual of V_x after control of V_1), and of the amount of age-related variance that is shared (i.e., total minus unique).

This type of statistical-control analysis can be illustrated with measures of performance on free-recall and matrix-reasoning tasks as the V_x and V_1 variables, respectively. The free-recall variable was the average number of items correctly recalled across three trials of a list of 15 unrelated words, and the matrix-reasoning variable was the score in an abbreviated version of the Raven Progressive Matrices Test. To express performance in each task in a common metric, all variables were converted to standard-score units. Participants in this study (Salthouse, 2001) consisted of 206 healthy adults ranging from 18 to 84 years of age.

Figures 3 to 5 contain scatterplots of the relations between pairs of variables, and figure 6 the scatter plot of the relation between age and the residual measure of free recall created by partialling out the linear effect of matrix reasoning from the free-recall variable. Comparison of figures 3 and 6 reveals that the age relation to free recall is much weaker after controlling for the influence of matrix reasoning. Expressing the two relations in terms of proportions of variance indicates that only a

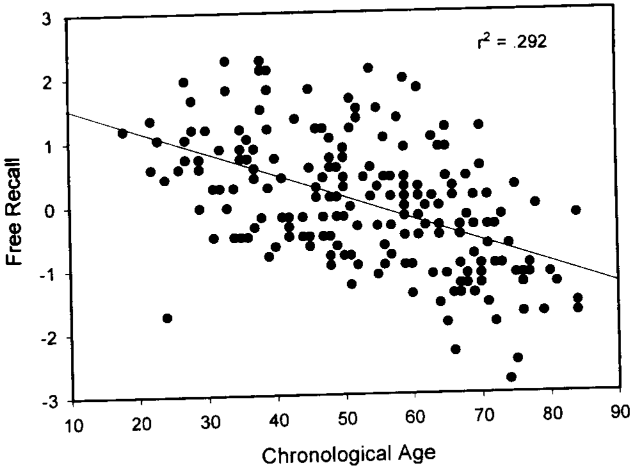

Figure 3
The relation between age and free recall in a sample of 206 adults. (Data from Salthouse, 2001.)

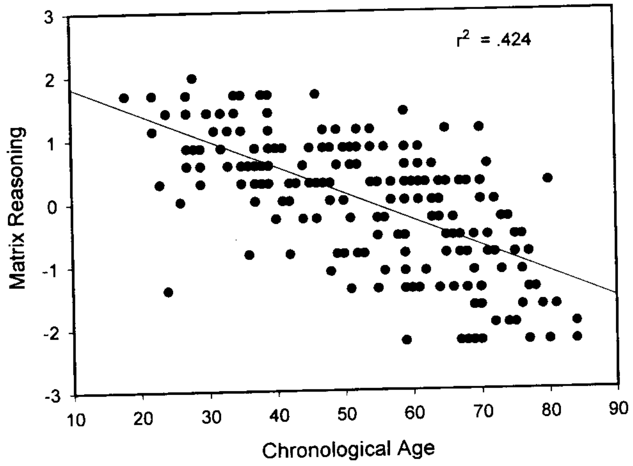

Figure 4
The relation between age and matrix reasoning in a sample of 206 adults. (Data from Salthouse, 2001.)

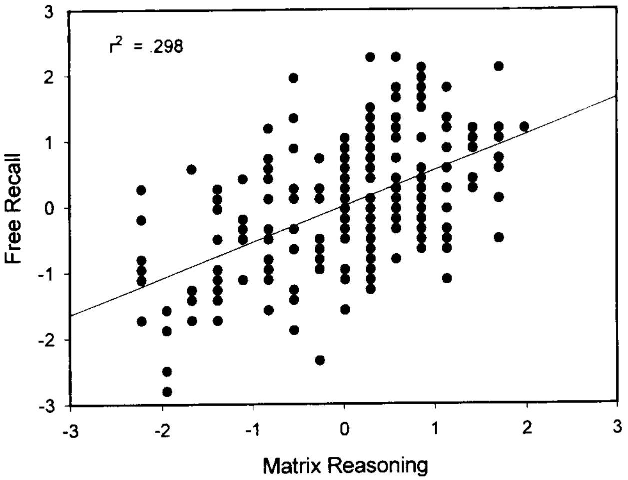

Figure 5
The relation between free recall and matrix reasoning in a sample of 206 adults. (Data from Salthouse, 2001.)

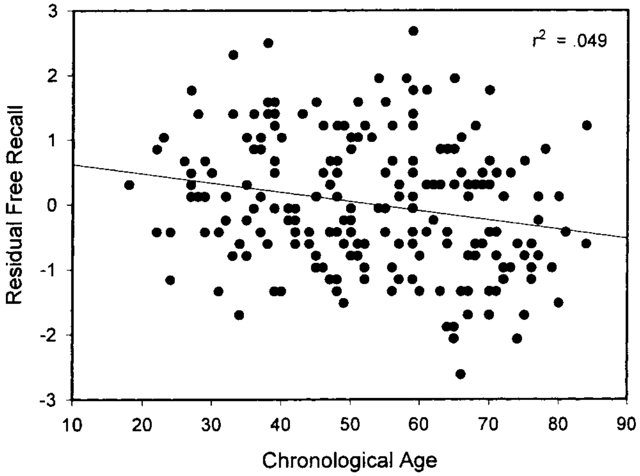

Figure 6
The relation between age and residual free recall after partialling out the linear effect of matrix reasoning on free recall. (Data from Salthouse, 2001.)

small proportion (i.e., .049/.292 = 17%) of the total age-related variance in the free recall variable was unique to that variable and independent of the variance in the matrix reasoning variable. Age-related effects on memory-specific mechanisms can therefore be inferred to be responsible for only a fraction of the total age-related effects observed in these particular free-recall measures.

Results with control of a single variable are informative about the relation between that particular variable and the target variable, but selection of the variable to function as the controlled or mediator variable is somewhat arbitrary. Certain variables or constructs are sometimes assumed to have a special status because they have been hypothesized to be causal mediators of the age-related effects on other variables. For example, a number of researchers have postulated that working memory and speed of processing function as mediators of age differences in other cognitive variables. However, many different types of variables could be hypothesized to serve in this role, and a large number of variables could be effective statistical mediators even if they are not plausible as causal mediators. To illustrate, the results summarized above indicate that matrix reasoning functions as an effective statistical mediator of age differences in free recall, but because matrix reasoning does not appear to be more fundamental or primitive than free recall, it is unlikely to be meaningful as a causal mediator. Unfortunately, distinguishing between mere statistical mediators and true causal mediators is difficult, if not impossible, with correlational analyses.

In part because of the ambiguity about the status of mediators, an alternative statistical control procedure has recently been used in which no variable is assumed to have causal priority, but instead all variables are viewed as sharing something negatively influenced by age. This perspective distinguishes two types of age-related effects on variables: one that is shared with other variables and a second that is unique to a particular variable. Shared age-related influences are those operating through a factor that accounts for the variance common to all variables, whereas unique influences on the variable in question are the independent effects associated with age that remain after control of the common effects.

This shared-influence analytical procedure can be implemented as follows. First, obtain an estimate of the variance the variables have in common by computing either the first principal component or the first principal factor that represents variance shared among all variables. Next, control the age-related effects on this estimate of what is common to all variables before examining the effects associated with age on individual variables. Any residual age-related effects on the target variable observed under these conditions can be inferred to be unique and independent of the age-related effects on other variables. When applied to variables reflecting memory functioning, the shared-influence analytical procedure provides a means of estimating the degree to which memory-specific factors contribute to the age differences observed in episodic memory variables. That is, by including variables from a variety of other cognitive tasks in this type of analysis, any unique age-related effects on memory variables can be inferred to be attributable to memory-specific mechanisms, whereas age-related influences shared with other types of cognitive variables would presumably require broader or more general explanatory mechanisms.

The shared-influence analytical procedure can be illustrated with results from my laboratory in which the target variables consisted of episodic-memory measures from free-recall and paired-associates tasks. The free-recall variable was the average number of words correctly recalled across two to six trials with either the same or different lists of 12 to 15 unrelated or categorized words, and the paired-associates variable was the average number of response terms recalled across two trials with six pairs of unrelated words. In addition to measures of episodic memory, each of the studies involved a mixture of other types of cognitive variables, primarily representing speed, reasoning, and spatial abilities. The samples of participants consisted of between 121 and 305 healthy adults who ranged from 18 to 95 years of age.

Figure 7 portrays the estimates of the total and unique age-related variance in the episodic-memory measures derived from the shared-influence analyses. It can be seen that only a very small proportion of the age-related effects on these episodic-memory variables was unique and independent of the age-related effects on other types of variables. Expressed in terms of shared influences, the percentage of age-related variance in the free-recall variables that was shared with other variables ranged from 94.0% to 99.9%, and from 95.1% to 99.9% for the per-

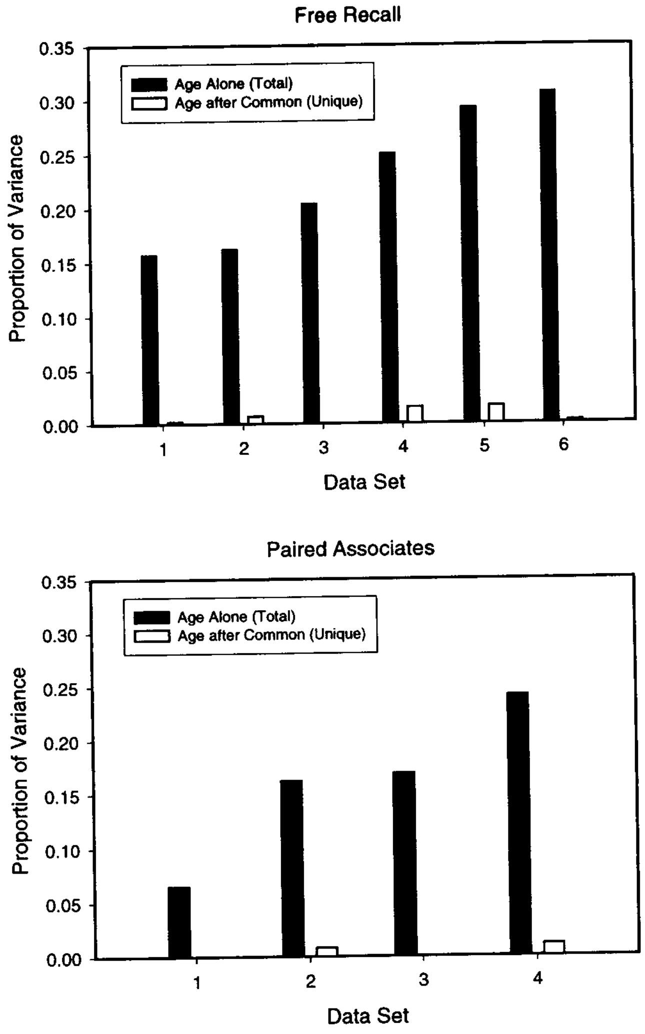

Figure 7
Proportions of variance in episodic memory variables associated with age. (Data sets for the free-recall analyses are as follows: 1—Salthouse, Hambrick & McGuthry, 1998; 2—Salthouse, 1993; 3—Salthouse, Toth, Hancock & Woodard, 1997; 4—Salthouse, Fristoe & Rhee, 1996; 5—Salthouse, 2001; and 6—Salthouse, 1996. Data sets for the paired-associates analyses are the following: 1—Salthouse, Toth, Daniels, Parks, Pak, Wolbrette & Hocking, 2000; 2—Salthouse, 1996; 3—Salthouse, 2001; and 4—Salthouse, Fristoe & Rhee, 1996.)

centage of age-related variance in the paired associates variables. These findings suggest that very little of the age-related effects on measures of episodic memory can be attributed to influences on processes that are specific to memory, as opposed to processes involved in other types of cognitive variables.

The shared-influence analytical procedure is relatively crude because it assumes no structure among the variables except that based on the relation each variable has with age. However, the assumption of no structure is unrealistic because most variables have small to moderate correlations with one another. Therefore, although the shared-influence method is informative about the nature of age-related effects on variables, it is incomplete, because it ignores interrelations that clearly exist among the variables.

Patterns of correlations among variables are often interpreted in terms of structural models. The currently most-accepted model of the structure of cognitive abilities is a hierarchical model in which there are from two to four levels intervening between the observed variables and the highest-order construct (e.g., Carroll, 1993; Cattell, 1987; Gustafson, 1984; Horn & Hofer, 1992). Variables representing episodic memory are not often included within hierarchical models, but when they have been included, they have been found to exhibit a coherent relation to other types of cognitive variables.

A major advantage of a hierarchical-structure representation is that it is possible to determine the level in the structure at which most of the age-related influences are operating. Age-related effects could be at the level of individual variables, such as the score in a particular task, at the level of first-order cognitive abilities or constructs, such as episodic memory, or at the level of the highest-order constructs representing variance common to all variables, such as Spearman's *g*. If the age-related influences on memory variables are specific to those variables, then many of the age-related effects would be expected to operate at low levels in the hierarchical structure. For example, if it is hypothesized that aging impairs the use of imagery in associating to-be-remembered items, then direct or independent age-related effects would be predicted on variables assessing paired-associates performance. Alternatively, direct or independent age-related effects on free-recall variables would be expected if it is postulated that increased age is associated with specific deficits in the effectiveness of organization-based retrieval. In contrast, any age-related effects found to operate at higher levels in the hierarchy are necessarily broader and more general because the influences are not restricted to particular variables.

The implications for understanding the nature of age-related effects on memory and other variables are therefore quite different depending on the level at which age-related influences operate. On the one hand, if the age-related influences operate at relatively low levels in the hierarchy, then this would indicate that at least some of the age-related influences on memory variables are independent of age-related influences on other types of variables, and explanations would be needed to account for the unique age-related influences on memory-specific processes. On the other hand, if most of the age-related influences operate at high levels in the hierarchy, then there would be little evidence for distinct age-related effects on memory variables when those variables are considered in the context of age-related effects on other variables. If this turned out to be the case, then explanations would be needed both for why aging has broad effects and for how those effects influence particular variables, such as those reflecting memory functioning.

Hierarchical models of the organization of memory and cognitive variables can be examined with structural-equation modeling procedures, first by specifying a model with hierarchical structure among the variables, and then by determining the levels at which age-related effects operate within that structure. Examination of the age-related influences in this type of analysis should start at the highest level, because it is the most general, and hence any effects at this level need to be controlled before considering effects at more specific levels (Carroll, 1993, p. 623).

Results of hierarchical analyses of age-related influences involving episodic memory and cognitive variables are available for three separate data sets. The first data set is from a study by Salthouse, Fristoe, and Rhee (1996) involving 259 adults between 18 and 94 years of age. The episodic-memory variables in this study were recall performance on the second and sixth trials of the Rey Auditory Verbal Learning Test, and paired-associates performance in terms of the number of associates recalled in each of two lists. The second data set is from a recent study

(Salthouse, 2001) involving 206 adults between 18 and 84 years of age. Memory was represented by recall on three successive lists of words and paired-associates recall on each of two lists. The third data set is based on the normative sample of 1,580 adults between 20 and 95 years of age for the Woodcock-Johnson Psycho-educational Battery, Revised (see Salthouse, 1998). Episodic memory in this data set was represented by four variables: (a) learning associations between unfamiliar names and pictures of novel creatures, (b) learning associations between unfamiliar visual symbols and familiar words, (c) immediate reproduction of auditorily presented words, phrases, or sentences, and (d) immediate reproduction of unrelated words in correct sequence.

Figures 8 to 10 illustrate the models with each data set, and tables 1 to 3 contain two types of information relevant to evaluating the accuracy of the models. One type of evaluative information consists of conventional fit statistics for structural-equation models. The other type of information consists of the observed and predicted age correlations for the memory variables. The predicted values were derived from the product of the coefficients for all paths in the model from age to the variable. Inspection of tables 1 to 3 reveals that the overall fits of the models were good, and that the age correlations were accurately predicted with the single age-related influence at the highest level in the hierarchy.

Within each data set, relations were also examined from age to the lower-level memory constructs or variables. None of these were significant except with the Woodcock-Johnson data in data set 3. In that case there was a positive relation from age to episodic memory because the negative age effects were overestimated on the basis of the age effects on the highest-level factor. Examination of table 3 indicates that this overestimation stemmed primarily from the memory-for-sentences variable, for which the predicted age correlation was −.41 but the actual correlation was −.29.

Conclusion

The results described above reveal a consistent pattern across the mediation, shared influences, and hierarchical analyses. In each case the age-related effects on different types of memory and cognitive variables were

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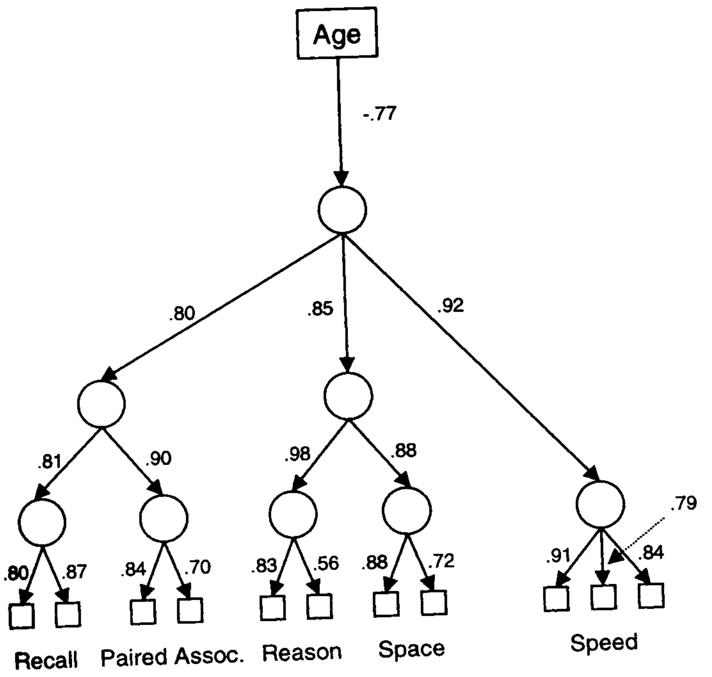

Figure 8
Hierarchical structural model for data from Salthouse, Fristoe, and Rhee (1996).

Table 1
Fit statistics and predicted age correlations for the hierarchical structure model for data set 1

$\chi^2(N = 259, df = 47) = 84.28$
NNFI = .97, CFI = .98, RMSEA = .06

	Age correlations	
	Predicted	Observed
Recall trial 2	−.40	−.47
Recall trial 6	−.43	−.45
PA 1	−.47	−.51
PA 2	−.39	−.35

NNFI: nonnormed fit index.
CFI: comparative fit index.
RMSEA: root mean square error of approximation.
PA: paired-associates recall.

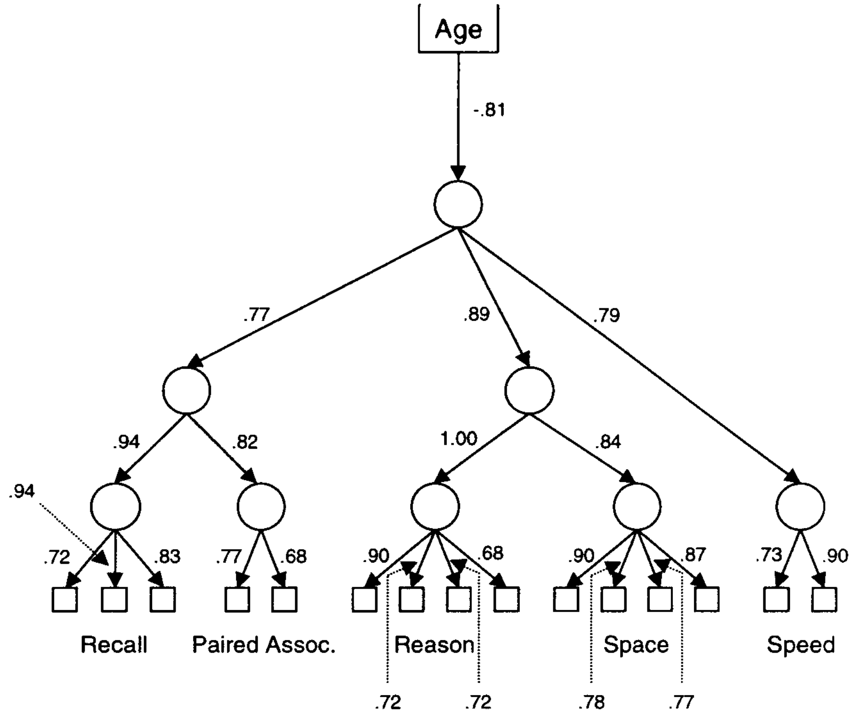

Figure 9
Hierarchical structural model for data from Salthouse (2001).

Table 2
Fit statistics and predicted age correlations for the hierarchical structure model for data set 2

$\chi^2(N = 206, \mathrm{df} = 97) = 161.91$
NNFI = .96, CFI = .97, RMSEA = .06

	Age correlations	
	Predicted	Observed
Recall 1	−.42	−.34
Recall 2	−.55	−.57
Recall 3	−.49	−.51
PA 1	−.39	−.37
PA 2	−.35	−.35

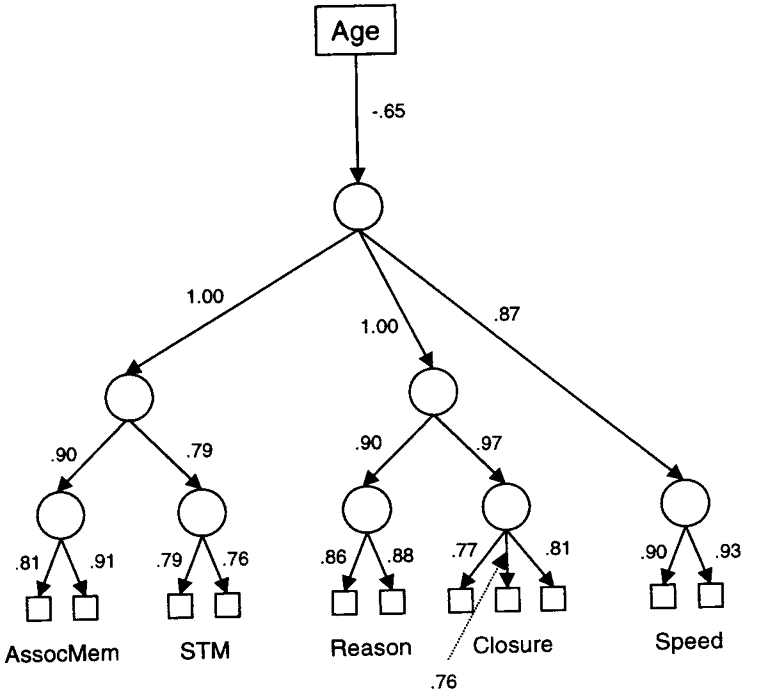

Figure 10
Hierarchical structural model for data from the normative sample of the Woodcock-Johnson Psycho-educational Test Battery.

Table 3
Fit statistics and predicted age correlations for the hierarchical structure model for data set 3

$\chi^2(N = 1580, \mathrm{df} = 47) = 551.21$
NNFI = .95, CFI = .96, RMSEA = .08

	Age correlations	
	Predicted	Observed
Memory for names	−.47	−.49
Visual-auditory learning	−.53	−.49
Memory for sentences	−.41	−.29
Memory for words	−.39	−.38

not independent, but instead most of the age-related variance on the different variables was shared. Moreover, in the hierarchical analyses the age differences in various episodic-memory variables were accurately predicted with a single age-related influence operating on all variables.

To summarize, the evidence discussed above strongly suggests that changes are needed in the nature of the explanations proposed to account for age-related effects on memory. In particular, because direct or unique effects associated with increased age on memory-specific processes contribute relatively little to the overall age-related effects on measures of episodic memory, memory-specific interpretations appear to be limited in their ability to account for age-related influences. However, because it now seems that age-related effects on memory variables do not occur in isolation, but rather in the context of age-related effects on a wide variety of cognitive variables, interpretations based on broad and general types of influences are likely to become more prominent, as will explanations of how these influences are manifested in the processes affecting particular memory tasks.

Let me now conclude by returning to the major question of what is responsible for adult age differences in episodic memory. I have suggested that there are two quite different approaches to this question. The dominant perspective at the current time can be termed the micro approach, as researchers within this perspective attempt to identify which specific aspect of task performance is most affected by increased age. This approach has relied on task analysis and various experimental decomposition procedures to attempt to specify the processes involved in successful task performance that are most affected by increased age.

The second approach can be termed the macro approach, because the goal of researchers within this perspective is to determine whether the age-related effects on the age-sensitive processes in the task are unique and specific to those processes, or are shared with processes involved in other types of tasks. If shared effects are identified, then the macro researcher would seek explanations for what might be responsible for those effects. The primary analytical tools used within the macro perspective are a variety of correlation-based statistical-control procedures.

In this chapter I have focused on the second approach, and the results I have described suggest that a substantial proportion of the age-related effects on episodic memory are shared with age-related effects on other types of cognitive variables. Evidence consistent with this inference was obtained in mediational analyses, in shared-influence analyses, and in analyses based on hierarchical structures of variables.

Among the speculations that might be proposed to account for the large proportions of age-related influences that appear to be shared across different types of variables are the following:

- General reductions in cognitive efficiency, as implied by hypotheses about processing resources
- Impairments in specific cognitive processes, such as formation of an internal representation or maintenance of a goal
- Declines in a critical cognitive construct, such as working memory or inhibition
- Decreases in neural efficiency, perhaps due to loss of myelin or reduced quantity of neurotransmitters
- Alterations in the functioning of particular neuroanatomical structures, such as the dorsolateral prefrontal cortex
- Disruption of a neural circuit, such as the dopaminergic pathway
- Reduced effectiveness of coordinating and monitoring cognitive processes or neural information.

All of these speculations are obviously very crude and tentative, however, and they are neither exhaustive nor mutually exclusive. An important goal for the future should therefore be the formulation and investigation of explicit hypotheses to account for shared age-related influences across memory and other types of cognitive variables.

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