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Attentional Blocks Are Not Responsible for Age-Related Slowing

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Reaction time (RT) data in two tasks from a total of 784 adults between 18 and 87 years of age were analyzed to determine the relation between age and parameters of the intra-individual RT distribution. Although the absolute magnitude of the age differences was greatest for the slowest RTs in each individual's RT distribution, there was little or no independent age-related variance in the slowest RTs after controlling for the variance in the fastest RTs. Furthermore, the relation between RT and measures of motor speed, perceptual speed, working memory, and accuracy in several cognitive tasks was of nearly the same magnitude when only the fastest responses were considered as when both fast and slow responses were considered. These results imply that age-related slowing is associated with a shift (and expansion) in the entire RT distribution, and is not attributable to a selective influence on the individual's slowest responses.

AGE-RELATED slowing is a robust and ubiquitous, but still largely unexplained, phenomenon. The focus of this article was the hypothesis that age-related slowing may be due to an increase with age in lapses of concentration or failures to sustain attention. That is, processing speed may be slower with increased age because of more frequent, or longer duration, attentional blocks in which rapid responding is impossible. One version of the attentional block hypothesis originated from research with vigilance tasks. For example, Thompson (1980, p. 241) noted that "... older individuals performed as well as or better than younger individuals during some intervals, but overall age differences could be attributed to a greater number of low-performance intervals for the old than for the young" (p. 241).

Bunce, Warr, and Cochrane (1993) have recently claimed that not only is there evidence that the proportion of attentional blocks, which they defined in terms of very slow reaction times (RTs), increases with age, but that attentional blocks might be attributable to irrelevant information momentarily preventing access to target information. They therefore suggested that an age-related increase in attentional blocks is consistent with the proposal by Hasher and Zacks (1988) that increased age is associated with a decline in the ability to inhibit or suppress task-irrelevant information.

Four specific predictions can be derived from the attentional block hypothesis. The most obvious is that increased age should be associated not only with an increase in average (mean or median) RT, but also with increases in measures of the variability and skewness of the distribution of RTs. These latter measures should increase with age because distributions containing a higher number of very slow RTs will have greater variability, and a larger degree of positive skew, than distributions with smaller numbers of very slow responses.

A second prediction is based on the idea that the variability of the RT distribution may be more fundamental or primary with respect to age-related influences on speed than is the central tendency of the distribution. That is, if increased age is associated with an increase in attentional blocks, then the increase in variability might in turn lead to an increase in the central tendency of the distribution. If this reasoning is correct, then one should expect asymmetric attenuation of the age-related variance when statistical control procedures are used to eliminate the variation in one variable while examining the age relations on the other variable. That is, if age-related effects on the mean are mediated through age-related effects on the standard deviation, then the reduction of age-related variance should be greater with the mean as the criterion variable and the standard deviation as the controlled variable compared to when the standard deviation is the criterion variable and the mean is the controlled variable.

A third prediction from the attentional block hypothesis is that age-related effects on the individual's fastest response times should be small to nonexistent, but that age-related influences on his or her slowest response times should be quite large. This phenomenon has been described informally several times (e.g., Fozard, Thomas, & Waugh, 1976; Thomas, Waugh, & Fozard, 1978), although direct statistical evaluations have seldom been reported. One way in which the prediction can be tested involves determining several percentiles (e.g., the 10th, 25th, 50th, 75th, and 90th) of each subject's RT distribution, and then examining the statistical significance of the Age × Percentile interaction. A robust interaction would be expected if the absolute magnitude of the age differences is greater at higher percentiles of the RT distribution than at lower percentiles of the distribution.

A fourth implication of the attentional block hypothesis is that at least some of the age-related influences on higher percentiles of the RT distribution should be independent of the age-related influences on lower percentiles of the distribution. In other words, one should expect a significant increment in the proportion of age-related variance associated with the slowest RTs after the age-related influences on the fastest RTs have been controlled by statistical means.

The reasoning is that attentional blocks or concentration lapses are postulated to be more likely with increased age, and their impact should be greatest on the slowest responses in the distribution. This leads to the expectation that there will be unique or distinct age-related influences on the higher (slowest) percentiles of the RT distribution that are independent of any influences on lower (fastest) percentiles.

Because previous research has established that a substantial proportion of the age-related variance in measures of working memory (Salthouse, 1992a; Salthouse & Babcock, 1991) and other types of cognition (Salthouse, 1991; 1992b) is shared with measures of perceptual speed, it is also interesting to examine the influence of various percentiles of the RT distribution on the relations between age and cognitive performance. If at least some age-related slowing is associated with attentional blocks, then there may be a stronger influence on age-cognition relations of the slowest RTs, which may directly reflect attentional blocks, than of the fastest RTs, which should be minimally influenced by attentional blocks.

All of the predictions described above were examined using data from studies originally conducted to investigate other issues. The research participants in the earlier studies, a total of 784 adults from a wide range of ages, all performed the same two reaction time tasks — Digit Symbol and Digit Digit — and it is data from those tasks that are reported here.

METHOD

Tasks. — The data to be reported are based on the same two RT tasks administered to four independent samples of between 100 and 258 adults. Each task was always preceded by 18 practice trials, and contained 90 experimental trials. However, the order of these two tasks, and the number and identity of the other tasks performed by the subjects in the session, varied across data sets.

The two tasks were described in Salthouse (1992c), and displays of sample trials were illustrated in Salthouse (1992b). The Digit Symbol task was based on the Digit Symbol Substitution Test from the Wechsler Adult Intelligence Scale, but was modified to be administered on a computer. Trials in this task consisted of a code table associating digits and symbols at the top of the display, and a digit and a symbol in the middle of the display. The code table remained the same across trials, but the digit and symbol presented in the middle of the display changed from trial to trial. The instructions to the subject were to decide, as rapidly and accurately as possible, whether the digit and the symbol matched according to the table at the top of the display. If the items did match then the "/" key on the keyboard was to be pressed, and if they did not match then the "Z" key was to be pressed. The Digit Digit task was formally similar except that the code table was uninformative because it contained pairs of identical digits, and the target items were a pair of digits rather than a digit and a symbol. The requirement was therefore to respond, again with the "/" and "Z" keys, on the basis of physical identity rather than associational equivalence. Because the percentage of errors averaged less than 5% in both tasks in each data set, they were ignored in the analyses reported here.

Data sets. — Four separate sets of data, each involving different samples of subjects, were available for analyses. Sets 1 and 2 were based on Studies 1 and 2 in Salthouse (1992a). Subjects in both of these studies performed two computer-administered tests of working memory — computation span and reading span — in addition to the Digit Digit and Digit Symbol tasks. Ninety young adults (mean age = 20.1 years) and 90 older adults (mean age = 63.5 years) participated in Study 1 (Data Set 1), and 100 adults between 18 and 80 years of age participated in Study 2 (Data Set 2). Data Sets 3 and 4 were based on Studies 1 and 2 in Salthouse (in press). There were 246 subjects between 18 and 84 years of age in Study 1 (Data Set 3), and 258 subjects between 20 and 87 years of age in Study 2 (Data Set 4). In addition to the Digit Digit and Digit Symbol tasks, subjects in both of these studies performed four paper-and-pencil speed tests, two (Boxes — requiring a line to be drawn to complete a square, and Digit Copy — requiring the copying of digits) assessing motor speed and two (Letter Comparison and Pattern Comparison — involving same/different decisions about the identity of either sequences of letters or line segment patterns) assessing perceptual speed, and three computer-administered cognitive tasks (Matrix Reasoning with geometric patterns, Paper Folding, and Associative Memory in Study 1, and Matrix Reasoning with letters and digits, Spatial Rotation, and Associative Memory in Study 2).

Procedure. — Composite scores were created for the cognitive measures by averaging the z-scores for the relevant measures. That is, a working memory score was formed by averaging the z-scores for the two working memory measures in Data Sets 1 and 2, and motor speed, perceptual speed, and cognitive accuracy composite scores were formed by averaging the z-scores for two motor speed, two perceptual speed, and three cognitive accuracy measures in Data Sets 3 and 4. It should be noted that the measure of performance in the computer-administered cognitive tasks corresponds to the percentage of correct responses when subjects were allowed as much time as desired to work on the items.

Within each data set, nine parameters were determined for both RT tasks for each subject: mean, standard deviation, skewness, kurtosis, and the 10th, 25th, 50th, 75th, and 90th percentile RTs. The skewness and kurtosis values were computed by the formulas described in the SAS Procedures Guide (SAS Institute, 1985, p. 11).

RESULTS

Because of the large number of statistical comparisons to be reported and the moderate sample sizes, an alpha of .01 was used as the level of statistical significance.

Means and standard deviations of the parameters of the RT distributions for the two tasks in the four data sets are displayed in Table 1. Two points should be noted about the results summarized in this table. First, the distributions were positively skewed. This is evident directly by the fact that the skewness values were all greater than zero, and indirectly by the fact that the means were always larger than the medians. And second, the kurtosis values were all greater than 3, indicating that the tails of the distribution were

Table 1. Means and Standard Deviations *(SD)* of RT Distribution Measures

	Data Set							
	1		2		3		4	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Digit Digit								
Median	661	207	706	187	801	289	750	208
Mean	734	250	809	299	959	338	898	302
SD	317	228	408	396	630	286	517	382
Skewness	3.63	2.03	3.82	1.78	4.87	2.09	3.42	1.53
Kurtosis	21.58	20.12	22.32	17.85	32.52	23.30	17.25	14.80
Digit Symbol								
Median	1550	482	1582	472	1668	465	1515	419
Mean	1693	533	1744	538	1838	534	1662	483
SD	634	306	699	348	731	382	625	329
Skewness	2.05	1.13	2.36	1.42	2.17	1.13	2.00	1.07
Kurtosis	7.72	8.88	10.30	12.01	8.37	8.63	7.39	8.10

Table 2. Age-Related Effects on RT Distribution Measures From Linear Regression Analyses

	Data Set							
	1		2		3		4	
	b	R^2	*b*	R^2	*b*	R^2	*b*	R^2
Digit Digit								
Median	5.84	.396*	6.53	.370*	9.04	.282*	4.44	.132*
Mean	7.42	.443*	10.01	.341*	11.28	.321*	6.67	.141*
SD	6.24	.375*	9.48	.174*	6.81	.164*	7.76	.119*
Skewness	0.03	.082*	0.00	.001	−0.03	.075*	0.01	.013
Kurtosis	0.22	.061*	0.00	.000	−0.34	.061*	0.06	.004
Digit Symbol								
Median	17.38	.651*	18.92	.489*	16.75	.375*	13.27	.290*
Mean	19.15	.645*	21.92	.504*	18.15	.335*	14.76	.270*
SD	9.08	.441*	12.23	.377*	8.79	.153*	6.87	.126*
Skewness	0.02	.101*	0.02	.058	0.01	.007	0.00	.002
Kurtosis	0.12	.099*	0.15	.046	0.05	.010	0.00	.000

$^*p < .01$.

thinner than those in a normal distribution. Comparison of the kurtosis values in the two RT measures reveals that the degree of leptokurtosis was more pronounced in the Digit Digit measures than in the Digit Symbol measures.

Results of regression analyses relating age to each of the distributional parameters from Table 1 are displayed in Table 2. The columns labeled *b* represent the difference per year in the parameter, and the column labeled R^2 indicates the proportion of variance in the parameter associated with age.

It is apparent in Table 2 that there were large and consistent linear age-related effects on the median, mean, and standard deviation parameters in both the Digit Digit and Digit Symbol measures. (Quadratic age trends were also significant in some of the analyses, but in all cases the proportion of variance associated with the quadratic trend was small relative to that associated with the linear trend, and consequently they were ignored in subsequent analyses.) It is also evident in Table 2 that the age-related effects on the skewness and kurtosis parameters were small and inconsistent. Significant age-related influences were evident in three of the eight (two RT measures in each of four data sets) analyses with each parameter, but one of the three significant effects with each measure was actually negative, indicating a decrease in the parameter with increased age.

The results summarized in Table 2 indicate that increased age was associated with increases in measures of central tendency and variability, but that there is little evidence of a systematic age-related shift in the shape of the RT distribution, either in terms of the thickness (kurtosis) or the length (skewness) of the tails of the distribution. The attentional block prediction of an age-related increase in variability is therefore supported, but not the related prediction of an increase in the skewness of the RT distributions.

A series of hierarchical regression analyses was conducted predicting either the means or the standard deviations of the RT distribution from age and the other variable. Prior to the main analyses, age × predictor interactions were examined with the cross-product interaction term entered after age and the predictor. No interactions were significant with analyses on the data from the Digit Symbol measure, but with the Digit Digit data the Age × Standard Deviation interaction was significant for Data Sets 2 ($F = 12.70$) and 3 ($F = 6.87$), and the Age × Mean interaction was significant for Data Set 3 ($F = 8.13$). These significant interactions indicate that the relations between the predictor and criterion varied as a function of age (i.e., the regression coefficients were not homogeneous), and thus the same adjustment equation apparently does not apply at all ages. However, because most of the interactions were not significant and yet a similar pattern was evident in all of the data, the results of the hierarchical regression analyses are reported for all of the data.

Results of the hierarchical regression analyses, in terms of the cumulative R^2 and the increment in R^2 associated with each successive predictor, are summarized in Table 3. It can be seen that there was significant residual age-related variance in all eight analyses with the mean as the criterion or predicted variable. This indicates that not all of the age-related variance in the mean overlaps with that in the standard deviation. The average attenuation of the age-related variance (i.e., the R^2 for age when it was the only predictor minus the increment in R^2 associated with age after control of the variance in the standard deviation, divided by the R^2 for age when it was the only predictor, multiplied by 100) was 82.1%. In contrast, the residual age-related variance with the standard deviation as the criterion or predicted variable was significantly greater than zero in only four of eight analyses after statistical control of the mean. Moreover, the average attenuation of the age-related variance in the measure of variability after eliminating the variation in the measure of central tendency was 96.6%. These results suggest that although the mean and the standard deviation are very highly correlated, the age-related influences on the mean may be more fundamental or basic than those on the standard deviation because the mean is associated with a larger amount of independent or unique age-related variance than is the standard deviation.

Table 3. Hierarchical Regression Analyses on Means and Standard Deviations

	Data Set							
	1		2		3		4	
	R^2	Incremental R^2	R^2	Incremental R^2	R^2	Incremental R^2	R^2	Incremental R^2
Digit Digit								
Mean as the criterion variable								
Age	.443	.443*	.341	.341*	.321	.321*	.141	.141*
SD	.615	.615*	.772	.772*	.457	.457*	.725	.725*
Age	.670	.055*	.829	.057*	.560	.103*	.733	.008*
Standard deviation as the criterion variable								
Age	.375	.375*	.174	.174*	.164	.164*	.119	.119*
Mean	.615	.615*	.772	.772*	.457	.457*	.725	.725*
Age	.630	.015*	.786	.014*	.458	.001	.726	.001
Digit Symbol								
Mean as the criterion variable								
Age	.645	.645*	.504	.504*	.335	.335*	.270	.270*
SD	.672	.672*	.684	.684*	.659	.659*	.699	.699*
Age	.792	.120*	.750	.066*	.740	.081*	.755	.056*
Standard deviation as the criterion variable								
Age	.440	.440*	.377	.377*	.153	.153*	.126	.126*
Mean	.672	.672*	.684	.684*	.659	.659*	.699	.699*
Age	.672	.000	.686	.002	.668	.009*	.707	.008*

$^*p < .01$.

The next set of analyses examined the influence of age on selected percentiles of the RT distribution. Two graphical methods were first used to portray the relevant relations. In one method, illustrated with the data from Data Set 1 in Figure 1, age and the RT measure were used as the curve parameters and the data plotted as a function of percentile of the distribution. If the distributions are symmetric, then the functions in this type of plot should be symmetric, with the same magnitude of difference from, for example, the 25th to the 10th percentile, as from the 75th to the 90th percentile. Inspection of the data in Figure 1 indicates that the distributions are not symmetric because the functions inflect upward at the higher percentiles, and particularly for older adults, indicating that the age differences are larger with the slowest RTs.

The second method of illustrating the relation between age and percentiles of the RT distribution consisted of plotting the RT corresponding to different percentiles as a function of age. This is done in Figure 2 with the data combined across Data Sets 2, 3, and 4, such that data points at each decade were based on the results from approximately 100 individuals. As in the previous figure, the age differences again appear to be greater at the higher percentiles in the distribution, in this case because the slopes of the age functions are steeper for higher percentile RTs.

The statistical significance of the relations between age and the various RT percentiles was evaluated by regression analyses focusing on Age × Percentile cross-product interactions. All of the main effects were significant (i.e., $F > 20$) in these analyses, as well as all interactions. The F-ratio for the interaction in Data Set 2 for the Digit Digit measure was only 6.04, but all other F-ratios for the interaction were greater than 15. These results therefore indicate that, as predicted from the attentional block hypothesis, the absolute differences between the age groups are significantly larger at the higher percentiles.

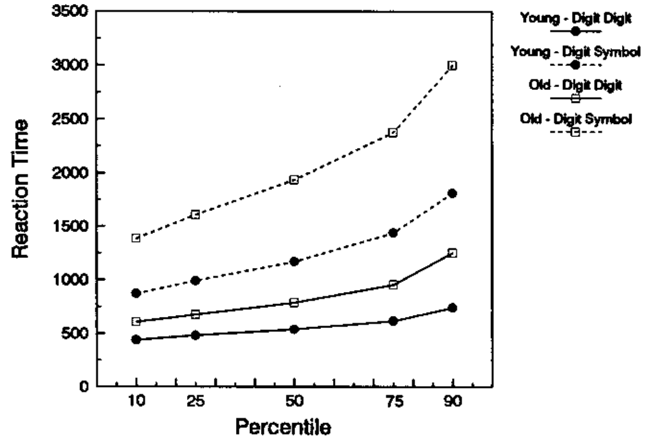

Figure 1. Means across subjects of successive percentiles of the RT distribution for Digit Digit and Digit Symbol measures in samples of 90 young and 90 old adults from Data Set 1.

The next set of analyses was designed to investigate the independence of the age-related influences at successive percentiles of the RT distribution. Figure 3 illustrates the framework used to guide these analyses. The procedure involved constructing separate regression equations for each percentile measure, with that measure as the criterion and the variables connected with arrows to that measure as the predictors. As an example, predictors for the 75th percentile measure were age (path 4) and the 50th percentile measure (path 8). Standardized regression coefficients from these analyses are reported in Table 4.

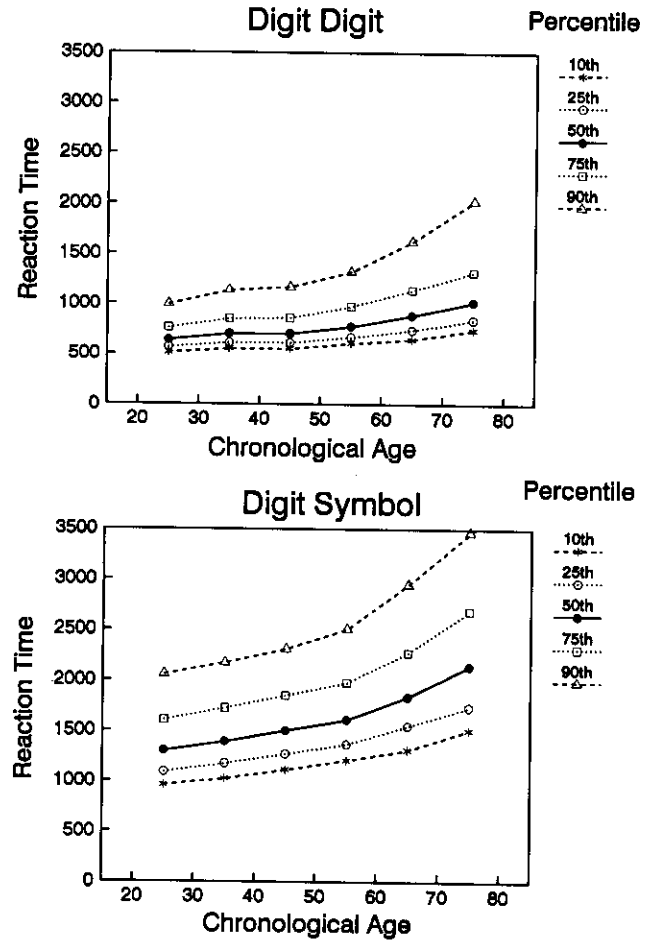

Figure 2. Means across subjects within each decade of successive percentiles of the RT distribution for Digit Digit and Digit Symbol measures. Data based on 604 subjects, aggregated across Data Sets 2, 3, and 4.

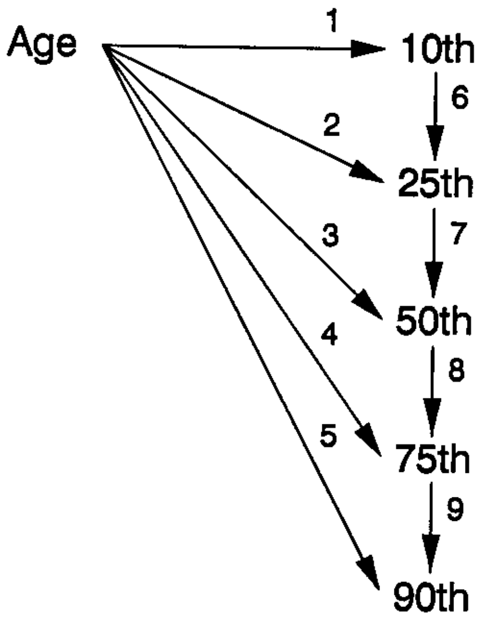

Figure 3. Illustration of possible relations among age and successive percentiles of the RT distribution. The magnitudes of the relations were evaluated in multiple regression analyses with the variables connected to a given variable as the predictors.

One aspect to be noted regarding the data in Table 4 is that the pattern is very similar for both the Digit Digit measure and the Digit Symbol measure. This indicates that despite the different requirements and mean levels of performance in the two tasks, comparable relations were evident both within the RT distributions, and with respect to the influence of age on various percentiles of the distributions. The two most important features of the data in Table 4 concern the relations between successive percentiles of the RT distribution, and the relations of age to those percentiles. It can be seen that all coefficients from a lower percentile to a higher one are significant, with most of the values very close to 1.0, indicating nearly perfect correspondence of variance. That is, an increase of one standard deviation in one of the percentile measures was associated with an almost identical increase in the measure from the next higher percentile. In contrast, when earlier percentiles are included as predictors of later percentiles, consistent age relations were evident only on the fastest responses (i.e., the 10th percentile RTs), implying that most of the age influence on slower responses (i.e., higher percentile RTs) is mediated through the age-related effect on the faster responses. That is, after one has removed the age-related influence on the fastest responses there is little or no age-related influence on the slower responses. It should also be noted that the only independent age relations on the 75th or the 90th percentile RTs with the Digit Symbol measure are negative rather than positive. This indicates that if anything, older adults were faster than young adults in the slowest responses when the variance in the fast responses was controlled. Perhaps the most important outcome of these analyses is that, contrary to the prediction from the attentional block hypothesis, there is no evidence of a distinct or unique age-related influence on the slowest, or highest percentile, response times.

Another set of analyses was conducted to extend the examination of the relations among age and percentiles of the RT distribution. Hierarchical regression analyses were conducted with the 50th and 90th percentile RTs as the criterion variables, and with age and the 10th percentile RTs as the predictor variables. An initial series of analyses tested for the presence of Age × Predictor interactions. No interactions were significant with the Digit Symbol measure, but four were significant with the Digit Digit measure. These were the prediction of the 50th percentile RT in Data Set 1 ($F = 12.28$) and in Data Set 3 ($F = 17.95$), and the prediction of the 90th percentile RT in Data Set 1 ($F = 17.95$), and Data Set 2 ($F = 29.97$). As in the analyses reported in Table 3, therefore, caution must be exerted when interpreting the statistical control results with some variables.

Cumulative R^2 and the increments in R^2 associated with age after control of the 10th percentile RT measures are presented in Table 5. The general pattern is quite clear in that there was little or no residual age-related variance in the 50th or 90th percentile RTs after eliminating the variance in the 10th percentile RTs. These results therefore indicate that nearly all of the age-related variance in the median (50th percentile) or the slowest (90th percentile) RTs overlaps with the age-related variance in the fastest (10th percentile) RTs.

A final set of analyses consisted of a series of hierarchical regression analyses using age and successively higher percentiles of the RT distribution to predict composite scores representing speed measures derived from paper-and-pencil tests, working memory, or cognitive accuracy. Only the Digit Symbol measure was used in these analyses because the analyses reported in Tables 3, 4, and 5 indicate that the results were similar for the Digit Digit and Digit Symbol measures, and other studies have reported a larger influence on age-cognition relations with the Digit Symbol measure than with the Digit Digit measure (Salthouse, in press). Results of these analyses are summarized in Table 6.

Table 4. Standardized Regression Coefficients for the Paths Illustrated in Figure 3

Path	Variables	Data Set 1	2	3	4
Digit Digit					
1	Age–10th	.67*	.66*	.49*	.38*
2	Age–25th	−.04	.01	.04	−.01
3	Age–50th	.03	−.03	.05*	.03
4	Age–75th	.01	.02	.07*	−.02
5	Age–90th	.02	−.01	.07	.02
6	10th–25th	1.00*	.98*	.96*	.97*
7	25th–50th	.93*	.98*	.95*	.93*
8	50th–75th	.96*	.96*	.93*	.96*
9	75th–90th	.95*	.72*	.87*	.94*
Digit Symbol					
1	Age–10th	.80*	.75*	.65*	.56*
2	Age–25th	.06*	−.03	.01*	.03
3	Age–50th	.03	−.04	−.02	−.02
4	Age–75th	−.06	−.02	−.09*	−.03
5	Age–90th	−.03	−.03	−.06*	−.04
6	10th–25th	.94*	1.01*	.98*	.97*
7	25th–50th	.97*	1.01*	1.00*	1.00*
8	50th–75th	1.03*	1.00*	1.03*	1.00*
9	75th–90th	.99*	.98*	.99*	.97*

$^{*}p < .01$.

First, consider the results with the composite working memory index as the criterion variable. In Data Set 1 there was a significant influence of the 50th percentile RT after control of the 10th percentile RT, and the residual age-related variance was slightly smaller when the 50th percentile RT was included in the regression equation. However, this pattern was not evident in Data Set 2 because in these data there were no independent influences of the 50th or 90th percentile RTs on the composite working-memory index.

The pattern with the composite motor speed index as the criterion variable resembled that with working memory as the criterion in that there was a significant influence of the 50th percentile RT after the 10th percentile RT in one data set (Data Set 3), but not in the other (Data Set 4). The analyses with the composite perceptual speed index as the criterion variable revealed a significant influence of the 50th percentile RT after control of the 10th percentile RT in both data sets. However, in both cases there was little further reduction of age-related variance relative to when only the 10th percentile RT was in the equation. This suggests that most of the shared age-related variance in the composite perceptual speed index is captured by the 10th percentile RTs. Results with the composite cognitive accuracy index as the criterion variable indicated a small influence of the 50th

Table 5. Hierarchical Multiple Regression Analyses on 50th and 90th percentile RTs

	Data Set 1		2		3		4	
	R^2	Incremental R^2	R^2	Incremental R^2	R^2	Incremental R^2	R^2	Incremental R^2
Digit Digit								
50th Percentile RT as the criterion variable								
Age	.396	.396*	.370	.370*	.282	.282*	.132	.132*
10th	.825	.825*	.835	.835*	.861	.861*	.732	.732*
Age	.825	.000	.836	.001	.868	.007*	.734	.002
90th Percentile RT as the criterion variable								
Age	.362	.362*	.180	.180*	.308	.308*	.107	.107*
10th	.665	.665*	.360	.360*	.515	.515*	.542	.542*
Age	.670	.005	.362	.002	.569	.054*	.545	.003
Digit Symbol								
50th Percentile RT as the criterion variable								
Age	.651	.651*	.489	.489*	.375	.375*	.290	.290*
10th	.932	.932*	.920	.920*	.895	.895*	.906	.906
Age	.935	.003*	.921	.001	.895	.000	.906	.000
90th Percentile RT as the criterion variable								
Age	.534	.534*	.397	.397*	.227	.227*	.207	.207*
10th	.721	.721*	.754	.754*	.645	.645*	.659	.659*
Age	.728	.007	.756	.002	.648	.003	.659	.000

$^{*}p < .01$.

Table 6. Hierarchical Regression Analyses With Different Criterion Variables and Age and Percentiles of the Digit Symbol RT Distribution as Predictor Variables

	Working Memory as the Criterion Variable					Perceptual Speed as the Criterion Variable			
	Data Sets					Data Sets			
	1		2			1		2	
	R^2	Incremental R^2	R^2	Incremental R^2		R^2	Incremental R^2	R^2	Incremental R^2
Age	.279	.279*	.146	.146*	Age	.399	.399*	.235	.235*
10th	.216	.216*	.201	.201*	10th	.433	.433*	.351	.351*
Age	.284	.068*	.206	.005	Age	.507	.074*	.386	.035*
10th	.216	.216*	.201	.201*	10th	.433	.264*	.351	.351*
50th	.255	.039*	.207	.006	50th	.476	.043*	.391	.040*
Age	.304	.049*	.213	.006	Age	.549	.073*	.424	.033*
10th	.216	.216*	.201	.201*	10th	.433	.433*	.351	.351*
50th	.255	.039*	.207	.006	50th	.476	.043*	.391	.040*
90th	.255	.000	.211	.004	90th	.477	.001	.399	.008
Age	.304	.049*	.216	.005	Age	.549	.072*	.432	.033*

	Motor Speed as the Criterion Variable					Cognitive Accuracy as the Criterion Variable			
	Data Sets					Data Sets			
	3		4			3		4	
	R^2	Incremental R^2	R^2	Incremental R^2		R^2	Incremental R^2	R^2	Incremental R^2
Age	.333	.333*	.117	.117*	Age	.189	.189*	.071	.071*
10th	.362	.362*	.209	.209*	10th	.232	.232*	.273	.273*
Age	.423	.061*	.220	.011	Age	.258	.026*	.273	.000
10th	.362	.362*	.209	.209*	10th	.232	.232*	.273	.273*
50th	.378	.016*	.225	.016	50th	.244	.012*	.280	.007
Age	.439	.051*	.249	.024	Age	.271	.027*	.281	.001
10th	.362	.362*	.209	.209*	10th	.232	.232*	.273	.273*
50th	.378	.016*	.225	.016	50th	.244	.012	.280	.007
90th	.381	.003	.238	.013	90th	.245	.001	.280	.000
Age	.439	.058*	.249	.009	Age	.271	.026*	.281	.001

$^*p < .01$.

percentile RT in Data Set 3, but little further attenuation of the age-related variance.

The analyses summarized in Table 6 therefore indicate that there is little or no unique influence of the 50th percentile RTs, and no significant influence of the 90th percentile RTs, on the relations between age and other measures of speed or cognitive functioning after the influence of the 10th percentile RTs was controlled. Contrary to the expectation from the attentional block hypothesis, the age-related influence on measures of speed, and the relation between measures of speed on cognition, are at least as pronounced with the fastest responses in the distribution as with the slowest responses.

DISCUSSION

The major conclusion from the analyses reported above is that age-related influences on speed are not due to more frequent, or longer duration, lapses in concentration or attentional blocks with increased age. Perhaps the most convincing evidence contradicting the attentional block hypothesis is the finding that nearly all of the age-related influence on speed, and its relation to other measures of speed or cognitive functioning, is evident in the individual's fastest responses. Moreover, the asymmetry of the attenuation of the age-related variance in predicting the standard deviation or the mean when the other variable was controlled is more consistent with the view that increased variability is a consequence, rather than a cause, of the age-related slowing phenomenon.

The absolute number of slow RTs does increase with age, but the age-related influences on RTs from the highest percentiles of the distribution are not independent of those on RTs from the lowest percentiles. The lack of independence in the variance suggests that there is a similar rank-ordering of individuals (i.e., high correlations) across successive percentiles of the RT distribution, but that the RT scale may simply stretch or expand with increased age. In other words, the absolute magnitude of the age differences may increase across successive percentiles of the RT distribution because of an expansion of the entire RT distribution when the distribution is shifted toward slower RTs. It is important to emphasize, however, that the slowest RTs appear to be determined by the same processes as those affecting the fastest RTs because virtually all of the age-related influences on the higher percentiles of the distribution can be predicted from the age-related influences on the lower percentiles.

Smith, Poon, Hale, and Myerson (1988) reached an analogous conclusion based on a finding of similar relations between the mean RTs of young and old adults across several percentiles of the intraindividual RT distributions for a number of different speeded tasks. That is, they claimed that "... whatever is inducing the slowing appears to be having a similar effect throughout the [RT distribution] ... [and that] ... slowing has a magnifying effect on the distribution, stretching it out" (p. 208). Systematic relations between different percentile RTs for adults of different ages have also been reported by Myerson, Hale, Hirschman, Hansen, and Christiansen (1989).

Unfortunately, although the results of these analyses seem unequivocal with respect to ruling out interpretations based on attentional blocks, they are less informative about what does contribute to age-related slowing. For example, the slowing could originate because of slower propagation of neural impulses, delays in the transmission across synapses, or the necessity of longer and more circuitous neuronal pathways because of the loss of functional neurons, but these alternatives cannot be distinguished on the basis of the results reported here. The present results nevertheless do place constraints on the types of explanations that are viable. That is, the discovery that almost all of the age-related variance on speed is evident in the fastest responses emitted by the individual implies that the causal mechanisms shift and expand the entire RT distribution, and thus hypotheses postulating a selective influence on the speed of responses in the middle or upper percentiles of the distribution are implausible.

If the suggestion by Bunce et al. (1993) that very slow responses can be interpreted as an index of inhibition failure is correct, then these data can also be viewed as inconsistent with the Hasher and Zacks (1988) position regarding age-related changes in inhibitory control. That is, because almost all of the age-related variance in the slowest RTs can be predicted by the age-related variance in the fastest RTs, the age-related slowing phenomenon cannot be attributed to the presence of failures of inhibition leading to attentional blocks.

In summary, the relation between the mean and the standard deviation of the intra-individual RT distribution, and between both of these measures and age, does not occur simply because of an age-related increase in the number of very slow responses. Increased age is associated with a higher number of slow RTs, but almost all of the age-related slowing is as evident in the fastest responses in the RT distribution as in the slowest responses, and the relation with other cognitive measures is as strong with the fastest responses as with the slowest responses.

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