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Where in an Ordered Sequence of Variables Do Independent Age-Related Effects Occur?

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A series of regression analyses was conducted to determine which variables in an ordered sequence had significant age-related effects after control of the immediately preceding variable in the sequence. Independent age-related effects in these types of analyses are particularly interesting because they represent age-related influences that are not mediated through earlier variables. A total of 56 analyses are reported with ordered variables representing: (a) successive trials or sessions in learning; (b) progressively more intervening events during the retention interval of a memory task; (c) successively longer stimulus presentation durations; and (d) increased processing complexity. In most of the analyses a very large proportion of the age-related effects on later variables was found to be mediated through earlier variables in the sequence.

ONE possible reason why there are currently few theories of cognitive aging phenomena (see Salthouse, 1991) is that there is still little agreement about the core phenomena that need to be explained. A major goal of the current report is to address this problem by providing a parsimonious description of the age-cognition relations in need of explanation. That is, the primary purpose is to specify where independent and distinct age-related influences appear to be operating. Information of this type is relevant to what needs to be explained, because separate explanations may not be necessary if the age-related influences on some measures are mediated through the effects on other measures.

Figure 1 portrays age-related effects in an ordered set of variables, with each variable postulated to be influenced by the preceding variable in the sequence and by age. In other words, performance on a given variable is hypothesized to be determined by performance on the same variable at an earlier position in the sequence as well as by age (see Note 1). The key question in this framework is where, or when, do unique or independent age-related effects occur? Or, stated from the opposite perspective, at what point in a sequence of ordered variables are the age-related effects merely carried by, or mediated through, the effects on variables earlier in the sequence?

If independent age-related effects are evident on every variable in the sequence, then one could infer that there are separate or specific age-related influences on each variable that do not completely overlap with the influences on variables occurring earlier in the sequence. An outcome of this type would suggest that there are several distinct age-related influences on the variables. The existence of independent age-related effects may be interpreted as originating from a shift in the identity of factors affecting variables at different positions in the sequence, or from a shift in what the variable represents as one moves from early to late in the sequence. Regardless of the cause, however, a finding of significant independent age-related effects on several variables in the sequence would suggest the need for multiple explanations of the age-related influences on the variables. In contrast, a discovery that most of the independent age-related effects occur early in an ordered sequence would suggest that effects later in the sequence are mediated by the earlier effects. Because the majority of the interesting age-related influences in this case would operate on the initial variables, an outcome of this type could be interpreted as suggesting that efforts at explanation of age-related effects would be most productive if directed at the influences occurring on the variables early in the ordered sequence.

Analyses

Similar analytical procedures were used in analyses of ordered variables representing learning across successive trials or sessions, forgetting across progressively more intervening events, effects of increased stimulus presentation time, and effects of increased task complexity as reflected by the number of required processing operations. Both correlation coefficients, indicating total age-related effects, and standardized regression (i.e., semi-partial) coefficients, indicating direct age-related effects, were computed for each variable in the sequence (see Note 2). In terms of Figure 1, the direct effects correspond to the path coefficients from age to the variable (i.e., paths *a* through *d*), the indirect effects correspond to the product of the paths from age to variable n-1 (i.e., *a* through *c*), and the paths from variable n-1 to variable n (i.e., *x* through *z*), and the correlation corresponds to the sum of the direct and indirect effects. In addition, because the relative contribution of a particular influence is often more interesting than merely whether that influence is significantly different from zero, an estimate of the percentage of mediated age-related variance is also reported for each variable. The estimate is derived by squaring the coefficients corresponding to the total and direct age-related effects, subtracting the latter from the former, and then dividing that difference by the square of the coefficient representing total age-related effects. To illustrate, if the correlation coefficient was .5 and the regression coefficient (i.e., the semi-partial correlation for age after controlling for the previous variable in the sequence) was .2, the percentage of mediated age-related variance would be $(.5^2-.2^2)/(.5^2) = .84$ (× 100) = 84.0%. Finally, the total R^2 value for the regression equation is reported to indicate the proportion of the total variance in the criterion variable that is accounted for by age and the prior variable.

A second analysis was also conducted in each data set after excluding research participants in the bottom quartile on the variable in the sequence with the highest level of performance. For example, in analyses of learning, the individuals in the bottom quartile on the measure of performance in the last learning trial would be eliminated in this analysis. The rationale was that the variation across the ordered sequence of variables might be reduced if some research participants had low levels of performance across all variables. This possibility should be minimized by eliminating those individuals with low levels of performance in the "easiest" condition in the data set. However, the pattern of results in this restricted sample was nearly identical to that in the complete sample, and thus only the results of the complete sample are reported.

The current analytical procedures are based on correlations and examinations of proportions of variance rather than more traditional analyses of variance and examinations of mean levels of performance because correlation-based procedures allow a determination of the relation between variables and, more specifically, allow an assessment of the degree to which the age-related influences on two or more variables are independent. This latter feature is important in the current context because — regardless of the absolute levels of performance — if two variables are perfectly correlated, then they necessarily share all of their age-related influences because the age-related effects on one variable can be predicted from those on the other variable. Admittedly, few variables have perfect correlations with one another, but it is probably also the case that few variables are completely independent of one another. Correlation-based procedures are thus needed to determine the relative amounts of common and unique variance, and especially common and unique age-related variance, in different combinations of variables (Salthouse, 1994b; Salthouse & Coon, 1994).

The data to be analyzed are measures of memory or fluid cognitive abilities obtained primarily from studies with moderately large samples of adults of different ages. Most samples consisted of adults from a continuous range of ages rather than two extreme groups such as college students between 18 and 25 and retired adults between 60 and 75 years of age. Finally, the majority of the analyses are based on data collected in my laboratory because they require information not typically reported in journal articles.

Learning

Some of the most interesting sets of ordered variables are those derived from successive trials or sessions in a learning situation. That is, in these data sets the variables in the sequence represent measures of performance at progressively greater levels of practice or training on the same task.

Several data sets are available in which five or more trials have been presented with the same stimulus materials. A number of studies have involved an associative learning task in which the research participant was required to determine which pairs of items, consisting of combinations of symbols, letters, or digits, were associated with each other. The typical procedure in this task has involved the display of a single stimulus item on the left of the computer screen, along with the entire set of response alternatives on the right of the screen. After the participant selected a response, by moving an arrow in front of one of the response alternatives, feedback was presented to indicate the correct response. The measure of performance is the percentage of stimulus terms (from a set of either four or six) with correct responses on each successive trial.

Typical data from this task are illustrated in Figure 2, which portrays results averaged across three different sets of stimuli from Study 2 in Salthouse (1995a). Although the sample in this study consisted of adults from a continuous range of ages, the research participants were classified into three groups to portray the age and trial effects in a single figure. Notice that although the three age groups started at nearly the same level, the amount of improvement across successive trials was smaller for older adults than for younger adults.

Results from sequential analyses of these data, of the data from similar tasks in other studies, and of data from maze learning and free recall tasks are summarized in Table 1. Also included in Table 1 are data from a mental squaring task

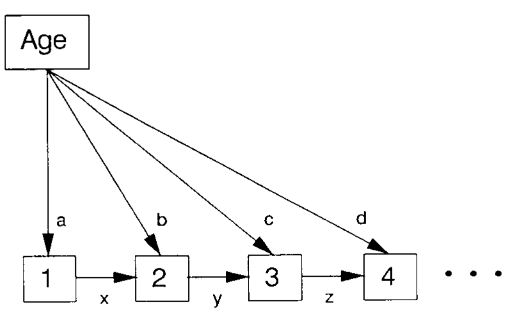

Figure 1. Framework for investigating direct (e.g., paths **a** through **d**) and indirect (e.g., **a–x**, **b–y**, etc.) relations between age and an ordered sequence of cognitive variables.

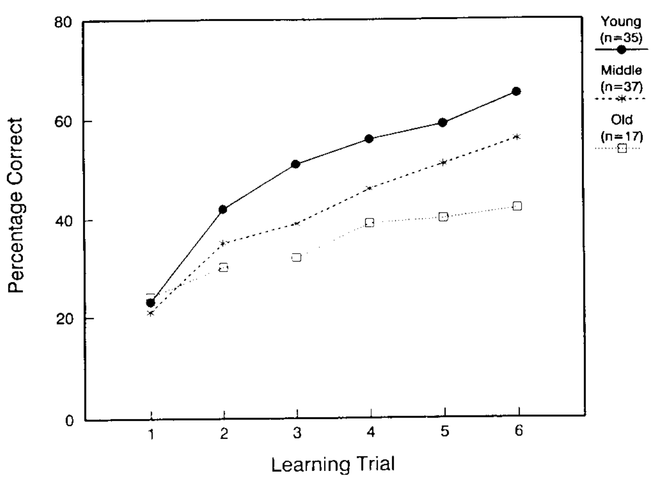

Figure 2. Mean percentage correct on six successive learning trials in three age groups, Salthouse (1995a, Study 2).

Table 1. Correlations and Path Coefficients for Relations Between Age and Measures of Time or Accuracy on Successive Learning Trials

Source	1	2	3	4	5	6	7	8	9	10
Paired Associate Learning										
	Trial/Block/Session									
Salthouse (1994a), Study 1										
n = 239										
Correlation	(−.12)	−.29	−.42	−.44	−.42	−.40				
Path coefficient	(−.12)	−.25	−.22	−.11	(−.04)	(−.02)				
% Mediated	0	25.7	72.6	93.8	99.1	99.8				
Total R^2	.01	.21	.64	.70	.78	.85				
Salthouse (1994a), Study 2										
n = 125										
Correlation	(−.15)	−.34	−.30	−.30	−.32	−.27				
Path coefficient	(−.15)	−.29	(−.04)	(−.07)	(−.09)	(0.00)				
% Mediated	0	27.2	98.2	94.6	92.4	100				
Total R^2	.02	.21	.61	.65	.68	.74				
Salthouse (1995a), Study 1, Digit-Letter										
n = 170										
Correlation	(−.14)	−.26	(−.18)	−.29	−.31	−.26				
Path coefficient	(−.14)	−.24	(−.08)	−.21	−.15	(−.08)				
% Mediated	0	14.8	80.2	47.6	76.6	90.5				
Total R^2	.02	.10	.17	.25	.39	.39				
Salthouse (1995a), Study 1, Symbol-Symbol										
n = 170										
Correlation	(−.07)	−.26	−.41	−.28	−.35	−.45				
Path coefficient	(−.07)	−.24	−.28	(−.04)	−.18	−.24				
% Mediated	0	14.8	53.4	98.0	67.3	71.6				
Total R^2	.00	.14	.38	.36	.46	.51				
Salthouse (1995a), Study 2										
n = 89										
Correlation	(−.04)	−.34	−.38	−.32	−.37	−.42				
Path coefficient	(−.04)	−.33	(−.14)	(−.03)	(−.10)	(−.11)				
% Mediated	0	5.8	86.4	99.1	92.7	93.1				
Total R^2	.00	.21	.56	.62	.76	.78				
Maze Learning										
	Trial/Block/Session									
Salthouse (1995a), Study 2										
n = 86										
Correlation	(.05)	(−.18)	(−.27)	(−.25)	(−.26)	(−.27)				
Path coefficient	(.05)	(−.19)	(−.15)	(−.03)	(−.07)	(−.05)				
% Mediated	0	—	69.1	98.6	92.8	96.6				
Total R^2	.00	.09	.49	.61	.64	.71				
Free Recall										
	Trial/Block/Session									
Salthouse, Fristoe, & Rhee (1996)										
n = 259										
Correlation	−.38	−.47	−.43	−.45	−.41					
Path coefficient	−.38	−.28	−.09	−.12	(−.06)					
% Mediated	0	64.5	95.6	92.9	97.9					
Total R^2	.14	.43	.60	.66	.64					
Mental Squaring										
	Session									
Charness & Campbell (1988)										
n = 48										
Correlation	.50	.56	.57	.61	.62					
Path coefficient	.50	(.15)	(.07)	(.08)	(.04)					
% Mediated	0	92.8	98.5	98.3	99.6					
Total R^2	.25	.82	.88	.92	.95					

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Table 1. Correlations and Path Coefficients for Relations Between Age and Measures of Time or Accuracy on Successive Learning Trials *(continued)*

Source	1	2	3	4	5	6	7	8	9	10
Visual Search – Varied Mapping										
	Successive 240-trial Blocks									
Cooper (1993)										
n = 89 Y, 88 O										
Correlation	.66	.57	.53	.51						
Path coefficient	.66	(–.09)	(–.02)	(–.01)						
% Mediated	0	100+	100+	100+						
Total R^2	.44	.87	.93	.94						
	Successive 600-trial Blocks									
Rogers et al. (1994)										
n = 70 Y, 70 O										
Correlation	.70	.68	.65	.67	.66					
Path coefficient	.70	(.01)	(–.01)	(.07)	(.03)					
% Mediated	0	99.9	100+	98.9	99.8					
Total R^2	.49	.92	.93	.93	.94					
Visual Search – Consistent Mapping										
	Successive 240-trial Blocks									
Cooper (1993)										
n = 89 Y, 88 O										
Correlation	.56	.57	.57	.58	.58	.63	.61	.61	.60	.62
Path coefficient	.56	(.05)	(.04)	(.02)	(.02)	.12	(–.01)	(.02)	(.02)	(.04)
% Mediated	0	99.2	99.5	99.9	99.9	96.4	100+	99.9	99.9	99.6
Total R^2	.31	.91	.93	.96	.96	.90	.95	.95	.95	.96
	Successive 600-trial Blocks									
Rogers et al. (1994)										
n = 70 Y, 70 O										
Correlation	.75	.78	.81	.83	.82					
Path coefficient	.75	.13	.08	.10	(.01)					
% Mediated	0	97.2	99.0	98.5	99.9					
Total R^2	.56	.95	.97	.97	.97					
Memory Search – Consistent Mapping										
	Successive 240-trial Blocks									
Cooper (1993)										
n = 87 Y, 87 O										
Correlation	.55	.59	.57	.61	.66					
Path coefficient	.55	.13	(.01)	.08	.11					
% Mediated	0	95.1	99.9	98.3	97.2					
Total R^2	.30	.85	.93	.94	.95					

Note: Values in parentheses are not significantly ($p < .01$) different from zero. A dash indicates that there was an increase in the age-related variance after control of the prior variable in the sequence.

reported by Charness and Campbell (1988) and data from visual and memory search tasks reported by Cooper (1993) and Rogers, Fisk, and Hertzog (1994) (see Note 3). The Charness and Campbell data correspond to the mean times needed to square two-digit numbers (Class 4 problems in the terminology of the authors) across five successive sessions. The Cooper data represent mean reaction times for varied and consistent mapping conditions in visual or memory search tasks across successive sets of 240 trials, and the Rogers et al. data reflect mean reaction times across successive sessions consisting of 600 trials each (see Note 4).

The first row in each data set (Table 1) represents the total age-related effects on the variable, in the form of the correlation coefficient with age. The second row contains the direct or independent age-related effects, in the form of the standardized regression coefficient for age when both age and the prior variable in the sequence were used as predictors in a simultaneous regression equation. The third row portrays the percentage of the total age-related variance in the variable that is mediated through the effects on the previous variable in the sequence. Finally, the fourth row represents the proportion of total variance in the variable that is predicted by age and, for variables other than the first in the sequence, the prior variable.

The most important point to note about the data in Table 1 is that even though the magnitude of the total age-related effects remains approximately constant in many of the data sets, there is a decrease in the direct age-related effects, and a concomitant increase in the mediated age-related effects, across successive trials or sessions. For example, for the Salthouse (1995a) Study 2 data set illustrated in Figure 2, the age correlations in trials 2 through 6 ranged from −.32 to −.42, but the percentage of mediated effects increased from less than 6% on trial 2 to over 90% on trials 4 through 6. This pattern suggests that distinct and independent age-related effects are evident primarily at early stages in learning, and that a large proportion of the age-related effects on later trials are mediated through the effects on earlier trials.

Although the majority of the data in Table 1 correspond to accuracy levels on single trials across several stimulus-response pairs in a given task, the data from the Charness and Campbell (1988), Cooper (1993), and Rogers et al. (1994) studies are based on means for much larger numbers of trials (i.e., 38 for Charness & Campbell, 1988; 240 for Cooper, 1993; and 600 for Rogers et al., 1994). The very similar pattern in the analyses of those data provides some generalizability to the inference that many of the age-related influences in simple learning tasks are apparent fairly early in the learning situation.

Although large proportions of the age-related effects were mediated, and the independent age-related influences decreased across successive trials, several of the direct age-related influences on later trials or sessions were significantly different from zero. Because this implies that the age-related effects on those variables were unique, or at least distinct from the effects carried through earlier variables, they warrant special attention even if the magnitudes of those effects are small relative to the mediated effects. Unfortunately, the pattern of significant independent age-related effects in these data is not very systematic, and thus it is difficult to identify a trend other than that already mentioned in which direct effects decrease, and indirect effects increase, across successive trials or sessions. For example, significant independent age-related effects occurred on the second, fourth, and fifth 240-trial blocks in the consistent mapping memory search task in the Cooper (1993) study, suggesting that distinct age-related influences were operating throughout learning in this task. However, the specific nature of those influences, and why they appear to be absent on the third 240-trial block, cannot be determined from the current analyses. The issue of how independent age-related effects on later variables in an ordered sequence might be investigated is considered in the General Discussion.

Lag Effects

Another type of ordered variable consists of measures of accuracy as a function of the number of events intervening between the presentation and test of the relevant information. Because it is the loss rather than the gain of information that is of interest in this context, analyses of performance as a function of the number of intervening events can be considered to reflect forgetting, or the converse of learning.

Several studies have been conducted with a continuous associative memory task in which the stimulus and response terms keep changing, and the research participant is occasionally asked to report which response term was most recently presented with a specific stimulus term. Typical data from comparisons of lag manipulations, consisting of the number of events intervening between the presentation and test of the relevant information, can be illustrated with results from Study 1 of Salthouse (1994a). Stimuli in this study consisted of letter-digit pairs, and on different trials either 0, 1, 2, or 3 other stimulus-response pairs intervened between presentation and test of the critical pair. Mean levels of accuracy at each lag for three age groups in this study are portrayed in Figure 3.

Results of sequential analyses of lag effects in this and other similar studies are summarized in Table 2. Notice that in many of the data sets the age correlations, corresponding to the total age-related effects, are small, although they were moderately large in the Salthouse (1995b) study. In most cases, however, the direct age-related effects tend to decrease, and the mediated effects tend to increase, with increased lag. This pattern implies that most of the age-related effects at longer lags are mediated through the effects at shorter lags. A similar strong mediational influence has also been found in studies with only lags of 0 and 1 (i.e., Kersten & Salthouse, 1993; Salthouse, 1994a).

The amount of relevant data on lag manipulations is clearly limited, and the magnitudes of the total age-related effects (and proportions of total variance explained) are relatively small. Nevertheless, the available data suggest that most of the age-related differences in forgetting occur within the first one or two items after the information is presented because there are little or no independent age-related effects on longer lags. If confirmed in additional studies, this pattern would imply that explanations may be needed only for the age-related influences on measures of performance with relatively short lags between presentation and test because the effects at longer lags appear to be mediated through those at shorter lags.

Stimulus Presentation Time

An ordered sequence of variables can also be created by manipulating the amount of time that relevant stimulus information is displayed. That is, the stimulus presentation

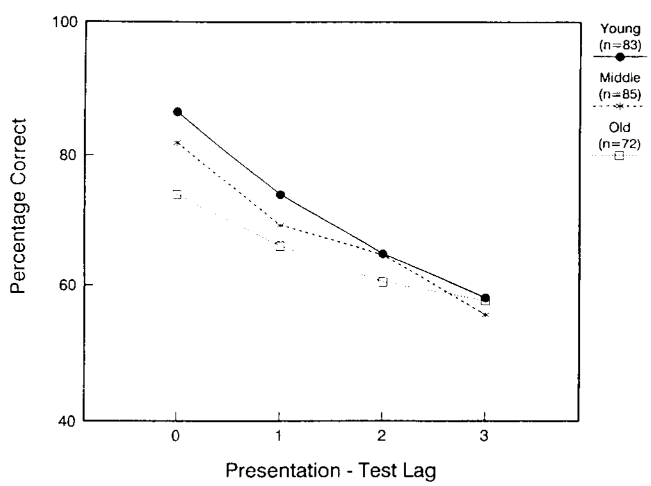

Figure 3. Mean percentage correct with 0 to 3 stimulus-response pairs between presentation and test for three age groups, Salthouse (1994a, Study 1).

Table 2. Correlations and Path Coefficients for Relations Between Age and Accuracy on Different Lags Between Presentation and Test

Source	Lag 0	1	2	3	4
Continuous Associative Memory					
Salthouse (1993), Study 1					
n = 246					
Correlation	(−.11)	—	−.21	—	−.21
Path coefficient	(−.11)	—	−.19	—	(−.16)
% Mediated	0		18.1		42.0
Total R^2	.01		.11		.10
Salthouse (1993), Study 2					
n = 258					
Correlation	−.16	−.24	−.20		
Path coefficient	−.16	−.18	(−.08)		
% Mediated	0	43.8	84.0		
Total R^2	.03	.22	.26		
Salthouse (1994a), Study 1					
n = 240					
Correlation	−.35	−.23	(−.16)	(−.03)	
Path coefficient	−.35	(−.03)	(−.06)	(0.01)	
% Mediated	0	98.3	85.9	100+	
Total R^2	.12	.33	.21	.07	
Salthouse (1995b)					
n = 50 Y, 50 O					
Correlation	−.52	−.56	−.54		
Path coefficient	−.52	−.26	(−.15)		
% Mediated	0	78.4	92.3		
Total R^2	.27	.56	.61		

Note: Values in parentheses are not significantly ($p < .01$) different from zero. A dash indicates that there was an increase in the age-related variance after control of the prior variable in the sequence.

time can be varied, and then the level of accuracy determined at each value of time. This procedure can be illustrated with data from an unpublished study by Kersten and Salthouse (1993), in which 39 young adults and 39 older adults performed a continuous associative memory task with letter stimuli and digit responses, and lags between presentation and test of either 0 or 1 stimulus-response pair. The presentation duration of the letter-digit pair was varied across trial blocks first from slow to fast durations, and then from fast to slow durations. Mean levels of accuracy at each duration averaged across lags 0 and 1 for the two age groups are portrayed in Figure 4.

Results of sequential analyses of the Kersten and Salthouse (1993) data, of data from three other associative memory studies, and of data from a serial letter memory task with recall of 5 letters in either original order or alphabetic order (Salthouse & Coon, 1993), are summarized in Table 3. Although the pattern is somewhat variable, it appears that independent age-related effects often occur for presentation times up to 500 msec, but not consistently for longer presentation times. To the extent that this is an accurate characterization of the results, independent and distinct age-related influences may operate primarily on measures within the first 500 msec of processing for some tasks. A broader range of tasks should be examined to explore the limits of this suggestion, but at least on the basis of the available data, distinct explanations for age-related influences appear to be

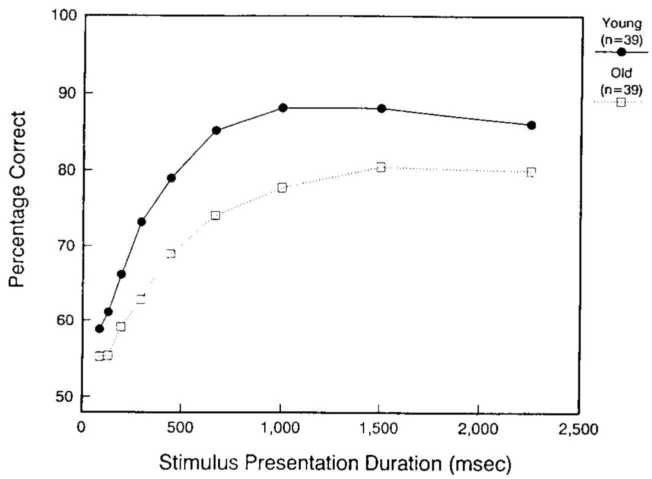

Figure 4. Mean percentage correct as a function of stimulus presentation time for two age groups. Kersten and Salthouse (1993).

needed largely for measures with relatively short presentation durations because most of the age-related effects on the measures at longer durations are mediated through the short-duration measures.

Complexity Effects

A final set of ordered variables can be derived from contrasts of different levels of complexity within the same task. Numerous comparisons exist with two levels of complexity, which typically involve a contrast between conditions with and without an additional hypothesized processing requirement. Contrasts of this type can be illustrated with data from two pairs of tasks recently administered to a total of 625 adults across three studies (i.e., Salthouse, 1995a; Salthouse, Fristoe, & Rhee, 1996; Salthouse & Meinz, 1995). The tasks were to copy digits (Digit Copy) or to first subtract 2 from the digits before copying them (Subtract Two), and to copy symbols (Symbol Copy) or to first rotate the symbols by 90 degrees before copying them (Rotation). Each task was performed twice, and the performance measure was the number of items answered correctly within 30 sec. Reliabilities, estimated by boosting the test-retest correlation by the Spearman-Brown formula, were high for each measure (i.e., Digit Copy = .96, Subtract Two = .95, Symbol Copy = .96, Rotation = .95).

The most informative analyses for the present purposes are the contrasts between the age correlation and the standardized regression coefficient for age for the measure from the presumably more complex task. The correlation with age for the subtraction measure was .26, but the regression coefficient, indicating the direct or unmediated age effects, was only .04. This pattern is consistent with a recent finding by Salthouse and Coon (1994), in that most (i.e., 97.6%) of the age-related variance in the subtraction measure was shared with simpler measures.

However, somewhat different results are evident in other two-variable complexity comparisons. For example, the age correlation for the rotation measure was .31, and the regression coefficient was .16, indicating that some (i.e., 73.4%), but not all, of the age-related effects in the rotation task were

Table 3. Correlations and Path Coefficients for Relations Between Age and Accuracy at Different Stimulus Presentation Durations

Source	Presentation Duration (msec)								
	Continuous Associative Memory								
	150	300	450	600	750				
Salthouse (1994a), Study 1									
n = 240									
Correlation	(−.14)	(−.15)	−.28	−.30	−.34				
Path coefficient	(−.14)	(−.10)	−.20	(−.12)	−.14				
% Mediated	0	55.6	49.0	84.0	83.0				
Total R^2	.02	.14	.37	.47	.49				
	250	500	750	Self-Paced					
Salthouse (1994a), Study 2									
n = 125									
Correlation	−.24	(−.20)	(−.14)	(−.11)					
Path coefficient	−.24	(−.05)	(0.00)	(−.02)					
% Mediated	0	93.8	100.0	96.7					
Total R^2	.06	.39	.54	.41					
	500	1000	1500	Self-Paced					
Salthouse (1995b)									
n = 50 Y, 50 O									
Correlation	−.62	−.56	−.58	−.39					
Path coefficient	−.62	(−.13)	(−.16)	(.02)					
% Mediated	0	94.6	92.4	100.0+					
Total R^2	.38	.61	.71	.48					
	88	132	196	296	444	667	1000	1500	2250
Kersten & Salthouse (1993)									
n = 39 Y, 39 O									
Correlation	(−.22)	−.35	−.42	−.47	−.45	−.48	−.50	−.45	−.33
Path coefficient	(−.22)	−.29	−.27	(−.22)	(−.11)	(−.17)	(−.17)	(−.06)	(.02)
% Mediated	0	31.3	58.7	78.1	94.0	87.5	88.4	98.2	100.0+
Total R^2	.05	.19	.35	.52	.61	.62	.63	.63	.59
	Letter Memory								
	200	400	800	1600					
Salthouse & Coon (1993), Study 2									
Original Order									
n = 38 Y, 38 O									
Correlation	−.53	−.59	−.49	−.47					
Path coefficient	−.53	−.29	(−.07)	(−.16)					
% Mediated	0	75.8	98.0	88.4					
Total R^2	.28	.58	.59	.52					
Alphabetic Order									
n = 38 Y, 38 O									
Correlation	−.59	−.48	−.58	−.62					
Path coefficient	−.59	(−.17)	−.25	−.22					
% Mediated	0	87.4	81.4	87.4					
Total R^2	.34	.42	.69	.69					

Note: Values in parentheses are not significantly ($p < .01$) different from zero.

apparently mediated by the effects in the copying task. This pattern could be interpreted as indicating that there are specific and independent age-related influences on the processes associated with rotation, in addition to those associated with symbol copying.

Another two-variable complexity comparison involves a contrast of memory span for digits or words with working memory span involving the same type of material, but with the research participant also required to carry out processing such as answering comprehension questions about sentences or performing simple arithmetic operations. Because the same tasks were performed in both studies reported in Salthouse and Babcock (1991), the relevant data were combined across the two studies to produce a total of 460 research participants. The age correlation with the listening span measure was −.49, and the standardized regression coefficient for age was −.29, indicating that 65.0% of the age-related variance in the working memory measure was mediated through the simple span measure. Corresponding values for the computation span measure were −.44 and

−.31, reflecting 50.4% mediated age-related variance. In both cases, therefore, it appears that some, but not all, of the age-related effects in the more complex measure were mediated by the effects on the simpler measure.

Although several of the comparisons just described indicate that distinct and independent age-related influences sometimes occur on more complex cognitive measures, qualitative and quantitative aspects of complexity are confounded in these comparisons. That is, in each of these cases the more complex condition can be viewed as involving not only different processing operations, but also more operations. Because this makes it difficult to determine whether it is the specific additional operation, as opposed to any additional operation, that is responsible for the observed effects, it is desirable to evaluate whether independent age-related influences also occur when complexity is increased only quantitatively, by the requirement to perform additional operations of the same type. Because quantitative variations of complexity form an ordered sequence, the data are amenable to the same types of sequential analyses on ordered variables conducted on the learning, forgetting, and presentation time data.

The relevant comparisons can be illustrated with data from a paper-folding task in which complexity was manipulated by varying the number of folds displayed prior to a hole punch. These data, from a study by Salthouse, Mitchell, Skovronek, and Babcock (1989), are portrayed in Figure 5.

Results of sequential analyses of the Salthouse et al. (1989) data, and of data from a variety of tasks involving different manipulations of complexity, are summarized in Table 4. An initial point to note about the entries in Table 4 is that the correlations with age do not always increase across successive levels of complexity, as might be expected by what has been termed the age-complexity phenomenon (Salthouse, 1991). This may be partly attributable to the inclusion of some (particularly older) participants who have relatively low performance across all levels of complexity. However, the overall pattern was similar in analyses restricted to individuals in the top 75% of the distribution on

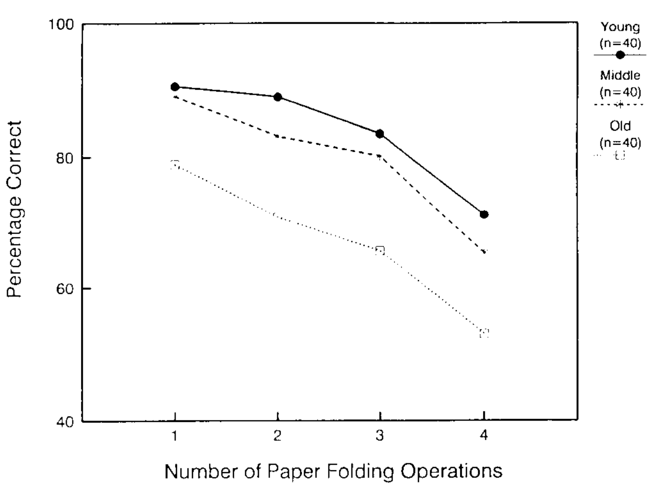

Figure 5. Mean percentage correct as a function of number of required paper-folding operations for three age groups, Salthouse et al. (1989).

the measure from the lowest level of complexity, and hence this is not the entire reason for the failure to find stronger age relations with greater complexity in these data.

Inspection of Table 4 reveals a mixture of outcomes. In some data sets (e.g., mental arithmetic, memory search, visual search, digit symbol substitution), nearly all of the age-related variance on more complex measures seems to be mediated through the measures at the simpler levels of complexity. Closer inspection of the data indicates that this pattern appears to hold for most of the analyses with response time measures, and with measures of the number of items completed in a fixed time. In contrast, data sets with percentage correct or other accuracy measures appear to have less mediation of the age-related effects on more complex variables through the age-related effects on simpler variables. Both of these patterns are evident in the paper-folding tasks because accuracy was the dependent measure in the first, second, and fifth data sets, but the dependent measure in the third and fourth data sets was the number of correct responses in a specified time. Notice that the degree of mediation of the age-related effects was smaller in the former data sets than in the latter.

To the extent that the distinction between time and accuracy variables is meaningful, separate age-related explanations may be needed for successive levels of complexity in tasks with accuracy measures but not in tasks with time measures. One possibility is that accuracy measures are more sensitive to cumulative errors introduced by deficient functioning of working memory necessary for maintaining intermediate products of processing (e.g., Salthouse, 1992), and that increased age is associated with impairments in working memory. The significant independent age-related influences on the larger set size conditions in the consistent mapping memory search task in the Cooper (1993) study may also be consistent with this interpretation because the working memory involvement is presumably larger when more target items have to be maintained in memory.

General Discussion

The major implication of the analyses summarized above is that only a relatively small number of distinct age-related causal factors appear necessary to account for a large proportion of the age-related variance in many cognitive measures. Stated somewhat differently, separate and distinct explanations are not required for all measures in which significant age-related differences have been reported because much of the age-related effects on these measures may be mediated through effects on measures that occur earlier in an ordered sequence.

In all but one of the data sets with paired associate learning, maze learning, and free recall tasks, over 90% of the age-related variance was mediated by the fourth exposure to the materials, and over 90% of the age-related variance was mediated from the second variable on in the mental squaring, visual search, and memory search tasks. The trend in the lag analyses was not as clear, perhaps because the total age-related effects, represented by the correlation coefficient, were not very large. Nevertheless, in the one data set with moderately large age correlations (i.e., Salthouse, 1995b), over 90% of the age-related variance

Table 4. Correlations and Path Coefficients for Relations Between Age and Measures of Time or Accuracy at Successive Complexity Levels

Source	Complexity 1	2	3	4	5
Paper Folding Task (Number of Folds)					
Salthouse (1988), Study 1					
n = 100 Y, 100 O					
Correlation	−.23	−.39	−.31	−.33	
Path coefficient	−.23	−.28	(−.14)	−.16	
% Mediated	0	48.5	79.6	76.5	
Total R^2	.05	.34	.25	.37	
Salthouse et al. (1989)					
n = 120					
Correlation	−.39	−.52	−.53	−.58	
Path coefficient	−.39	−.31	−.20	−.22	
% Mediated	0	64.4	85.8	85.6	
Total R^2	.15	.52	.56	.67	
Salthouse (1992), Study 1					
n = 228					
Correlation	−.25	(−.16)	(−.12)		
Path coefficient	−.25	(.02)	(.00)		
% Mediated	0	100+	100.0		
Total R^2	.06	.51	.58		
Salthouse (1992), Study 2					
n = 223					
Correlation	−.43	−.21	(−.11)		
Path coefficient	−.43	(.00)	(.02)		
% Mediated	0	100.0	100+		
Total R^2	.18	.25	.37		
Salthouse (1993), Study 1					
n = 246					
Correlation	−.47	−.32	−.31		
Path coefficient	−.47	(−.13)	−.17		
% Mediated	0	83.5	69.9		
Total R^2	.22	.22	.28		
Integrative Reasoning Task (Number of Premises)					
Salthouse et al. (1989)					
n = 120					
Correlation	−.27	−.43	−.52	−.44	
Path coefficient	−.27	−.31	−.26	(−.03)	
% Mediated	0	48.0	75.0	99.5	
Total R^2	.07	.38	.57	.66	
Salthouse (1992), Study 1					
n = 228					
Correlation	−.32	−.36	−.41		
Path coefficient	−.32	−.15	−.15		
% Mediated	0	82.6	86.6		
Total R^2	.11	.49	.63		
Salthouse (1992), Study 2					
n = 223					
Correlation	−.59	−.26	(−.02)		
Path coefficient	−.59	(−.04)	.17		
% Mediated	0	97.6	—		
Total R^2	.35	.17	.29		
Geometric Analogies Task (Number of Elements)					
Salthouse (1988), Study 1					
n = 100 Y, 100 O					
Correlation	−.28	−.39	−.32	−.52	
Path coefficient	−.28	−.24	(−.09)	−.35	
% Mediated	0	62.1	92.1	54.7	
Total R^2	.08	.45	.40	.51	
Geometric Analogies Task (Number of Elements) *(continued)*					
Salthouse (1992), Study 1					
n = 228					
Correlation	−.34	−.41	−.50		
Path coefficient	−.34	−.11	−.18		
% Mediated	0	92.8	87.0		
Total R^2	.11	.85	.76		
Salthouse (1992), Study 2					
n = 223					
Correlation	−.34	−.48	−.33		
Path coefficient	−.34	−.28	(−.10)		
% Mediated	0	66.0	90.8		
Total R^2	.12	.51	.29		
Mental Arithmetic (Number of Operations)					
Salthouse & Coon (1994), Study 2					
n = 40 Y, 40 O					
Correlation	.76	.74	.64	.63	.60
Path coefficient	.76	(.05)	(.20)	(.10)	(.07)
% Mediated	0	99.5	90.2	97.5	98.6
Total R^2	.58	.89	.57	.81	.77
Salthouse et al. (1995), Study 2					
Sequential Arithmetic performed alone					
n = 131					
Correlation	.46	.56	.41	.36	.34
Path coefficient	.46	.45	(−.09)	(.03)	(.01)
% Mediated	0	35.4	100+	99.3	99.9
Total R^2	.21	.36	.71	.68	.82
Sequential Arithmetic with concurrent memory load					
n = 131					
Correlation	.72	.65	.46	.46	.38
Path coefficient	.72	(.11)	(−.10)	(.11)	(−.01)
% Mediated	0	97.1	100+	94.3	100+
Total R^2	.52	.69	.64	.69	.68
Cube Assembly Task (Number of Folds)					
Salthouse (1992), Study 1					
n = 228					
Correlation	(−.15)	(−.12)	(−.11)		
Path coefficient	(−.15)	(−.01)	(−.02)		
% Mediated	0	99.3	96.7		
Total R^2	.02	.54	.61		
Salthouse (1992), Study 2					
n = 223					
Correlation	−.55	−.30	(−.15)		
Path coefficient	−.55	(−.11)	(.04)		
% Mediated	0	86.6	100+		
Total R^2	.31	.17	.37		
Memory Search Task (Number of Memory Set Items)					
Salthouse (1993), Study 2 – Letters					
n = 258					
Correlation	.39	.41	.42	.41	
Path coefficient	.39	(.07)	(.04)	(.01)	
% Mediated	0	97.1	99.1	99.9	
Total R^2	.15	.81	.89	.89	
Salthouse (1993), Study 2 – Digits					
n = 258					
Correlation	.41	.42	.44	.41	
Path coefficient	.41	(.03)	.06	(−.01)	
% Mediated	0	99.5	98.1	100+	
Total R^2	.17	.90	.91	.90	

(continues next page)

Table 4. Correlations and Path Coefficients for Relations Between Age and Measures of Time or Accuracy at Successive Complexity Levels *(continued)*

Source	Complexity 1	2	3	4	5
Digit Symbol (Number of Pairs)					
Salthouse (1993), Study 1					
n = 246					
Correlation	.51	.59	.59	.61	
Path coefficient	.51	.23	(.04)	.06	
% Mediated	0	84.8	99.5	99.0	
Total R^2	.26	.72	.91	.94	
Geometric Matrix Reasoning (Number of Relations)					
Salthouse (1993), Study 1					
n = 246					
Correlation	−.34	−.35	−.35		
Path coefficient	−.34	(−.09)	−.14		
% Mediated	0	93.4	84.0		
Total R^2	.12	.63	.46		
Spatial Rotation Task (Number of 90-degree Rotations)					
Salthouse (1993), Study 2					
n = 258					
Correlation	−.18	−.29	−.24		
Path coefficient	−.18	−.19	(−.08)		
% Mediated	0	57.1	88.9		
Total R^2	.03	.40	.33		
Geometric Analogies Task (Number of Relations)					
Salthouse (1988), Study 1					
n = 100 Y, 100 O					
Correlation	−.32	−.36	−.48	−.54	
Path coefficient	−.32	−.19	−.31	−.31	
% Mediated	0	72.1	58.3	67.0	
Total R^2	.10	.39	.43	.48	
Visual Synthesis Task (Number of Frames)					
Salthouse (1988), Study 1					
n = 100 Y, 100 O					
Correlation	−.27	−.21	−.32	−.36	
Path coefficient	−.27	(−.16)	−.24	−.19	
% Mediated	0	42.0	43.8	72.1	
Total R^2	.08	.08	.25	.35	
Visual Search – Consistent Mapping (Number of Display Set Items)					
Cooper (1993)					
n = 89 Y, 88 O					
Early in Practice (Trials 1–240)					
Correlation	.57	.54	.55		
Path coefficient	.57	(−.02)	(.04)		
% Mediated	0	100+	99.5		
Total R^2	.32	.94	.95		
Late in Practice (Trials 2161–2400)					
Correlation	.63	.61	.60		
Path coefficient	.63	(.01)	(.01)		
% Mediated	0	99.9	99.9		
Total R^2	.40	.91	.94		

Source	Complexity 1	2	3	4	5
Visual Search – Consistent Mapping (Number of Display Set Items)					
Rogers et al. (1994)					
n = 70 Y, 70 O					
Early in Practice (Trials 1–600)					
Correlation	.77	.74	.72		
Path coefficient	.77	(−.04)	(−.00)		
% Mediated	0	100+	100+		
Total R^2	.59	.97	.96		
Late in Practice (Trials 2401–3000)					
Correlation	.83	.81	.80		
Path coefficient	.83	(−.05)	(.03)		
% Mediated	0	100+	99.9		
Total R^2	.70	.97	.96		
Visual Search – Varied Mapping (Number of Display Set Items)					
Cooper (1993)					
n = 89 Y, 88 O					
Early in Practice (Trials 1–240)					
Correlation	.66	.65	.65		
Path coefficient	.66	(.01)	(.04)		
% Mediated	0	99.9	99.6		
Total R^2	.44	.94	.96		
Late in Practice (Trials 721–960)					
Correlation	.53	.51	.49		
Path coefficient	.53	(.01)	(−.01)		
% Mediated	0	99.9	100+		
Total R^2	.28	.91	.95		
Rogers et al. (1994)					
n = 70 Y, 70 O					
Early in Practice (Trials 1–600)					
Correlation	.73	.71	.65		
Path coefficient	.73	(−.01)	(−.07)		
% Mediated	0	100+	100+		
Total R^2	.53	.96	.94		
Late in Practice (Trials 2401–3000)					
Correlation	.75	.65	.54		
Path coefficient	.75	−.13	−.13		
% Mediated	0	100+	100+		
Total R^2	.56	.92	.89		
Memory Search – Consistent Mapping (Number of Memory Set Items)					
Cooper (1993)					
n = 87 Y, 87 O					
Early in Practice (Trials 1–240)					
Correlation	.52	.56	.53		
Path coefficient	.52	.10	(−.00)		
% Mediated	0	96.8	100+		
Total R^2	.27	.89	.92		
Late in Practice (Trials 961–1200)					
Correlation	.60	.67	.69		
Path coefficient	.60	.16	.07		
% Mediated	0	94.3	99.0		
Total R^2	.36	.91	.95		

Note: Values in parentheses are not significantly ($p < .01$) different from zero. A dash indicates that there was an increase in the age-related variance after control of the prior variable in the sequence.

in the lag 2 measure was mediated through the measures from shorter lags. A fairly consistent pattern in which 80% or more of the age-related variance on variables with long presentation times was mediated through variables with presentation times shorter than 500 msec was apparent in the analyses of the presentation time data. The most diverse results occurred with the complexity manipulations, but even in this case a median of 95.6% of the age-related variance in the measures of the second complexity level was mediated through the measures at the lowest complexity level, and a median of 99.0% of the age-related variance in the measures at the third complexity level was mediated through the measures at the second complexity level.

The discovery of substantial mediated, or shared, age-related variance in these analyses is similar to findings of large proportions of age-related variance shared across different cognitive variables in which there is no a priori basis for ordering the variables (e.g., Salthouse, 1993, 1994a, 1994b; Salthouse et al., 1994; Salthouse, Fristoe, Lineweaver, & Coon, 1995). In both situations, the available evidence suggests that a surprisingly large amount of the age-related effects on a wide range of cognitive measures can be accounted for by the operation of a relatively small number of independent and distinct age-related factors.

Two questions naturally emerge from the sequential analysis framework. The first concerns the explanation of the age-related effects on variables that occur early in an ordered sequence. The results of the current analyses are not directly informative about this issue (but see Salthouse, 1993, for relevant speculations). Whatever the nature of these causal factors, however, they are presumably fairly fundamental because the current results indicate that they are present early in learning, with short lags between presentation and test, with brief presentation durations, and at low levels of processing complexity. One important direction for future research should be investigation of the factors that vary with age and are responsible for variations in measures of simple processing efficiency.

The second question of interest in sequential analyses concerns the factors responsible for the independent age-related effects on later variables in the sequence. Because these effects represent unique age-related influences that are distinct from the influences on earlier variables in the sequence, they are not only of interest in their own right, but may also be informative about the nature of the influences on earlier variables. That is, because the age-related influences on the later variables are independent of the influences mediated through the earlier variables, examination of these specific influences may contribute to understanding the nature of the presumably common influences from which they are distinct.

In the analyses reported above, independent age-related effects were apparent on later variables in the sequence in several of the data sets. For example, independent age-related effects occurred across the first several trials in the paired associate and free recall learning tasks. Distinct age-related influences were also evident in some, but not all, blocks of trials in the consistent mapping visual search tasks of Cooper (1993) and Rogers et al. (1994). (Also, see Note 4.) Independent age-related effects occurred for long presentation times when letters were to be recalled in alphabetical order, and when more processing operations were required with accuracy-based measures of performance. Finally, distinct age-related influences were evident with larger memory set sizes in Cooper's (1993) consistent mapping memory search task, particularly late in practice.

Independent age-related effects on later variables in an ordered sequence have also been reported by Kliegl, Smith, and Baltes (1990) in a study involving method-of-loci mnemonic training in young and old adults. These investigators found significant age-related variance in a measure of performance in a later session after a measure of serial recall performance in an initial session was statistically controlled. Furthermore, the age-related variance was still significant even when a measure of serial word recall after mnemonic instruction was controlled. (Also, see Baltes & Kliegl, 1992.) A possible explanation for the independent age-related effects in the later sessions of the Kliegl et al. (1990) study is that younger adults, to a greater extent than older adults, were able to improve the speed with which they could execute the mnemonic procedure with additional practice. In support of this interpretation are the additional findings that most of the improvement in memory performance occurred with moderately fast presentation durations, and that the relation between memory performance and a speed measure (i.e., Digit Symbol Substitution performance) increased across sessions. The Kliegl et al. (1990) study is therefore instructive in illustrating how independent age-related influences on later variables in an ordered sequence might be analyzed and interpreted. Not only is it desirable to include manipulations to explore the source of the later age-related effects, but other variables should also be assessed to detect possible changes in the pattern of relations.

It is useful to consider the factors that could contribute to the existence of unique or independent age-related effects late in a sequence of ordered variables. One possibility is that the likelihood of detecting independent effects varies according to the type of ordered sequence under consideration. For example, at least two different types of ordered sequences — causal and temporal — can be distinguished. Causal sequences are those in which the preceding variable is logically prior to the criterion variable in the sense that it represents a constituent of the criterion variable. Sequences composed of variables hypothesized to correspond to different levels of processing complexity, where each successive level includes the prior levels plus an additional level, are examples of causal sequences. Sequences in which successive variables represent progressively greater amounts of processing time could also be considered as causal if the increased time corresponds to more complete processing. A second type of ordered sequence is temporal or longitudinal in that successive variables in the sequence represent different points along a temporal continuum. Measurements at different levels of practice, or with various intervals between presentation and test (i.e., forgetting), are examples of longitudinal sequences. Note that causal and temporal sequences are not mutually exclusive because a temporal sequence could also be causal. That is, successive variables in a longitudinal sequence could represent simpler or less complete amounts of processing (i.e., causal), or they may involve all of the same operations but at different levels of proficiency (i.e., noncausal).

Although it is clearly possible that the pattern of independent age-related influences could vary according to the type of ordered sequence, there is little evidence of this in the data reported above. Instead, the general trend seems to be for large proportions of the age-related effects to be evident early in the sequence, regardless of the nature of the sequence. Nevertheless, the available data are not definitive with respect to this issue, and future research may reveal that the presence or magnitude of distinct age-related influences varies depending on the type of ordered sequence.

Statistical factors could also play a role in the detection of independent age-related effects late in an ordered sequence. For example, an effect of the same absolute magnitude is more likely to be statistically significant when the proportion of explained variance in the variable is high compared to when it is low. Furthermore, increases in the proportion of explained variance could occur because of increased reliability of the criterion variable (due to the greater amount of systematic variance available to be associated with other variables), or because of increases in the magnitude of the relation of the variable to the prior variable in the sequence. Both the reliability of the criterion variable and the strength of the relations between successive variables could therefore contribute to the detection of independent age-related effects in variables late in an ordered sequence.

Two final factors that could contribute to the existence of independent age-related variance are shifts in either the nature of the processes required in the task, or in what the variables represent. That is, successive variables in the ordered sequence may be dependent upon different combinations of abilities, and age-related influences may be evident on abilities that become important late in the sequence. Alternatively, there may not be a shift in the pattern of influences on the same variable, but rather the variable itself may be changing with respect to what it is measuring. In other words, early in the sequence the variable may reflect one construct, but later in the sequence it may reflect a different construct. A possible example is when the ordered sequence is composed of measures representing performance at progressively longer times. In this case the variables at short presentation times may primarily reflect processes concerned with rapid information processing, but at longer presentation times the variables may reflect whatever ability construct is relevant to the particular task being performed. Examination of the pattern of correlations between variables at different positions in the sequence and measures of other abilities might allow these possibilities to be distinguished.

In conclusion, the framework of conceptualizing where independent age-related influences occur seems to be a fruitful perspective for understanding what needs to be explained with respect to age-related effects on cognition. The data sets examined above are obviously very limited in many respects, but they nevertheless raise the possibility that far fewer explanations of age-related influences are needed than the number of variables in which age-related effects have been reported. Not only were few of the independent age-related effects on later variables in the ordered sequence significantly different from zero, but even when significant they were often responsible for very small percentages of the total age-related variance. Important priorities for future research should therefore be the explanation of age-related influences on the variables that occur early in an ordered sequence, because they may be responsible for large proportions of the age-related effects, and of the independent age-related influences on variables that occur later in the sequence, because they can be viewed as representing distinct or unique age-related effects.

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Appendix

Notes

1. The reported analyses are restricted to first-order (i.e., immediately prior) autoregression analyses rather than also including higher-order relations for two reasons. First, although analyses of second-order (e.g., variable 1 on variable 3) and third-order (e.g., variable 1 on variable 4) relations revealed that some of those relations were significantly different from 0, the increments in proportions of total variance accounted for were generally rather small. And second, inclusion of additional mediated paths to the criterion variable tended to reduce the magnitude of the direct coefficients from age, and thus the reported values can be viewed as liberal (i.e., potentially larger than the true value) estimates of the unmediated age-related influences.

2. The standardized regression coefficients were obtained from hierarchical regression equations in which the effects of age were determined after control of the prior variable in the sequence. These coefficients are equivalent to what would be obtained in a path analysis with a model such as that illustrated in Figure 1 in which paths were constrained to adjacent variables in the sequence.

3. The same research participants performed in all conditions of the Cooper (1993) study, with the varied mapping visual search performed after four sessions of psychometric ability tests. The two sessions of the consistent mapping visual search task were performed next, followed after a transfer session by a session with the consistent mapping memory search task. A mixed design was also used in the Rogers et al. (1994) study, with each session consisting of 600 trials of the consistent mapping task intermixed with 600 trials of the varied mapping task.

4. Because trials in the Cooper (1993) and Rogers et al. (1994) studies were presented in blocks of 60, the analyses were repeated with means for each 60-trial block as the variables in the ordered sequence. In the Cooper (1993) study, the path coefficients, representing direct or unmediated age-related effects, were significantly ($p < .01$) different from zero only in block 1 in the varied mapping visual search data, in blocks 1, 3, 5, 18, 21, 25, 29, 38, and 40 in the consistent mapping visual search data, and in blocks 1, 2, 3, 7, 11, 13, 15, 17, and 19 in the consistent mapping memory search data. The percentage of mediated age-related variance was greater than 96% for all variables except the first in the sequence, and the variable representing the first block in the second session of the consistent mapping visual search task (i.e., block 21 = 89.2% mediated).

Only 5 of the 98 comparisons (excluding the first block in each task) in the Rogers et al. (1994) data had less than 90% mediated age-related variance. These were the first block of trials in the varied mapping task on sessions 2 (89.2%), 3 (82.0%), 4 (83.5%), and 5 (86.1%), as well as the sixth block in session 5 (85.9%). Path coefficients for age were significantly ($p < .01$) greater than zero in the consistent mapping visual search task occurred on blocks 1, 3, 4, 7, 10, 11, 13, 15, 17, 18, 20, 21, 23, 25, 27, 31, 32, 33, 35, 36, 38, 40, 41, 42, 45, 46, 47, and 50. The significant ($p < .01$) path coefficients for age in the varied mapping visual search task occurred on blocks 1, 6, 9, 11, 21, 26, 29, 30, 31, 35, 37, 40, 41, 42, 46, and 48. Although these patterns are more complex than those in the analyses based on data aggregated across more trials, it is noteworthy that in all cases the direct age-related effects corresponded to a relatively small percentage of the total age-related variance.

In order to explore the generalizability of the phenomenon of mediated age-related effects, analyses were also conducted to determine the percentage of mediated age-related variance from the first to the last trial block in these data sets. Estimates from the Cooper (1993) data were 84.5% for consistent mapping visual search, 99+% for varied mapping visual search, and 65.8% for consistent mapping memory search. Estimates from the Rogers et al. (1994) data were 76.3% for consistent mapping visual search, and 99% for varied mapping visual search.