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Aging, Inhibition, Working Memory, and Speed

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An implication of the hypothesis that failures of inhibition contribute to adult age differences in working memory (Hasher & Zacks, 1988) is that statistical control of measures of inhibition should reduce the age-related effects on working memory. This implication was tested in a study in which interference measures from three variants of a Stroop task served as the measures of inhibition. Although the age-related variance in measures of working memory was substantially reduced after control of the interference measures, the degree of attenuation was at least as large when speed measures from other tasks were controlled. Furthermore, additional analyses revealed that speed measures from tasks requiring oral, written, and keypress responses shared large proportions of their age-related variance. It was suggested that age-related influences on specific processes, such as inhibition, cannot be accurately assessed unless the contributions of more general age-related influences are taken into consideration.

THERE has recently been considerable interest in inhibition as a factor that might contribute to adult age-related effects on cognition. For example, Hasher and Zacks (1988) suggested that age differences in working memory functioning originate because of reduced inhibition abilities. According to these authors, either irrelevant material gets into working memory and lowers its functional capacity, or off-track material within working memory is not inhibited and distraction occurs during processing. Because working memory is postulated to play a critical role in many cognitive tasks, a mechanism such as this has the potential to explain the age-related effects in a wide variety of cognitive measures.

An implication of the Hasher and Zacks view is that if one could control the individual difference variation in a measure of inhibition, then the age-related effects on working memory, and on other measures of cognition, should be considerably reduced. (See Salthouse, 1992a, for a discussion of the rationale underlying the application of statistical control methods in research on aging and cognition.) Although the statistical procedures for controlling the variance in one variable when examining the relation between two other variables are fairly straightforward, the challenge in the application of these procedures in the current context is in identifying adequate measures of the inhibition construct.

Several requirements can be identified for such measures. One is that the measure should be reliable, because if a measure has little systematic variance then it is unrealistic to expect much of the total variance in the measure to be shared with other measures. The measure should also be valid in order to have confidence that it actually reflects the target construct — in this case inhibition, rather than some other construct. This often must be determined from the pattern of correlations with other measures hypothesized to reflect the same construct because there is currently no external criterion against which one can validate measures of the inhibition construct. Both reliability and validity benefit if the construct is assessed with multiple measures. Not only is the reliability greater due to aggregation (Rushton, Brainerd, & Pressley, 1983), but the validity is often higher because construct variance can be emphasized by cancelling out the specific variance associated with the particular methods, materials, and measures.

Several alternative methods have been used to measure inhibition, but nearly all are indirect, and the reliability of some of the measures can be questioned because the effects are often quite small (e.g., measures of negative priming sometimes used as an index of inhibition often average only 10–15 msec). The potentially low reliability may have contributed to the lack of strong correlations among measures presumed to assess inhibition in earlier studies (e.g., Hartman & Hasher, 1991; Stolzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993).

Inhibition is assessed in this study with three variants of the Stroop interference task. The dominant interpretation of interference in this task is that the slower response to name the color of a target word when the identity of the word is in conflict with the color occurs because the word information is activated automatically and the research participant needs to inhibit the irrelevant (word) information when attempting to name the color (e.g., Cohn, Dustman, & Bradford, 1984; Dulaney & Rogers, 1994; MacLeod, 1991). It may therefore be possible to use the amount of interference in the task as an index of the effectiveness of inhibition, with larger interference interpreted as a reflection of decreased inhibition.

If this interpretation of the interference measure is correct, and if older adults have reduced inhibitory abilities relative to younger adults, then the amount of interference in the Stroop task would be expected to increase with increased age. In fact, there are numerous reports of greater interference with increased age in Stroop tasks (Cohn et al., 1984; Comalli, Wapner, & Werner, 1962; Daigneault, Braun, & Whitaker, 1992; Dulaney & Rogers, 1994; Hartley, 1993; Hartman & Hasher, 1991; Houx, Jolles, & Vreeling, 1993; Panek, Rush, & Slade, 1984).

However, several issues need to be considered before these results can be accepted as indicating an age-related decrease in inhibitory ability. First, greater interference with increased age could originate either because of reduced inhibition and equal strength of automatic activation or because of equal inhibition and increased strength of automatic activation. That is, instead of older adults having less effective inhibition processes, their greater interference may occur because of more potent or effective automatic activation such that the irrelevant word information is activated more strongly in older adults than in young adults. One way in which these possibilities might be distinguished is by also measuring facilitation, or the benefit of compatible word and color information relative to a neutral condition. Facilitation should reveal any benefits of automatic activation, and thus if older adults have more automatic activation than young adults, then they should have more interference and also more facilitation. However, if the greater interference with increased age is primarily due to decreased inhibition, then the amount of facilitation should not systematically differ as a function of age.

Second, it is important to consider the manner in which the inhibition measures are derived. Interference and facilitation are typically assessed by difference scores, with the former defined as the time in the incompatible condition minus the time in the neutral condition, and the latter defined as the time in the neutral condition minus the time in the compatible condition. Difference scores have been criticized because the reliability is often low and because they have a high correlation with the baseline (neutral) score. The question of reliability can be examined by administering repeated trials in each condition to allow the reliability of the difference scores to be computed. However, Cohen and Cohen (1983, p. 414) suggest that a better method of taking performance on one task (neutral) into consideration when examining performance on a second task (incompatible) is to partial variance in the original score first. It is therefore desirable to use both the difference score and the partialling methods in assessing relations between age and interference.

Third, it is also possible that what are presumed to be measures of specific processes such as inhibition may actually reflect the contribution of a more general or common influence (cf., Salthouse & Coon, 1994). This possibility can be examined by partialling out the effects of other measures to determine whether the age-related effects are independent of one another. Measures from several different tasks should be included in these types of analyses to determine if there are effects of a more general factor.

Finally, it is desirable to have multiple measures of the relevant theoretical constructs. This is important not only to increase reliability and validity for the reasons mentioned earlier but also because MacLeod (1991) has noted that little research has examined correlations of the interference measures in different versions of the task.

To summarize, the major goal of this study was to examine age-related effects in measures of inhibition and to determine the extent to which inhibition may contribute to the age-related differences in working memory. The working memory construct was assessed with two tasks, the reading-span task and the computation-span task. Both have been used in several previous studies (e.g., Salthouse, 1991, 1992b, 1992c; Salthouse & Babcock, 1991; Salthouse & Coon, 1994; Salthouse, Mitchell, Skovronek, & Babcock, 1989; Salthouse & Skovronek, 1992) and have been found to yield reliable measures, which have moderate positive relations with one another and with several measures of cognitive performance and moderate negative relations with age. Interference and facilitation were assessed with three parallel Stroop tasks similar to those used by other researchers (e.g., see MacLeod, 1991, for citations), but specifically designed to be structurally parallel (see Figure 1). Subjects were always instructed to name the color, the quantity, or the position of target items, and the stimulus items consisted of either a neutral string of Xs, a compatible word or number string, or an incompatible word or number string. Finally, additional tests of processing speed were administered to examine the relation of these measures to the purportedly specific measures of interference and facilitation.

METHOD

Research participants. — Characteristics of the 242 adults who participated in the study are summarized in Table 1. The participants were recruited from newspaper advertisements and community organizations. It can be seen that the average level of education was quite high and that most participants reported themselves to be in good to excellent health.

Tasks. — The different versions of the Stroop tasks (see Figure 1) were designed to have a similar format. The stimulus materials in each consisted of a page containing two columns of 10 stimuli each. The alphanumeric characters were 5 mm high, except in the position task where they were 3 mm high. The rectangles surrounding the stimuli were 17 × 30 mm, except in the position task where they were 17 × 37 mm. Research participants were instructed to name the colors (i.e., red, blue, green, yellow) of the items in the color version, to name the quantity (i.e., one, two, three, or four) of the items in the number version, and to name the positions (i.e., above, below, right, left) relative to the internal line in the position version. In all cases the oral responses were to be made as quickly as possible and were timed with a stopwatch to a resolution of 0.1 sec. The participants were instructed to correct their errors, but be-

Table 1. Demographic Characteristics of Research Participants

	20s	30s	40s	50s	60s	70–89
Number	45	32	43	37	56	29
% Female	40.0	68.8	62.8	67.6	58.9	51.7
Age						
Mean	23.4	35.2	44.4	53.7	65.1	74.9
SD	3.3	3.1	2.8	2.8	3.1	4.5
Education						
Mean	15.1	15.2	15.5	16.3	15.2	14.2
SD	1.8	2.6	2.0	1.6	2.4	2.0
Health						
Mean	1.9	1.6	2.0	1.8	1.9	2.1
SD	0.8	0.7	1.1	0.9	0.9	0.9

Note: Education refers to the number of years of formal education completed, and health is a self-rating on a scale ranging from 1 for Excellent to 5 for Poor. Because there were very few individuals in the two oldest age groups, they have been combined in the interest of space.

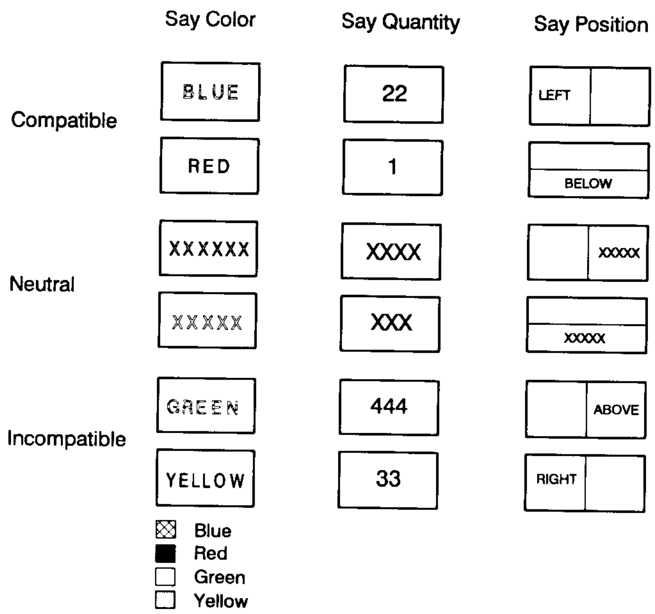

Figure 1. Illustration of stimulus materials in the compatible, neutral, and incompatible conditions in the color, number, and position versions of the Stroop task.

cause very few errors were uncorrected, the errors were reflected in longer response times and were not analyzed separately.

A reading speed task consisted of a page containing 20 randomly arranged words from the set of four colors, four positions, and four numbers. As in the Stroop tasks, the research participant was instructed to name (read) the items as quickly as possible, and timing was performed with a stopwatch.

The tasks were individually administered to all research participants in the following order: reading speed, color, number, position, position, number, color, and reading speed. A single page was used in each administration of the reading speed conditions, but six pages were presented in each administration of the other conditions in the order neutral, compatible, incompatible, incompatible, compatible, and neutral. Four different arrangements of 10 target stimuli were prepared for each Stroop version, and each arrangement was presented once in each condition. For purposes of reliability assessment, the times for the first two administrations of each condition were averaged and correlated with the average times for the last two administrations of each condition.

The working memory tasks were administered on computers according to the procedures described in Salthouse and Coon (1994). Briefly, the reading span task involved the presentation of a series of sentences, with each sentence accompanied by a question with three alternatives. The task for the research participant was to select the correct answer to the question and remember the last word in the sentence. Both the selection of the correct alternative and the recall of the target words were entered by keyboard responses. The individual's reading span was the largest number of items in which he or she was correct on both processing (answering the questions) and storage (recalling the words) in at least two of three trials. The computation span was very similar but involved the presentation of a series of arithmetic problems, with each problem accompanied by three alternatives. As in the reading span task, the research participant was instructed to select the correct answer to the problem and remember the last item in the problem. Both the selection of the correct alternative and the recall of the target digits were communicated by keyboard responses. The individual's computation span was the largest number of items in which he or she was correct in both the arithmetic problem and the recall of the last digit in at least two of three trials. The reading span and computation span tasks were each administered twice, in immediate succession, to allow reliability to be determined.

The other tasks designed to assess processing speed have also been described in previous reports (e.g., Salthouse & Coon, 1994). The letter comparison and pattern comparison tasks required the research participants to make rapid judgments about whether a pair of letter strings (letter comparison) or line patterns (pattern comparison) were the same or different. Stimuli in this task consisted of two columns of items, and responses consisted of writing the letter S (for same) or D (for different) on the line between the two members of the pair. Two computer-administered speed tasks were the digit digit and digit symbol tests. These tasks were described by Salthouse and Coon (1994) as follows:

> The digit symbol test involved the presentation of a code table containing digits paired with symbols and probes of a digit paired with a symbol. The subject was instructed to decide as rapidly as possible whether the digit and symbol were associated according to the code table. If the digit and symbol were associated in the code table then the slash key was to be pressed, and if they were not paired in the code table then the Z key was to be pressed. The digit digit version of the task was identical except that the symbols were replaced with digits, and thus the yes-no decision was based on physical identity rather than associational equivalence. In both tasks subjects were instructed to respond as rapidly and accurately as possible (p. 1175).

Each of these four tasks (i.e., letter comparison, pattern comparison, digit digit, and digit symbol) was administered twice, in immediate succession, to allow reliability to be computed.

Results

Descriptive characteristics of the dependent measures are presented in Table 2. Reliability was estimated by boosting the correlation between the score on the first administration (average of two trials for the Stroop tasks) and on the second administration by the Spearman-Brown formula. It is apparent that most measures have good reliability, and even the interference difference score measures have reliabilities greater than .62. As expected, most of the measures had moderately large linear relations with age.

Age relations in the Stroop measures from the three tasks are displayed in Figure 2. It is apparent in Figure 2 that the quadratic relations reported for a few measures in Table 2 are attributable to larger-than-linear slowing among the oldest participants.

Table 2. Means, Standard Deviations, Estimated Reliabilities, and Age Trends for Primary Dependent Variables

				Proportion of Variance	
Variable	Mean	*SD*	Est. Rel.	Age	Age²
Letter Comparison	9.54	2.69	.77	.310*	.009
Pattern Comparison	16.53	4.01	.87	.401*	.004
Digit Digit RT	739	163	.93	.353*	.009
Digit Symbol RT	1511	415	.97	.400*	.003
Reading Span	2.50	1.37	.78	.035*	.001
Computation Span	4.06	2.17	.83	.018	.000
Reading Speed	8.25	1.65	.81	.073*	.000
Colors — Neutral	11.23	2.44	.89	.253*	.034*
Colors — Compatible	9.63	2.23	.84	.227*	.010
Colors — Incompatible	19.01	4.82	.91	.323*	.002
Colors — Interference	7.78	3.25	.72	.217*	.005
Colors — Facilitation	1.60	1.60	.57	.010	.020
Numbers — Neutral	9.82	2.21	.92	.229*	.009
Numbers — Compatible	9.79	2.66	.93	.304*	.005
Numbers — Incompatible	12.32	2.72	.91	.234*	.012
Numbers — Interference	2.50	1.49	.62	.031*	.002
Numbers — Facilitation	0.03	1.14	.47	.133*	.001
Positions — Neutral	14.05	3.30	.94	.202*	.026*
Positions — Compatible	10.82	2.94	.94	.235*	.013
Positions — Incompatible	17.53	4.82	.95	.193*	.023*
Positions — Interference	3.48	2.34	.70	.073*	.007
Positions — Facilitation	3.23	1.98	.75	.001	.011

Note: Letter Comparison and Pattern Comparison measures are the number of correct minus the number of incorrect responses in 30 sec, and Digit Digit RT and Digit Symbol RT are times in msec. Reading Span and Computation Span measures represent the largest sequence in which both processing and recall were correct on at least two of three trials. All remaining measures are in sec, with the observed measures corresponding to the time required to complete the page of 20 items, and the difference score measures (interference and facilitation) representing differences between observed times.

*$p < .01$.

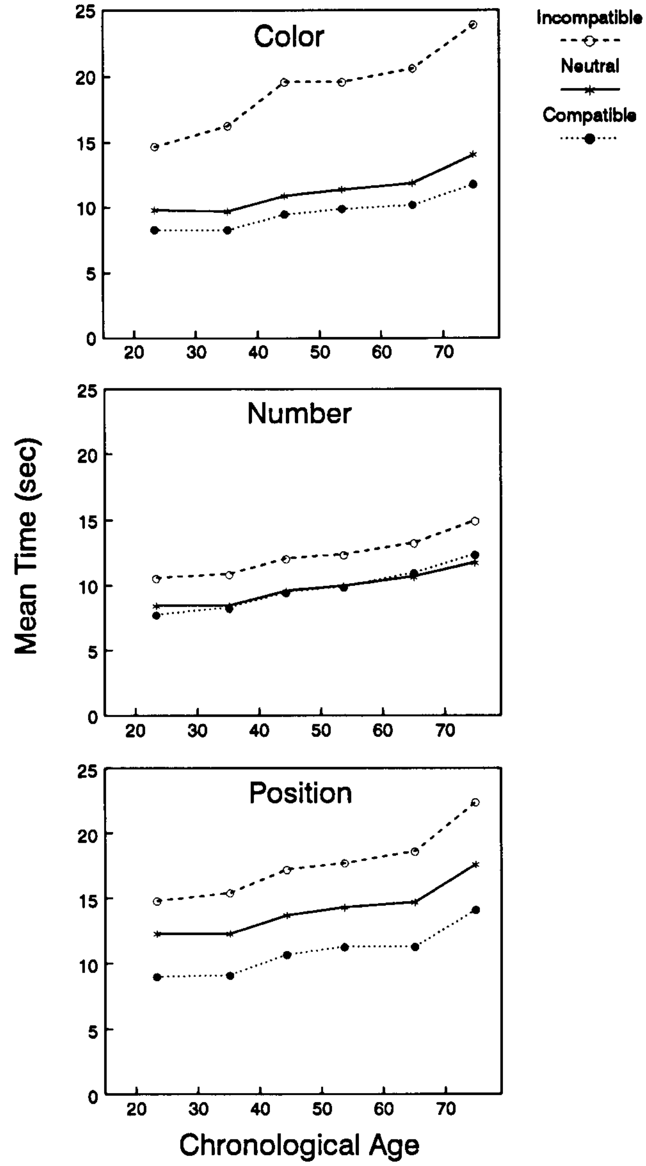

Figure 2. Mean time by age decade in the three conditions of the color, number, and position versions of the Stroop task. Bars adjacent to the data points represent one standard error.

Inspection of Table 2 reveals that there were relatively small age-related effects on working memory in this sample. Correlations between age and the reading span and computation span measures were −.19 and −.13, respectively, compared to values of −.37 and −.26, respectively, in another study (Salthouse, in press) with very similar procedures. The difference in the two samples is largely attributable to the older adults in this study performing better than the older adults in the other study, which may be related to a slightly greater average amount of education for the older adults in this study.

Main effects, and interactions with age, of education, health status, and gender for the measures in Table 2 were examined in a series of regression analyses. Main effects of education were significant on many measures (i.e., letter comparison, pattern comparison, reading span, computation span, reading speed, color-neutral, color-compatible, numbers-neutral, numbers-compatible, numbers-incompatible, positions-neutral, positions-compatible, positions-incompatible, and positions-interference), but there was a significant interaction of age and education only on the positions-facilitation measure. Health main effects were significant on numerous variables (i.e., reading speed, color-neutral, color-compatible, numbers-neutral, numbers-compatible, numbers-incompatible, positions-neutral, positions-compatible, and positions-incompatible), but none of the interactions with age were significant. Females had significantly higher scores (longer times) on the digit digit, digit symbol, color-interference, numbers-incompatible, positions-neutral, positions-compatible, and positions-interference measures, but there no significant interactions of age and gender.

Consistent with earlier research on the Stroop phenomenon (e.g., MacLeod, 1991), reading words (8.25 sec) was faster then naming colors (11.23 sec), naming quantities (9.82 sec), or naming positions (14.05 sec). The finding of smaller facilitation than interference in each task is also consistent with earlier research (MacLeod, 1991) on these types of tasks. Although the facilitation effects were small, they were significantly greater than zero in the color (t = 15.53) and position (t = 25.31) tasks, but not in the number task (t = 0.48). Moreover, the pattern was consistent across individuals because 88.0% of the participants had positive facilitation scores for the color task, 51.2% for the number task, and 97.9% for the position task. These results, in combination with the moderate reliabilities, suggest that at least the facilitation measures from the color and position tasks were not at a measurement floor.

Age effects were small to nonexistent on the facilitation measures except for the number task, suggesting that age-related effects on interference measure are not attributable to stronger automatic activation with increased age. The significant age effects on the number facilitation measure appear due to a shift from positive (benefit) to negative (cost) with increased age, and thus suggest that, if anything, there may be a decrease with increased age in the strength of automatic activation in this task. Regardless of how that particular result is interpreted, however, the lack of an age-related increase in facilitation implies that the greater interference with age cannot be attributed to an increase in automatic activation.

Correlations were computed among the difference scores, both before and after correction for attenuation by dividing the correlation by the square root of the product of reliabilities. These correlations, with the disattenuated correlations in parentheses, were .38 (.57) for the color and number interference measures, .52 (.73) for the color and position interference measures, .28 (.42) for the number and position interference measures, .16 (.31) for the color and number facilitation measures, .45 (.69) for the color and position facilitation measures, and .14 (.24) for the number and position facilitation measures. It is apparent that the interference and facilitation measures from the color and position tasks have moderate correlations with one another, particularly after adjustment for reliability, but that the measures from the number task have smaller relations with other measures. Although this pattern raises questions about the extent to which the measures all reflect a common construct, a composite interference measure was nevertheless formed by averaging z-scores for measures from all three tasks. However, results are also reported for each individual measure to allow the generalizability of the results to be examined.

A composite working memory measure was also created by averaging the z-scores for the reading span and computation span measures. The correlation between the two measures was .57, and .71 after correction for attenuation due to unreliability. Composite speed measures were also created from the other speed tasks by averaging z-scores from the similar tasks. The correlations were .67 (.82 after correction for unreliability) between the letter comparison and pattern comparison measures, and .84 (.88 after correction for unreliability) between the digit digit and digit symbol measures.

Results of the statistical control analyses on the age-related influences on working memory are summarized in Table 3 (see Appendix, Note 1). All regression analyses except the first were performed hierarchically, with the increment in R^2 determined for each successive variable. The relevant contrasts for the current purposes are between the initial age-related variance (Equation 1) and the increment in variance associated with age after control of one or more other variables. Notice that there was large attenuation of the age-related effects in working memory when the measures of inhibition were controlled, both those from the difference scores measures (Equations, 2, 4, and 10, but not the difference score from the number task, Equation 7) and those from the sequential partialling procedure (Equations 3, 5, 8, and 11). However, the attenuation was at least as large when the measures from the neutral condition were controlled (Equations 6, 9, and 12), and when speed measures from separate tasks were controlled (Equations 13, 14, and 15). These results indicate that the phenomenon of attenuated age-related variance in working memory is not simply attributable to inhibition. Speed, or whatever it is that is common to all these measures, appears to be more important than inhibition as a factor contributing to the adult age differences in working memory.

Because of the unusually small relation between age and working memory in this sample, another sample was created with more typical relations between age and working memory. This was achieved by eliminating data from participants (n = 9) above the median age (50) with working memory composite scores in the top 10% of the overall distribution, and data from participants (n = 9) below the median age with working memory composite scores in the bottom 10% of the distribution. The age-related variance (R^2) in the composite working memory measure in this sample of 224 adults was .104, which is more in line with the values from other studies than the .033 value in the complete sample. However, the same pattern of reduction of age-related variance in working memory after control of the speed variables was apparent in this more typical sample. That is, the residual age-related variance in the composite working memory measure was .035 after control of the color-interference measure, .099 after control of the number-interference measure, .050 after control of the position-interference measure, .061 after control of the reading speed measure, .016 after control of the perceptual speed composite measure, and .018 after control of the reaction time composite speed measure. The reduction of 84.6% after control of the perceptual speed composite is similar to that reported in other studies (Salthouse, 1991, 1992c; Salthouse & Babcock, 1991). For example, a recent study (Salthouse, in press) with the same measures and a similar sample had a decrease in the age-related variance in the composite working memory measure of 78% (from .141 to .031) after control of the perceptual speed composite, and a decrease of 79% (from .141 to .029) after control of the reaction time speed composite (see Appendix, Note 2).

Relations Among Measures

The next set of analyses examined the interrelations of the speed measures. The initial analysis determined the effects of statistical control of the speed measures on the relations between age and the naming measures. The results of these analyses, in terms of the proportion of age-related variance remaining after control of specified measures, are presented in Table 4. It can be seen that there was significant residual age-related variance in several measures, but in all cases the residual was only a small fraction of the total age-related

Table 3. Age-Related Variance in Working Memory Measures Before and After Control of Other Variables

	Composite Measure		Reading Span		Computation Span	
Controlled Variable	R^2	Incr. R^2	R^2	Incr. R^2	R^2	Incr. R^2
Eq. 1						
Age	.033	.033*	.035	.035*	.018	.018
Eq. 2						
Int. (Composite)	.091	.091*	.079	.079*	.065	.065*
Age	.096	.005	.086	.007	.066	.001
Eq. 3						
N (Composite)	.104	.104*	.062	.062*	.104	.104*
I (Composite)	.129	.025*	.095	.033*	.114	.010
Age	.129	.000	.096	.001	.118	.004
Eq. 4						
C-Int.	.091	.091*	.085	.085*	.059	.059*
Age	.093	.002	.089	.004	.060	.001
Eq. 5						
CN	.067	.067*	.038	.038*	.070	.070*
CI	.112	.045*	.091	.053*	.091	.021
Age	.112	.000	.092	.001	.093	.002
Eq. 6						
CN	.067	.067*	.038	.038*	.070	.070*
Age	.071	.004	.049	.011	.070	.000
Eq. 7						
N-Int.	.004	.004	.001	.001	.007	.007
Age	.034	.030*	.036	.035*	.021	.014
Eq. 8						
NN	.097	.097*	.063	.063*	.091	.091*
NI	.099	.002	.063	.000	.095	.004
Age	.100	.001	.069	.006	.096	.001
Eq. 9						
NN	.097	.097*	.063	.063*	.091	.091*
Age	.098	.001	.069	.006	.091	.000
Eq. 10						
P-Int.	.113	.113*	.111	.111*	.069	.069*
Age	.122	.009	.122	.011	.073	.004
Eq. 11						
PN	.095	.095*	.054	.054*	.098	.098*
PI	.145	.050*	.120	.066*	.117	.019
Age	.145	.000	.125	.005	.118	.001
Eq. 12						
PN	.095	.095*	.054	.054*	.098	.098*
Age	.097	.002	.063	.009	.098	.000
Eq. 13						
Reading Speed	.047	.047*	.031	.031*	.044	.044*
Age	.063	.016	.052	.021	.050	.006
Eq. 14						
Perceptual Speed	.091	.091*	.082	.082*	.062	.062*
Age	.092	.001	.082	.000	.064	.002
Eq. 15						
RT-Speed	.058	.058*	.051	.051*	.040	.040*
Age	.059	.001	.054	.003	.040	.000

Note: Int. refers to the interference difference scores, CN, NN, and PN refer to the color, number, and position neutral scores, respectively, and CI, NI, and PI refer to the color, number, and position incompatible scores, respectively.

$^*p < .01$ for Increment in R^2.

Table 4. Age-Related Variance in Naming Measures Before and After Control of Other Variables

Criterion Variable	Alone	After control of: Neutral	RdSpd	PSpd	RTSpd
Color					
Incompatible	.323*	.038*	.201*	.037*	.046*
Compatible	.227*	.011	.092*	.014	.041*
Interference	.217*	.085*	.161*	.033*	.028*
Facilitation	.010	.021	.013	.002	.000
Number					
Incompatible	.234*	.009*	.108*	.007	.006
Compatible	.304*	.018*	.144*	.030*	.038*
Interference	.031*	.031*	.027*	.002	.002
Facilitation	.133*	.098*	.102*	.076*	.047*
Position					
Incompatible	.193*	.001	.097*	.006	.002
Compatible	.235*	.019*	.106*	.011	.021*
Interference	.073*	.007	.047*	.001	.001
Facilitation	.001	.042*	.000	.000	.001
MEAN	.165	.032	.092	.018	.019

Note: RdSpd is Reading Speed, PSpd is the Perceptual Speed composite (letter comparison and pattern comparison), and RTSpd is the reaction time speed composite (Digit Digit RT and Digit Symbol RT).
$^*p < .01$.

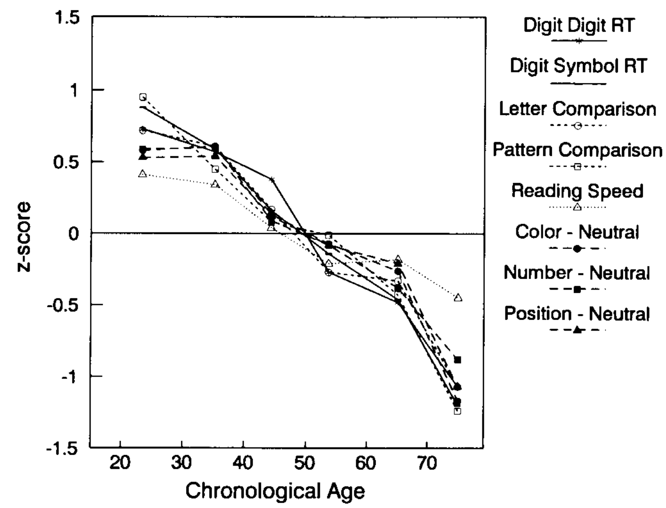

Figure 3. Means by age decade for speed scores expressed in standard deviation units from the entire sample. Note that the measures have been reflected such that higher z-scores correspond to faster performance.

effects. For example, the residual age-related variance in the color-interference measure was only 39% of the initial age-related variance after control of the color-neutral measure, and was only 15.2% of the initial variance after control of the composite perceptual speed measure. It therefore appears that most of the age-related variance in these measures is shared with the other measures. The reading speed measure is somewhat of an exception because it shares relatively little variance with the other naming measures.

Speed measures from different tasks were converted to z-scores, and plotted by age decade in Figure 3. Similar trends are evident for all measures, except for a slightly shallower age relation for the reading speed measure. This discrepancy is also apparent in the proportions of age-related variance in Table 2 because the value for the reading speed measure was only .073, compared to values of .202 or greater for the other measures.

The similar age functions apparent in Figure 3 raises the possibility that one or more common factors might contribute to the age-related influences in the speed measures. This was examined by determining the proportion of the age-related variance shared between pairs of speed measures. These proportions, which are presented in Table 5, were calculated by computing the R^2 for age in the criterion measure, next computing the increment in R^2 for age after removing the variance in the controlled measure, and then subtracting the latter from the former and dividing by the former. To illustrate, the total age-related variance in the color-incompatible measure was .323, and the increment in variance in that measure associated with age after control of the color-neutral measure was .038. The ratio of (.323–.038)/.323 = .882, which corresponds to the entry in the 6th row and 8th column in Table 5.

The pairs in the table are not symmetric because the age-related variance in the two measures is not identical. To illustrate, the age-related variance in the color-neutral measure is .253, and the estimate of the proportion of this age-related variance that was shared with the color-incompatible measure is .984. However, the proportion of the age-related variance (.323) in the color-incompatible measure that was shared with the color-neutral measure was .882 (see Appendix, Note 3).

The mean of all entries in Table 5 is .863, which indicates that there is considerable commonality among the age-related variance in these measures. Substantial commonality also exists in the age-related influences on the derived measures. This is evident in the proportion of age-related variance in the interference difference score measures that was shared with the other speed measures. The proportions shared with the respective neutral measures were .608 (Color), 1.00 (Number), and .904 (Position), the proportions shared with the reading speed measure were .258 (Color), .129 (Number), and .356 (Position), those shared with the perceptual speed composite were .848 (Color), .935 (Number), and .986 (Position), and the proportions shared with the reaction time speed composite were .871 (Color), .935 (Number), and .986 (Position). As in the other analyses, therefore, the reading speed measure appears to have a relatively small proportion of age-related variance in common with the other speed measures.

It is also possible to compute the geometric mean of the two proportions of shared age-related variance for a pair of measures, and then take the square root of that value to yield a type of correlation termed the quasi-partial correlation (Salthouse, 1994). The quasi-partial correlation is analogous to a correlation coefficient but, instead of representing the proportion of total variance that is shared, it represents only the proportion of age-related variance that is shared. The quasi-partial correlation for the variance proportions in Table 5 are presented in Table 6. The mean of the entries in this table is .886, and the median is .877.

Table 5. Proportion of Shared Age-Related Variance in Speed Measures

	Criterion Variable														
Controlled Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Mean
1 — DDRT	X	.933	.629	.579	.973	.735	.705	.749	.830	.757	.906	.901	.796	.917	.801
2 — DSRT	.983	X	.835	.776	.986	.846	.828	.864	.939	.885	.970	.970	.919	.995	.907
3 — LetCom	.558	.683	X	.758	.932	.767	.767	.721	.852	.697	.803	.757	.762	.788	.757
4 — PatCom	.652	.780	.910	X	.999	.877	.907	.833	.943	.885	.957	.960	.936	.959	.892
5 — RdSpd	.266	.265	.287	.262	X	.514	.595	.378	.620	.526	.538	.559	.549	.497	.450
6 — CN	.550	.580	.648	.606	.973	X	.952	.882	.939	.859	.906	.941	.872	.922	.818
7 — CC	.473	.513	.590	.581	.945	.905	X	.762	.926	.885	.868	.886	.957	.819	.778
8 — CI	.694	.735	.745	.698	.986	.984	.947	X	.974	.908	991	.980	.945	.999	.891
9 — NN	.584	.625	.677	.628	.904	.893	.930	.811	X	.941	.962	.960	.932	.964	.832
10 — NC	.669	.725	.687	.718	.767	.949	.996	.876	.996	X	.996	.990	.991	.995	.873
11 — NI	.674	.685	.645	.658	.986	.870	.881	.861	.969	.905	X	.975	.911	.984	.846
12 — PN	.586	.608	.529	.586	.999	.826	.824	.755	.904	.816	.915	X	.919	.995	.789
13 — PC	.567	.618	.606	.633	.973	.838	.969	.777	.943	.901	.910	.975	X	.959	.821
14 — PI	.586	.630	.529	.561	.959	.779	.727	.777	.891	.789	.915	.985	.864	X	.769
Mean	.603	.645	.640	.619	.952	.829	.848	.773	.902	.827	.895	.911	.873	.907	.863

Note: DDRT = Digit Digit reaction time; DSRT Digit Symbol reaction time; LetCom = Letter Comparison; PatCom = Pattern Comparison; RdSpd = Reading Speed. The remaining variables are from Stroop tasks with the first letter designating the Stroop version (Color, Number, or Position) and the second letter designating the condition (Neutral, Compatible, or Incompatible).

Table 6. Quasi-Partial Correlations

	Variable													
Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 — DDRT	X													
2 — DSRT	.978	X												
3 — LetCom	.771	.868	X											
4 — PatCom	.784	.883	.911	X										
5 — RdSpd	.712	.718	.719	.715	X									
6 — CN	.797	.837	.838	.854	.841	X								
7 — CC	.759	.807	.820	.853	.867	.963	X							
8 — CI	.850	.892	.856	.873	.784	.965	.921	X						
9 — NN	.836	.875	.871	.877	.866	.957	.962	.943	X					
10 — NC	.843	.896	.833	.892	.798	.950	.967	.944	.984	X				
11 — NI	.883	.904	.848	.890	.854	.942	.934	.961	.983	.974	X			
12 — PN	.853	.876	.796	.867	.863	.940	.925	.929	.965	.949	.972	X		
13 — PC	.821	.867	.824	.877	.856	.925	.982	.925	.969	.973	.953	.973	X	
14 — PI	.858	.889	.804	.857	.833	.919	.877	.938	.962	.940	.975	.994	.953	X

An exploratory factor analysis was next conducted on the matrix of quasi-partial correlations. The first factor in this analysis was associated with 89.5% of variance, and inclusion of a second factor accounted for only an additional 3.7% of the variance. Communality estimates for the measures, indicating the proportion of variance accounted for by the single factor, ranged from .744 (for reading speed) to .976 (for numbers-interference). Furthermore, communality values for the interference measures were all greater than .91, indicating that a very high proportion of the variance in these measures was shared with the common factor.

Discussion

The results of this study provide some support for the inhibition construct as measured from similar tasks because moderate correlations were found among several of the interference measures after adjusting for unreliability. At first impression, the results also appear to provide support for the mediation of the age-related effects on working memory through decreased inhibition because control of the inhibition measures resulted in a substantial reduction in the age-related variance in working memory. However, the interference measures were not independent of the speed with which many tasks, even separate and distinct tasks, can be performed. That is, although age-related effects in the working memory measures were reduced when the variance in the inhibition measures was controlled, at least as much reduction was evident when other speed measures were controlled.

The first major conclusion of this study is that, contrary to some interpretations, interference scores from Stroop tasks are not simply measures of inhibition because they share most of their age-related variance with other measures of processing speed, even those derived from quite different types of tasks. The interference measures may be a better reflection of inhibition in samples in which there is little