Working Memory and Perceptual Speed Mediation of Age-Associated Changes in Cognition Within a Sample of Highly-Educated Adults

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The effects of education, continued intellectual engagement, and the possible mediative roles of working memory and perceptual speed on age-associated cognitive change were investigated in a sample of 104 members of the professional and college communities in a Southern part of the United States (Ages 30-76). All participants were administered a 60 to 80 minute battery that measured different aspects of memory, intelligence, and cognitive performance. Age was predictive of full-scale IQ, some measures of the *Wisconsin Card Sorting Test*, the Logical and Figural Memory components of the *Wechsler Memory Scales*, and both versions of the *Trail Making Test*. Statistical control of working memory and perceptual speed attenuated the age R^2 associated with age in full scale IQ, Figural Memory, and some measures of the *Wisconsin Card Sorting Test.* Conversely, statistical control of working memory and perceptual speed did not attenuate the R^2 associated with age on the Logical Memory I and II measures of the *Wechsler Memory Scales*, Trails A, and certain *Wisconsin Card Sorting Test* measures. The findings suggest that, at least among the highly educated, certain cognitive abilities may receive some degree of amelioration because of continued intellectual engagement. However, the effects may be associated more with compensation rather than protection against the effects of aging.

The theory of intelligence developed by Horn and Cattell (1966), originally characterizing intelligence in terms of two factors, crystalized intelligence (Gc) and fluid intelligence (Gf), has been quite useful for the assessment of age-associated changes in cognitive ability. Crystallized intelligence comprises abilities that include those aspects of intelligence

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influenced by educational and cultural opportunities. Conversely, fluid intelligence includes a set of abilities acquired as a result of genetic factors (Horn, 1982, 1991; Horn & Cattell, 1966). Although the conceptualization of these two factors has undergone considerable theoretical evolution, Gc and Gf have remained an essential part of the theory.

Where found, the actual rate of intellectual decline observed in older adults is a source of some controversy (Cornelius & Caspi, 1987; Kaufman, Reynolds, & McLean, 1989; Siegler & Botwinick, 1979). Nonetheless, although many older adults have attained a tremendous pool of knowledge from their life experiences, the available evidence does suggest that at least some aspects of intellectual function decline (e.g., Horn & Cattell, 1967; Kaufman et al., 1989; Salthouse, 1992a). One factor that can influence the assessment of normative changes in intellectual ability involves the reports of considerable variability in cognitive performance among older adults (Albert, Duffy, & Naeser, 1987; Shimamura, 1990; Siegler & Botwinick, 1979; Sward, 1945; Zelinski, Gilewski, & Schaie, 1993). As a result, a representative cross-section of adults may include a broad spectrum of individuals ranging from those with little or no demonstrable change in cognitive performance to others with severe cognitive deficits (Compton, Bachman, Brand, & Avet, 2000; Shimamura, Berry, Mangels, Rusting, & Jurica, 1995). The result may be a substantial increase in within-group variability (Siegler & Botwinick, 1979; Sward, 1945). Among other factors, the amount of formal education can have a marked influence on the successful aging of older adults (Shimamura et al., 1995). Coupled with factors such as general health, genetic predispositions to illness and disease, and socioeconomic status, years of formal education and continued cognitive stimulation contribute to the somewhat large within-group variability seen in older adults. Last, intellectual changes include a mixed pattern of both decline and growth. In a series of observations with 50- to 70-year-old individuals, Cornelius and Caspi (1987) found an increase in measures of Gc but a decrease in measures of Gf.

On a general level, working memory can be described as a temporary memory system involved in many cognitive tasks, including reasoning, comprehending, learning, and retrieving (Baddeley, 1998). While working memory has a number of different definitions, generally it is used to describe a memory system that processes all transient information currently available to solve problems. As such, it includes information in the sensory buffers and rehearsal loops (Baddeley, 1998) and what is active in long-term memory. When seen as a component of memory involving the simultaneous processing and storage of information, working memory resources can be estimated by measures that tap both processing and storage requirements (Salthouse, 1992b). In fact, working memory measures are correlated with such constructs as inductive reasoning and may be a good index of many measures of fluid intelligence (Salthouse, 1994b). There is substantial evidence that many reported age-associated declines in cognition on a variety of complex tasks reflect changes in working memory (Hultsch, Hertzog, & Dixon, 1990; Salthouse, 1991a, 1992b; Salthouse, Mitchell, Skovronek, & Babcock, 1989; Stine & Wingfield, 1987; but see also, Light & Anderson, 1985). Because many age-associated declines in cognition have been reported (Compton, Bachman, & Logan, 1997, Compton, Bachman, et al., 2000; Shimamura et al., 1995; Sward, 1945), the reported differences could at least be partially explained as reduced working memory resources.

In addition to the possible mediational role of working memory resources, a long-standing hypothesis is that an age-associated reduction in perceptual speed can account for differences in cognitive performance on many tasks (Smith, 1996). Perceptual speed can be thought of as the speed of apprehension (Kranzler & Jensen, 1989). Thus, perceptual speed can be seen as the capacity to rapidly recognize details in a demanding perceptual environment and to differentiate them from irrelevant material. In fact, older adults are typically slower as task complexity increases, and such deficits are not simply due to declines in motoric performance (Light & Spirduso, 1990; Salthouse, 1991a; Smith, 1996). Thus, working memory and perceptual speed may lie at the heart of the reported age-associated differences in cognitive performance (Smith, 1996).

In previous reports (Compton et al., 1997, 2000), we explored the issue of age-associated changes in intellectual performance using samples consisting of individuals with a high level of education. Additionally, in order to provide further illumination into the subset of factors that may contribute to successful aging (Albert et al., 1995; Baltes & Baltes, 1990; Schaie, 1990, 1994; Shimamura et al., 1995), we examined the effect of continued intellectual stimulation on intellectual and cognitive performance. Thus, our work and those of others (e.g., Colsher & Wallace, 1991; Evans et al., 1993, Shimamura et al., 1995; Sward, 1945; White et al., 1994) suggested that education and continued intellectual stimulation provided either a protective effect or compensatory strategy mitigating the intellectual (i.e., fluid & crystallized intelligence), memory, and other cognitive changes collectively considered as components of the blanket term Acognition@ that often accompany aging. Because of the putative roles of working memory resources and perceptual speed in age-associated differences in cognition, the purpose of the present investigation was to examine whether individual differences in working memory resources and processing speed could account for differences in performance among a highly-educated sample of young, middle-aged, and older adults. Specifically in order to examine these issues, our primary goal was to explore the roles of working memory processes and perceptual speed as potential mediators of the age-associated difference in performance on many measures of cognition. To accomplish this goal, a series of hierarchical regression analyses was conducted. Thus, we examined the role of age alone, age after the effect of the working memory estimate was partialed out, age after the effect of the processing speed estimate was partialed out, and age after the joint effects of both estimates were partialed out.

METHOD

Participants

In all, the investigation was based on a convenience sample consisting of 104 (54 men & 50 women) highly-educated (*M* = 19.29 years) adults with a median age of 49 years (range = 30-79 years). The specific sample was chosen in order to reflect professionals with comparable levels of occupational status, amount of formal education, and verbal ability of different ages across the life span. All participants were engaged in full-time employment and rated their health as average, good, or excellent. On the basis of the *Wechsler Adult Intelligence Scales-Revised* (WAIS-R) WAIS-R and *Wechsler Memory Scales-Revised* (WMS-R) scores, all of the participants were judged as competent. An additional ten individuals were contacted but declined to participate or were excluded because of a current medical condition. Five individuals agreed to participate but terminated participation during the assessment, producing a final sample size of 104 participants. Of the 104 participants, 96 were of Caucasian ancestry. Eighty-seven participants were active college professors. The remaining 17 participants were members of the professional community with full-time active programs in some form of community-based or industrial research activity that required a considerable amount of reading and writing. Thus, all participants were currently engaged in at least moderately demanding cognitive activities. Finally, all participants were born in the continental United States and used English as their primary language. All participants were individually tested with testing occurring at the participant's convenience. Last, power determinations using software developed by Rothstein, Cohen, Schoenfled, Berlin and SPSS (2000) suggested incremental power (depending on the model) ranging from .17 to .30.

Procedure

All testing occurred in a quiet room. The assessment battery consisted of subtests from a short version of the Wechsler Adult Intelligence Scales-Revised (WAIS-R; Wechsler, 1981) developed by Kaufman and colleagues (cf., Kaufman, 1990), the *Wechsler Memory Scales- Revised* (WMS-R; Wechsler, 1987), a computerized version (Loong, 1990) of the *Wisconsin Card Sorting Test* (WCST; Heaton, 1981), and forms A and B of the *Trail Making Test* (Reitan, 1958). The assessment battery was designed to examine age-associated changes in cognitive performance (e.g., fluid & crystallized intelligence, memory, frontal lobe impairment) in about an hour.

Instruments

Wechsler Adult Intelligence Scale-Revised (WAIS-R). A brief version of the WAIS-R consisting of the Similarities, Arithmetic, Picture Completion, and Digit Symbol subtests was administered. The Digit Span subtest was also used for the formation of a working memory estimate. This tetrad of subtests was selected because of its high reliability and validity coefficients (.93 & .95; Kaufman, 1990, p. 135) with the IQ scores derived from the full WAIS-R and its short administration time. Full scale IQ was derived from the four subtests using the formula proposed by Kaufman, Ishikuma, and Kaufman-Packer (1991).

Wechsler Memory Scales-Revised (WMS-R). It has been reported that high verbal ability can offer some protection against age-related deficits in memory tasks designed to assess recall for prose (e.g., Hartley, 1989; Meyer & Rice, 1983). The Logical Memory I and II (immediate & delayed recall) and Figural Memory subtests of the WMS-R were chosen to assess verbal and pictorial memory. Scores on each subtest were converted to scaled scores for group comparisons. Despite some concern about the WMS-R (Spreen & Strauss, 1998), factor analytic results suggest that the subscales associated with the WMS-R and contributing to a General Memory Scale provide a good indicator of group differences in cognitive performance independent of estimates of intelligence (Kaufman, 1990).

Trails A & B. Part of the *Halstead-Reitan Neuropsychological Battery* (cf., Reitan, 1985), Trails A and B are considered measures of Fluid intellectual ability. In addition, both are considered sensitive to neurological deficits including those associated with motor and perceptual speed (Spreen & Strauss, 1998).

Wisconsin Card Sorting Test (WCST). A computerized version of the WCST (Loong, 1990) was employed. The WCST is considered sensitive to frontal lobe impairment (Heaton, 1981). In addition, because the participant is required to acquire a learning strategy throughout the test and the requirements change without notice, abstract reasoning and mental flexibility are required. Thus, the WCST may also be considered a test of fluid intelligence (Compton et al., 1997).

Working Memory & Perceptual Speed Measures. Using a strategy similar to Salthouse (1991a), performance on the WAIS-R Digit Span and Arithmetic subtests were converted to z scores and averaged to yield a composite measure of working memory. For the perceptual speed estimate, WAIS-R Digit Symbol scores for each subject were converted to z scores.

Scoring and Statistical Analyses

Five individuals failed to complete the assessment battery. Of the five, three individuals were in their 40s. The other two were in their 30s and 60s, respectively. Available data from these five individuals were not considered in any of the bivariate or multivariate analyses.

To repeat, scores from the component WAIS-R subtests were converted to a Full Scale IQ score. The WMS-R scores were converted to standard scores. One dependent measure, time to complete the task, was used as an index of performance on Trail A and Trail B. Finally, several different measures of performance were derived from the *Wisconsin Card Sorting Test* (e.g., time to complete the task, percent correct and errors, the number of categories completed, etc.). Computation of Pearson product-moment coefficients constituted a first level of analysis. Specifically, bivariate correlations were calculated between the variables age, education, working memory resources, perceptual speed and the dependent measures. Following the bivariate analyses, we wanted to determine the amount of variance on each dependent measure accounted for by age alone, and age after education was partialed out.

Because our primary interest was the possible roles of working memory processes and perceptual speed as potential mediators of the age-associated difference in performance on many measures of cognition, a series of hierarchical regression analyses was conducted. Thus, we examined the role of age alone, age after the effect of the working memory estimate was partialed out, age after the effect of the processing speed estimate was partialed out, and age after the joint effects of both estimates were partialed out.

RESULTS

Bivariate Correlation Analysis

For the interested reader, bivariate correlations between the variables of interest, age, education, the working memory and perceptual speed estimates, and all dependent measures are presented elsewhere (http://faculty.pba.edu/callisto/research/aging/NJP/).

Hierarchical Regression Analyses

In order to determine the independent contributions of age and education to performance on each cognitive measure, a series of hierarchical regression analyses was performed. Specifically, we wanted to determine the amount of variance on each dependent measure accounted for by age alone (Model 1), and age after education was partialed out (Model 2). The results of these analyses appear in Table 1. Following consideration of the effects of age and education, an additional set of hierarchical regression analyses was performed to determine the amount of variance on each dependent measure accounted for by age alone (Model 1), age after the working memory estimate was partialed out (Model 2), age after the perceptual speed estimate was partialed out (Model 3), and age after the working memory and perceptual speed estimates were partialed out (Model 4). The results of these analyses appear in Table 2. In Tables 1 and 2, the cumulative R^2 associated with age, or after the inclusion of each additional measure followed by age, is presented in the second column. Incremental R^2 associated with the addition of age is presented in column 3. The F ratios and p values showing the significance of R^2 for the first variable, either age or education, or the incremental change in R^2 after the inclusion of age in Model 2, appear in the fifth and sixth columns. The fourth column entries are the attenuation (if any) in the effect of age after the working memory composite measure and/or the measure of perceptual speed was partialed out. This percentage was determined by the following formula: (R^2 Age [Model 1] - R^2 Age [Model 2, 3, or 4]/R^2 Age [Model 1]). For example, the drop in the variance in full-scale IQ from 6.8% (Model 1) to 5.8% (Model 2), after statistical control of education, suggests that education accounts for 14.7% of the age-associated variance in intelligence as measured by the WAIS-R (i.e., .068 - .058/.068 = .147). Only analyses with at least one significant predictor are considered below.

Age & Education

WAIS-R Measures. Examining the relationship between full scale IQ and age revealed that age accounted for 6.8% of the variance in this variable. Education accounted for 5% of the variance, and following the statistical control of education, the R^2 associated with age was reduced to 5.8%. In the first model, age accounted for 3.8% of the variance in Digit Symbol performance. In the analyses of the second model, education accounted for 3.1% of the variance. The R^2 associated with age after statistical control of education increased to 4.5%. In the first analysis, age alone accounted for 2.6% of the variance in Similarities performance ($p >$ .05). In the second analysis, education accounted for 5.7% of the variance and inclusion of age after statistical control of education reduced age to

2% ($p > .05$). Age and education were nonsignificant predictors (i.e., all $ps > .05$) of Picture *Completion and Arithmetic performance.*

Trails A and B. Inspection of Table 1 indicates that age alone (Model 1) accounted for 15.3% of the variance in Trails A performance. In the second analysis (Model 2), education was entered first, accounting for less than 1% of the variance. The addition of education did not reduce the amount of variance accounted for by age, 15.3%. Similarly, age alone accounted for 19.1% of the variance in Trails B performance. In the second analysis, education again accounted for less than 1% of the variance, and the statistical control of education did not have a substantive influence on the R^2 (19%) associated with age.

WMS-R Measures. In the first model, age alone accounted for 2% of the variance in Logical Memory I performance ($p > .05$). In the second analysis, education accounted for 14.3%. The R^2 associated with age after the statistical control of education increased to 3.1%, a contribution that was marginally significant ($p < .054$). Similar patterns of results were observed in the analyses of Logical Memory II and Figural Memory performance. In the first model, age alone accounted for 4.2% and 6.4% of the variance in Logical Memory II and Figural Memory performance, respectively. In the analyses with the second model, education accounted for 13% and 7.2% of the variance in these two dependent measures. After statistically controlling for education, the contribution of age increased to 5.7% of the variance in Logical Memory II performance. The R^2 associated with age after controlling for education was reduced to 5.3% of the variance in Figural Memory performance.

WCST Measures. Age alone accounted for 8.9% of the variance in Duration. In the second model, education accounted for 2.5% of the variance. When age was added to the equation, it accounted for an additional 9.8% of the variance in this dependent measure. Similarly, in the first model, age alone accounted for 24.1% of the variance in response time, and 12.5% of the variance in the number of categories completed. In model 2, education accounted for 2.9% and 2.5% of the variance. After statistically controlling for education, the contribution of age increased to 25.9% and 13.6% of the variance in these two measures of WCST performance. In the remaining analyses where a significant effect of age was detected, age alone accounted for 10.7%, 12.9%, 6.7%, and 12.3% of the variance in the number of trials completed, the percent correct, the percentage of perseverative errors, and the percent conceptual level responses measures of the WCST (see Table 1). The contributions of education to the equations (Model 2) ranged from less than 1% (percent perseverative errors) to 2.9% (response time, $p < .05$). In the analysis of the number of trials completed, the R^2 associated with age after controlling for education increased slightly to 10.7%. A similar pattern was seen after controlling for education, where age accounted for 25.9%, 13.8%, 7.1%, and 13.2% of the variance in the response time, percent correct, the percent of perseverative errors, and the percent conceptual level responses measures. Age and education were nonsignificant predictors of performance in the analyses of the remaining dependent measures.

TABLE 1 Summary of Hierarchical Regression Analyses for Each Measure of Cognitive Performance

Cognitive Measure	Predictor Variable	R^2	ΔR^2	F
WAIS-R				
Full-Scale IQ				
Model 1	Age	.068		7.32***
Model 2	Education	.050		4.51**
	Age	.108	.058	13.86***
Wechsler Memory Scales-R				
Logical Memory I				
Model 1	Age	.020		2.08
Model 2	Education	.143		18.84***
	Age	.174	.031	3.79
Logical Memory II				
Model 1	Age	.042		4.50*
Model 2	Education	.130		18.01***
	Age	.187	.057	7.11**
Figural Memory				
Model 1	Age	.064		7.02**
Model 2	Education	.072		7.03**
	Age	.125	.053	6.13**
Trails A				
Model 1	Age	.153		18.37***
Model 2	Education	.000		0.09
	Age	.153	.153	18.29***
Trails B				
Model 1	Age	.191		24.07***
Model 2	Education	.001		0.01
	Age	.191	.190	23.68***
WCST				
Test Duration				
Model 1	Age	.089		9.98**
Model 2	Education	.025		3.92
	Age	.123	.098	11.35***
Response Time				
Model 1	Age	.241		32.42***
Model 2	Education	.029		6.68*
	Age	.288	.259	36.72***

Number of Categories Completed				
Model 1	Age	.125		14.55***
Model 2	Education	.025		4.36
	Age	.161	.136	16.40***
Total Trials				
Model 1	Age	.100		11.35***
Model 2	Education	.010		1.91
	Age	.117	.107	12.21***
Percent Correct				
Model 1	Age	.129		15.12***
Model 2	Education	.014		2.76
	Age	.152	.138	16.45***
Percent Perserverative Errors				
Model 1	Age	.067		7.35**
Model 2	Education	.005		1.00
	Age	.076	.071	7.78**
Percent Conceptual-Level Responses				
Model 1	Age	.123		14.30***
Model 2	Education	.015		2.83
	Age	.147	.132	15.61***

Notes Only analyses with at least one significant outcome are reported. ΔR^2 denotes the incremental increase in R^2 associated with the inclusion of one or more of the predictor variables into the regression equation. The F statistic indicates the statistical significance of R^2 for the first variable or the increment in R^2 associated with each additional predictor variable entered into the equation. *$p < .05$. **$p < .01$. ***$p < .001$.

TABLE 2 Summary of Hierarchical Regression Analyses for Each Measure of Cognitive Performance.

Cognitive Measure	Predictor Variable	R^2	ΔR^2	F
WAIS-R				
Full-Scale IQ				
Model 1	Age	.068		7.32*
Model 2	WM	.348		62.86***
	Age	.427	.079	13.86***
Model 3	PS	.111		19.24***
	Age	.218	.107	13.71***
Model 4	PS	.111		1.63
	WM	.374	.263	38.44***

	Age	.437	.063	11.04***
Wechsler Memory Scales-R				
Logical Memory I				
Model 1	Age	.020		2.08
Model 2	WM	.139		15.98***
	Age	.154	.015	1.78
Model 3	PS	.203		23.61***
	Age	.206	.003	0.38
Model 4	PS	.203		7.02**
	WM	.205	.002	0.46
	Age	.209	.004	0.50
Logical Memory II				
Model 1	Age	.068		7.32*
Model 2	WM	.348		62.86***
	Age	.427	.079	13.86***
Model 3	PS	.111		19.24***
	Age	.218	.107	13.71***
Model 4	PS	.111		1.63
	WM	.374	.263	38.44***
	Age	.437	.063	11.04***
Model 1	Age	.042		4.50*
Model 2	WM	.090		9.67**
	Age	.126	.036	4.19*
Model 3	PS	.142		14.23***
	Age	.161	.019	2.19
Model 4	PS	.142		4.36
	WM	.143	.001	0.23
	Age	.163	.020	2.34
Figural Memory				
Model 1	Age	.064		7.02*
Model 2	WM	.018		1.57
	Age	.079	.061	6.70*
Model 3	PS	.010		2.52
	Age	.078	.068	8.57**
Model 4	PS	.010		17.47***
	WM	.108	.098	16.38***
	Age	.216	.108	13.68***
Trails A				
Model 1	Age	.153		18.37***
Model 2	WM	.061		6.58*
	Age	.204	.143	18.18***
Model 3	PS	.068		4.43*
	Age	.188	.120	14.95***
Model 4	PS	.068		0.08
	WM	.074	.006	2.12
	Age	.205	.131	16.47***
Trails B				
Model 1	Age	.191		24.07***
Model 2	WM	.042		4.38*

	Age	.225	.183	23.74***
Model 3	PS	.026		0.74
	Age	.225	.199	21.53***
Model 4	PS	.026		1.18
	WM	.042	.016	4.79*
	Age	.234	.192	24.95***
WCST				
Test Duration				
Model 1	Age	.089		9.98**
Model 2	WM	.125		14.53***
	Age	.204	.079	9.99**
Model 3	PS	.077		5.86*
	Age	.139	.062	7.30**
Model 4	PS	.077		0.32
	WM	.125	.048	8.45**
	Age	.206	.081	10.21***
Response Time				
Model 1	Age	.241		32.42***
Model 2	WM	.114		14.99***
	Age	.339	.225	34.39***
Model 3	PS	.111		8.54***
	Age	.300	.189	27.26***
Model 4	PS	.111		0.14
	WM	.129	.018	5.90*
	Age	.339	.210	31.85***
Number of Categories Completed				
Model 1	Age	.125		14.55**
Model 2	WM	.049		4.99*
	Age	.166	.117	14.20***
Model 3	PS	.022		0.74
	Age	.131	.109	12.75***
Model 4	PS	.022		1.57
	WM	.050	.028	5.81*
	Age	.179	.129	15.74***
Total Trials				
Model 1	Age	.100		11.35***
Model 2	WM	.135		16.14***
	Age	.224	.089	11.55***
Model 3	PS	.063		4.33*
	Age	.137	.074	8.73**
Model 4	PS	.063		1.70
	WM	.137	.074	13.10***
	Age	.237	.100	13.11***
Percent Correct				
Model 1	Age	.129		15.12***
Model 2	WM	.088		9.93**
	Age	.207	.119	15.11***
Model 3	PS	.049		2.85

	Age	.153	.104	12.40***
Model 4	PS	.049		0.97
	WM	.088	.039	7.85**
	Age	.215	.127	16.07***
Percent Perserverative Errors				
Model 1	Age	.067		7.35**
Model 2	WM	.058		5.94*
	Age	.119	.061	7.00**
Model 3	PS	.035		2.15
	Age	.087	.052	5.71*
Model 4	PS	.035		0.29
	WM	.058	.023	3.98*
	Age	.122	.064	7.23**
Percent Conceptual-Level Responses				
Model 1	Age	.123		14.30***
Model 2	WM	.073		7.93**
	Age	.187	.114	14.12***
Model 3	PS	.044		2.74
	Age	.144	.100	11.77***
Model 4	PS	.044		0.64
	WM	.073	.029	5.95*
	Age	.192	.128	14.69***

Notes Only analyses with at least one significant outcome are reported. WM = working memory; PS = perceptual speed. The composite working memory measure is based on the standardized average of the Digit Span and Arithmetic measures of the WAIS-R. The perceptual speed measure is based on the standardized Digit Symbol subtest of the WAIS-R. ΔR^2 denotes the incremental increase in R^2 associated with the inclusion of one or more of the predictor variables into the regression equation. The F statistic indicates the statistical significance of R^2 for the first variable or the increment in R^2 associated with each additional predictor variable entered into the equation. $^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Age, Working Memory Resources, & Perceptual Speed

It has been suggested that working memory processes and perceptual speed operate as mediators of the age-associated difference in performance on many measures of cognition. To examine this issue, a series of hierarchical regression analyses were conducted to determine the possible mediating roles of working memory and perceptual speed on our measures of cognitive performance with this highly selective sample.

Trails A and B. Age alone (Model 1) accounted for 15.3% of the variance in Trails A performance. In the second analysis (Model 2), the working memory estimate was entered first, accounting for 6.1% of the variance and following statistical control of working memory, the $\underline{R}^2$ associated with age was reduced to 14.3%. Thus, 6.5% of the age-associated variance in Trails A performance can be attributed to working memory. In the third analysis, perceptual speed accounted for 6.8% of the variance. After statistical control of this estimate, the R^2 associated with age was reduced to 12%, suggesting that 21.2% of the age-associated variance in Trails A performance is attributable to perceptual speed. Finally, the analysis of Model 4 suggested that after both variables were partialed out, they jointly can account for 14.3% of the age-associated variance in Trails A performance.

Examination of the role of each variable in Trails B performance revealed that the working memory estimate accounted for 4.2% of the variance. The R^2 associated with age after controlling for working memory was reduced to 18.3%, suggesting that working memory resources accounted for 4.2% of the age-associated variance in Trails B performance. Conversely, the R^2 associated with age after the effect of perceptual speed was partialed out was not attenuated but increased to 19.9%. Similarly, no attenuation in the R^2 associated with age after partialing out the effects of working memory and perceptual speed (Model 4) was observed.

WMS-R Measures. Although age alone accounted for a small amount of the variance in Logical Memory I ($p > .05$) and II ($p < .05$) performance, as expected, partialing out the effect of working memory led to a marked attenuation in the age-associated variance for these two measures. Here, working memory accounted for 25% and 14.3% of the age-associated variance in Logical Memory I and II performance. The effect of partialing out perceptual speed was an even greater attenuation, 85% and 55.8%, respectively. When considered jointly (Model 4), partialing out the effects of working memory and perceptual speed accounted for 80% and 52.4% of the age-associated variance in Logical Memory I and II performance.

Inclusion of age after partialing out the effect of working memory reduced the R^2 associated with age on the Figural Memory measure to 6.1%, an attenuation of 4.7%. Conversely, no attenuation in the R^2 associated with age was observed in an examination of perceptual speed (Model 3) or after working memory and perceptual speed were partialed out (Model 4).

WCST Measures. Age alone accounted for 8.9% of the variance in the duration measure of the WCST. After partialing out the effect of working memory resources, this was reduced to 7.9%, suggesting that working memory resources accounted for 11.2% of the age-associated variance in duration to complete the test. As can be seen in Table 2, a similar pattern emerged on the assessment of many of the WCST measures, as working memory accounted for 6.6% of the age-associated variance in response time to a high of 11% of the age-associated variance in the trials completed measure. Assessments of the effect of age after partialing out perceptual speed revealed a stronger attenuation. Here, partialing out the effect of perceptual speed attenuated the R^2 associated with age from 12.8% (number of categories completed) to 30.4%. Consideration of the fourth Model generally revealed more modest attenuation effects, suggesting that although some age-associated variance is accounted for by our measures of working memory and perceptual speed, these are limited to values of 18.7% (percent conceptual-level responses) or less.

The pattern of results has several implications. First, unlike Salthouse (1991a), statistical control of perceptual speed in isolation, or in combination with the working memory measure, resulted in a much smaller attenuation of age-associated variance than the 80% to 90% reported by Salthouse (e.g., Salthouse, 1991a, Salthouse et al., 1989). Similarly, the working memory measure generally produced a much smaller attenuation than the 48.2% Salthouse reported (M = 10.1% across analyses). Second, after partialing out the effects of both variances as in the fourth model, the observed reductions typically remained small or absent ($M = < 1\%$ across analyses). As an issue originally suggested by Salthouse (1991a,b) then, the age-associated differences on many of our dependent measures, working memory and perceptual speed are not independent but may share some degree of common variance. In fact, the working memory estimate accounted for 56.6% of the variance in the perceptual speed measure (i.e., the Digit Symbol subtest). Further, working memory accounted for 36.8% of the age-associated variance in Digit Symbol performance. Thus, unlike the results reported by Salthouse, who used multiple measures of perceptual speed, working memory was an important variable in accounting for the age-associated differences in Digit Symbol performance. This incongruent result may be explained by the restrictive sample we used; however, the use of a single measure of perceptual speed is an important limitation.

DISCUSSION

The present investigation of different aspects of human cognition in a highly educated sample has highlighted several neuropsychological features associated with aging. Age was predictive of performance on many of the tasks, including some generally associated with the assessment of psychomotor speed. Further, these age differences in performance were observed even after controlling for differences in education, working memory, and perceptual speed. Although partialing out the effects of working memory or perceptual speed attenuated the age-associated variance on some measures of performance, the attenuation was small, and often absent.

Nonetheless, the results of our previous report (Compton et al., 2000), and the amount of variance accounted for by age observed in the present report, are suggestive that certain cognitive experiences can provide some protection, maintaining or perhaps even enhancing cognitive performance, at least into late adulthood (e.g., Charness, 1989; Salthouse, 1987). Our research is generally in accord with previous reports suggesting that above average intelligence and the effects of education may provide some moderating influence against the changes in cognitive performance associated with aging (e.g., Avolio & Waldman, 1994; Christensen & Henderson, 1991; Osterweil, Mulford, Syndulko, Martin, 1994; Shimamura et al., 1995; Sward, 1945). A low level of education is associated with an increased level of deterioration in cognitive performance (Colsher & Wallace, 1991; Farmer, Kittner, Rae, Bartko, & Regier, 1995). Thus, coupled with the effects of good health (Perlmutter & Nyquist, 1990), appropriate occupation (Avolio & Waldman, 1994), and active engagement in the surrounding environment (Schooler, 1984, 1990), continued intellectual stimulation may offset at least some of the normative changes that accompany aging (Christensen, Henderson, Griffiths, & Levings, 1997a). Nonetheless, as pointed out by Christensen et al. (1997a,b) and others (e.g., Gold et al., 1995; Hultsch & Dixon, 1990; Hultsch, Hertzog, & Dixon, 1984; Shimamura et al., 1995), while intellectual ability and continued intellectual or educational experiences may provide an ameliorative effect, such protection appears to extend primarily to verbal abilities.

The Role of Working Memory Resources

While a number of accounts of aging and reduced working memory resources have been proposed (Hasher & Zacks, 1988; Light, 1991; Salthouse, 1991a,b, 1992b, 1994), most if not all can be categorized as either proposed reductions in working memory capacity (e.g., see Salthouse, 1992b) or a failure to inhibit irrelevant information in working memory (e.g., see Hasher & Zacks, 1988; Light, 1991). The proponents of the first viewpoint assert that older adults have a reduced working memory capacity, thus reducing performance on many cognitive tasks. When working memory is partialed out, the association between age and cognitive performance is no longer significant, or the degree of the association is markedly reduced (Salthouse, 1992b). Proponents of an inhibition theory of aging and working memory suggest that the heart of the problem, rather than one of reduced resources per se, is a diminished ability to inhibit information irrelevant to current task demands. In brief, the problem is more one of selective attention rather than capacity. Thus, it is suggested that older adults are susceptible to an increased level of "cognitive noise," producing an increased level of interference during processing (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; McDowd, Oseas-Kreger, & Fillion, 1995). Nonetheless, the two accounts of diminished working memory resources are not mutually exclusive, as an impaired ability selectively to filter irrelevant information would leave less capacity for the storage and processing of relevant information (Stoltzfus, Hasher, & Zacks, 1996).

On the basis of distinctions proposed by Turner and Engle (1989), de Jonge and de Jong (1989) categorized working memory tasks into two categories, simple and complex span tasks. Briefly, the digit forward portion of the WAIS-R Digit Span subtest is considered a simple span task measuring the storage component of working memory. Simple span tasks measure the storage component of working memory because the manipulation of task information is not emphasized. Complex span tasks, such as the digit backward component of the Digit Span subtest or the Arithmetic subtest, require that the participant simultaneously perform two different types of mental processes, reordering information and performing complex calculations. Thus, complex tasks assess both the processing and storage efficiency of working memory. Although age-associated declines in working memory appear to be primarily due to the processing component of such tasks (Salthouse & Babcock, 1991), de Jonge and de Jong (1996) have demonstrated that these types of working memory tasks form a single dimension.

Although likely to result in some controversy, unlike the research involving adults with more representative levels of education (e.g., Salthouse 1991a, 1992a; Salthouse et al., 1989), working memory generally appears to be a minor factor contributing to age-associated differences in cognition, at least among the highly educated. Specifically, it would appear that, at least among educated and intellectually engaged older adults, the age-associated variance in cognition after statistical control of working memory revealed little if any of the attenuation reported by others. Salthouse (1992b) suggested that one cause of age-associated differences in many cognitive tasks is the result of an impaired ability to retain information during processing, a deficit typically described as a working memory impairment. Perhaps, because of the very nature of job requirements, college professors use and place considerable demands on working memory. Consequently, age-associated changes in working memory are attenuated by their somewhat unique cognitive experiences, an idea that awaits further study.

The Role of Perceptual Speed

In the present study, age appeared to be relevant on some neuropsychological measures that include a perceptual or psychomotor speed component. Consistent with prior research, age was predictive of both Trails A and B performance. While the argument has been raised that such inferior performance on these tasks can be attributed to psychomotor speed (e.g., LaRue & D'Elia, 1985), other research contradicts this position (Horn & Cattell, 1967; Kaufman et al., 1991; Kennedy, 1981; Salthouse, 1994a,b; Storandt, 1976). For example, Storandt (1976) compared two forms of the WAIS Digit Symbol subtest. The standard version required the coding of symbols as a way to monitor cognitive speed. To measure motor speed, a modified version was used where the participant was only required to copy the symbols. The results suggested that some age-associated differences in observable performance may be attributable to changes in cognition as well. Thus, according to the above research and Salthouse (1994a), the age-associated variance on the *Trail Making Test* and components of the WCST we observed could be attributed to age-related declines in processing speed.

Perceptual speed has been reported to account for a substantial amount of the age-associated variance on many different cognitive tasks, including paired associates and free recall memory tasks (Lindenberger, Mayr, & Kliegl, 1993; Park, Smith, Lautenschlager, Earles, Frieske, Zwahr, & Gaines, 1996; Salthouse, 1993), fluency and knowledge (Lindenberger et al., 1993), reasoning and integration of information (Park et al., 1996; Salthouse, 1993), and working memory (Salthouse & Babcock, 1991). Thus, perceptual speed may be an important predictor of cognitive performance and may at least in part operate through working memory (Park et al., 1996). Using structural equation modeling in an assessment of general memory ability, Park, et al. (1996) demonstrated that the age-associated variance in performance operated entirely through the perceptual speed path. Nonetheless, both perceptual speed and working memory contributed to memory function. Further, it has been suggested that decreases in processing speed may explain the age-associated differences that may underlie many if not all the observed differences on such diverse cognitive tasks as measures of fluid intelligence, reasoning ability, and spatial cognition, as well as other forms of memory (Birren, 1965; Mayr & Kliegl, 1993; Park et al., 1996; Salthouse, 1996).

For example, Hultsch et al. (1984) examined, among other variables, the influence of age and verbal ability on a set of cognitive measures including general intelligence, associative memory, and verbal ability, including a measure of verbal comprehension. Unlike young adults, the measures of general intelligence did not determine the performance of older adults. Verbal comprehension did not appear to influence age-associated differences in text memory, and the effect of associate memory was small. Clear demonstrations of education and verbal ability in the assessment of aging and cognitive performance have been reported(e.g., Meyer & Rice, 1983, see also, Meyer, 1987) and the present results lend additional support for the roles of education and intellectual engagement in ameliorating some age-associated deficits in cognitive performance reported when highly-educated older individuals are compared to age cohorts of average intelligence and education (see Dixon & von Eye, 1984).

Aging and Cognitive Function

On the basis of the observed lack of or small but significant associations on some aspects of cognitive function observed here and reported by others (e.g., Compton et al., 1997; Dixon, Hultsch, Simon, & von Eye, 1984; Shimamura et al., 1995; Sward, 1945; Zelinsky & Gilewski, 1988), at least two compatible processes are suggested. First, given the intellectual demands associated with their occupation, college professors may develop compensatory strategies and adapt to changes in cognitive ability. Certainly, by possessing a certain basal level of intellectual ability and having their respective disciplines developed during such protracted and advanced education, an enhanced ability to compensate for changing performance is realistic. The level of mental activity incumbent with the demands of the academic world may reduce the age-associated variance, including the size of the attenuation normally associated working memory.

Thus, it may be that there is a “slowing” of the biological aging process among the highly educated and presumably intellectually engaged (cf., Orrell & Sahakian, 1995). On the other hand, the observed protective effects of a high level of education may be more a result of compensation, mostly as a direct result of the concomitantly higher levels of expertise, verbal knowledge, and ability. If true, these crystallized intellectual advantages would serve for compensatory strategies in a number of cognitive domains, perhaps masking otherwise similar rates of biological aging (Christensen et al., 1997b). In fact, this latter explanation has received some indirect or direct support (e.g., Christensen & Henderson, 1991; Christensen et al., 1997a,b; Foulds & Raven, 1948). Thus, as Christensen et al., (1997b) point out, such effects may provide the individual with greater compensatory resources rather than protection against the effects of biological aging.

Given that age is associated with the variability in performance on many cognitive measures, attempts have been made to determine the nature of intellectual changes that occur at the neural level (see Moscovitch & Winocur, 1992, for a review). Using many approaches such as the assessment of release from proactive inhibition (Moscovitch & Winocur, 1983), changes to source memory (Craik, Morris, Morris, & Loewen, 1990; Parkin & Walter, 1992), and assessment of short-term memory (Parkin & Walter, 1991), investigators have focused on frontal lobe dysfunction in an attempt to examine a possible linkage between frontal lobe deterioration and age-associated changes in fluid intelligence (e.g., Isingrini & Vazou, 1997). Further, requiring conceptual reasoning for successful performance, the WAIS-R Similarities subtest may be especially sensitive to frontal lobe pathology (Lezak, 1995). Thus, on the basis of past results on the Similarities subtest (Compton et al., 2000), the variance in performance accounted for by age on elements of the WCST in the present investigation and the results reported by others (Isingrini & Vazou, 1997; Lezak, 1995; Pillon & Dubois, 1992; see also, Salthouse, 1991b), it could be argued that the observed age-associated differences in fluid intellectual functioning are due to changes in the efficiency of function in areas of the frontal lobe (Isingrini & Vazou, 1997).

Limitations of the Present Investigation

One limitation of the present investigation and shared by cross-sectional research overall is the problem of potential cohort effects. Generational shifts in performance on measures of mental abilities are well-documented (Schaie, 1989, 1995; Williams & Klug, 1996), with advantages typically observed among later-born cohorts. Such advantages have been explained in terms of greater educational opportunities and improved nutritional, medical, and other lifestyle variables (Schaie, 1996). Thus, the present results suggest patterns of age “differences” rather than age “change” or decline. Nonetheless, our results provide additional support for the proposal that the effects of higher levels of education, coupled with continued intellectual challenges, may at the very least provide a compensatory strategy or perhaps even to some extent offset some cognitive declines associated with the aging process.

Another limitation of the present investigation was the lack of a comparison group, consisting of adults with more normative educational experiences. Such a range restriction in education may reduce the size of the observed associations in the present investigation. Because of the available data on the intellectual performance of older adults with a high school education or less (e.g., Blum & Jarvik, 1974; Granick & Friedman, 1973), such a control group was not included. However, the younger members of the sample (i.e., the 30-39 year old participants) may be considered an appropriate comparison group.

An additional area of concern is that the working memory and perceptual speed estimates were constructed with a limited number of measures, thus potentially limiting the ability to capture these two constructs fully. However, as Salthouse (1991a) pointed out, the use of multiple measures of a construct may not increase the validity of its assessment. The use of multiple measures may allow, however, for a greater ability to rule out artifacts associated with a specific task. In the present investigation, the working memory estimate was derived from two separate tasks administered separately. Unfortunately, time constraints limited our ability to utilize a second task for the estimate of perceptual speed.

One additional area of some concern and one noted previously was the issue of psychomotor speed. Although we did not make any formal attempt to determine the specific level of motoric ability among the participants, all participants were asked about medical conditions and/or medications that could have influenced the test results. Individuals with medical conditions that could have influenced the results were excluded from the study.

Several personality factors have been suggested as an important component in understanding age changes in intellectual performance. Among these is a flexible attitude entering mid life. In one research report (Schaie, 1995), individuals with more flexible attitudes experienced less intellectual decline than individuals with more rigid attitudes. In addition, motor-cognitive flexibility in older adults is associated with verbal and numerical abilities (O'Hanlon, 1993). While personality variables were not examined in the present study, owing to their possible moderating influence on intellectual ability (Schaie, 1995), they could be considered an important limitation of the present study.

REFERENCES

Albert, M. S., Duffy, F. H., & Naeser, M. (1987). Nonlinear changes in cognition with age and their neuropsychological correlates. *Canadian Journal of Psychology, 41,* 141-157.

Avolio, B. J., & Waldman, D. A. (1994). Variations in cognitive, perceptual, and psychomotor abilities across the working life span: Examining the effects of race, sex, experience, education, and occupational type. *Psychology & Aging, 9,* 430-442.

Baddeley A. (1998). *Human memory: Theory and practice* (2nd ed.). Needham Heights, MA: Allyn and Bacon.

Baltes, P. B., & Baltes, M. M. (1990). *Successful aging: Perspectives from the behavioral sciences*. Cambridge, UK: Cambridge University Press.

Birren, J. E. (1965). Age changes in speed of behavior: Its central nature and physiological correlates. In A. T. Welford & J. E. Birren (Eds.), *Behavior, aging, and the nervous system* (pp. 191-216). Springfield, IL: Charles C Thomas.

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin, 98,* 67-83.

Blum, J. E., & Jarvik, L. F. (1974). Intellectual performance of octogenarians as a function of education and initial ability. *Human Development, 17,* 364-375.

Charness, N. (1989). Age and expertise: Responding to Talland's challenge. In L. W. Poon, D. C. Rubin, & B.A. Wilson (Eds.), *Everyday cognition in adulthood and late life* (pp. 437-456). Cambridge, UK: Cambridge University Press.

Christensen, H., & Henderson, A. S. (1991). Is age kinder to the initially more able? A study of eminent scientists and academics. *Psychological Medicine, 21,* 935-946.

Christensen, H., Henderson, A. S., Griffiths, K., & Levings, C. (1997a). Does ageing inevitably lead to declines in cognitive performance? A longitudinal study of elite academics. *Personality and Individual Differences, 23,* 67-78.

Christensen, H., Korten, A. E., Jorm, A. F., Henderson, A. S., Jacomb, P. A., & Rodgers, B. (1997b). Education and decline in cognitive performance: Compensatory but not protective. *International Journal of Geriatric Psychiatry 12,* 323-330.

Colsher, P. L., & Wallace, R. B. (1991). Longitudinal application of cognitive function measures in a defined population of community-dwelling elders. *Annals of Epidemiology, 1,* 215-230.

Compton, D. M., Bachman, L. D., Brand, D., & Avet, T. L. (2000). Age-associated changes in cognitive function in highly educated adults: Emerging Myths and realities. *International Journal of Geriatric Psychiatry, 15,* 75-85.

Compton, D. M., Bachman, L. D., & Logan, J. A. (1997). Aging and intellectual ability in young, middle-aged, and older educated adults: Preliminary results from a sample of college faculty. *Psychological Reports, 81,* 79-90.

Cornelius, S. W., & Caspi, A. (1987). Everyday problem solving in adulthood and old age. *Psychology and Aging, 2,* 144-153.

Craik, F. I. M., Morris, L. W., Morris, R. G., & Loewen, E. R. (1990). Relation between source amnesia and frontal lobe functioning in older adults. *Psychology and Aging, 5,* 148-151.

de Jonge, P., & de Jong, P. F. (1996). Working memory, intelligence, and reading ability in children. *Personality and Individual Differences, 21,* 1007-1020.

Dixon, R. A., & von Eye, A. (1984). Depth processing and text recall in adulthood. *Journal of Reading Behavior, 26,* 109-117.

Dixon, R. A., Hultsch, D. F., Simon, E. W., & von Eye, A. (1984). Verbal ability and text structure effects adult age differences in text recall. *Journal of Verbal Learning and Verbal Behavior, 23,* 569-578.

Evans, D. A., Beckett, L. A., Albert, M. S., Herbert, L. E., Scherr, P. A., Funkenstein, H. H., & Taylor, J. O. (1993). Level of education and change in cognitive function in a community population of older persons. *Annals of Epidemiology, 5,* 1-7.

Farmer, M. E., Kittner, S. J., Rae, D. S., Bartko, J. J., & Regier, D. A. (1995). Education and change in cognitive function. The Epidemiological Catchment Area study. *Annals of Epidemiology, 5,* 1-7.

Foulds, G. A., & Raven, J. C. (1948). Normal changes in the mental abilities of adults as age advances. *Journal of Mental Science, 94,* 133-142.

Gold, D. P., Andres, D., Etezadi, J., Arbuckle, T., Schwartzman, A., & Chaikeson, J. (1995). Structural equation model of intellectual change and continuity and predictors of intelligence in older men. *Psychology and Aging, 10,* 294-303.

Granick, S., & Friedman, A. S. (1973). Effect of education on intellectual decline of psychometric test performance with age. *Journal of Gerontology, 22,* 191.

Hartley, J. T. (1989). Memory for prose: Perspectives on the reader. In L. W. Poon, D. C. Rubin, & B. A. Wilson (Eds.), *Everyday cognition in adulthood in late life* (pp. 135-156). Cambridge, UK: Cambridge University Press.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193-225). San Diego, CA: Academic Press.

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. A. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 163-169.

Heaton, R. (1981). *Wisconsin card sort test*. Lutz, FL: Psychological Assessment Resources.

Horn, J. L. (1982). The theory of fluid and crystallized intelligence in relation to the concepts of cognitive psychology and aging in adulthood. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 237-278). New York: Plenum.

Horn, J. L. (1991). Measurement of intellectual abilities: A review of theory. In K. S. McGrew, J. K. Werder, & R.W. Woodcock (Eds.), *Woodcock-Johnson technical manual: A reference on theory and current research*. Allen, TX: DLM Teaching Resources.

Horn, J. L., & Cattell, R. B. (1966). Refinement and test of the theory of fluid and crystallized general intelligence. *Journal of Educational Psychology, 57,* 253-270.

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. *Acta Psychologica, 26,* 107-129.

Hultsch, D. F., & Dixon, R. A.(1990). Learning and memory in aging. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (3rd ed., pp. 258-274). San Diego, CA: Academic Press.

Hultsch, D. F., Hertzog, C., & Dixon, R. A. (1984). Text processing in adulthood: The role of intellectual abilities. *Developmental Psychology, 20,* 1193-1209.

Hultsch, D. F., Hertzog, C., & Dixon, R. A. (1990). Ability correlates of memory performance in adulthood and aging. *Psychology and aging, 5,* 356-368.

Isingrini, M., & Vazou, F. (1997). Relation between fluid intelligence and frontal lobe functioning in older adults. *International Journal of Aging and Human Development, 45,* 99-109.

Kane, M. J., Hasher, L., Stolzfus, E. R., Zacks, R. T., & Connelly, S. L. (1994). Inhibitory attentional mechanisms and aging. *Psychology and aging, 9,* 103-112.

Kaufman, A. S. (1990). *Assessing adolescent and adult intelligence.* Boston, MA: Allyn and Bacon.

Kaufman, A. S., Ishikuma, T., & Kaufman-Packer, J. L. (1991). Amazingly short forms of the WAIS-R. *Journal of Psychoeducational Assessment, 9,* 4-15.

Kaufman, A. S., Reynolds, C. R., & McLean, J. E. (1989). Age and WAIS-R intelligence in a national sample of adults in the 20 to 74-year age range: A cross-sectional analysis with educational level controlled. *Intelligence, 13,* 235-253.

Kennedy, K. J. (1981). Age effects on Trail Making Test performance. *Perceptual and Motor Skills, 52,* 671-675.

Kranzler, J. K., & Jensen, A. R. (1989). Inspection time and intelligence: A meta-analysis. *Intelligence, 13,* 329-347.

LaRue, A., & D'Elia, L. F. (1985). Anxiety and problem solving in middle-aged and elderly adults. *Experimental Aging Research, 11,* 215-220.

Lezak, M. D. (1995). *Neuropsychological Assessment* (3rd ed.). New York: Oxford University Press.

Light, L. L. (1991). Memory and aging: Four hypotheses in search of data. *Annual Review of Psychology, 42,* 333-376.

Light, L. L., & Anderson, P. A. (1985). Working memory capacity, age, and memory for discourse. *Journal of Gerontology, 40,* 737-747.

Light, K. E., & Spirduso, W. W. (1990). Effects of adult aging on the movement complexity factor of response programming. *Journal of Gerontology: Psychological Sciences, 45,* P107-P109.

Lindenberger, U., Mayr, U., & Kliegl, R. (1993). Speed and intelligence in old age. *Psychology and aging, 8,* 207-220.

Loong, J. W. K. (1990). *The Wisconsin Card Sorting Test* [Computer Software]. San Luis, Obispo, CA: Author.

Mayr, U., & Kliegl, R. (1993). Sequential and coordinative complexity: Age-based processing limitations in figural transformations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 1297-1320.

McDowd, J. M., Oseas-Kreger, D. M., & Fillion, D. L. (1995). Inhibitory processes in cognition and aging. In F. N. Dempster & C. J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 363-400). San Diego, CA: Academic Press.

Meyer, B. J. F. (1987). Reading comprehension and aging. In K. W. Schaie (Ed.), *Annual review of gerontology and geriatrics* (Vol. 7, pp. 93-115). New York: Springer.

Meyer, B. J. F., & Rice, G. E. (1983). Learning and memory from text across the adult life span. In J. Fine & R. O. Freedle (Eds.), *Developmental studies in discourse* (pp. 291-306). Norwood, NJ: Ablex.

Myerson, J., Ferraro, F. R., Hale, S., & Lima, S. D. (1992). General slowing in semantic priming and word recognition. *Psychology and Aging, 7,* 257-270.

Moscovitch, M., & Winocur, G. (1983). Contextual cues and release from proactive inhibition in young and old people. *Canadian Journal of Psychology, 83,* 331-344.

Moscovitch, M., & Winocur, G. (1992). The neuropsychology of memory and aging. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 315-372). Hillsdale, NJ: Erlbaum.

O'Hanlon, A. M. (1993). *Inter-individual differences of intellectual change: The influence of environmental factors*. Unpublished doctoral dissertation, The Pennsylvania State University.

Orrell, M., & Sahakian, B. (1995). Education and dementia. Research evidence supports the concept "use it or lose it." *British Medical Journal, 310,* 951-952.

Osterweil, D., Mulford, P., Syndulko, K., & Martin, M. (1994). Cognitive function in old and very old residents of a residential facility: Relationship to age, education, and dementia. *Journal of the American Geriatric Society, 42,* 766-773.

Park, D. C., Smith, A. D., Lautenschlager, G., Earles, J. L., Frieske, D., Zwahr, M., & Gaines, C. L. (1996). Mediators of long-term memory performance across the life span. *Psychology and Aging, 11,* 621-637.

Parkin, A. J., & Walter, B. M. (1991). Aging, short-term memory, and frontal dysfunction. *Psychobiology, 19,* 175-179.

Parkin, A. J., & Walter, B.M. (1992). Recollective experience, normal aging, and frontal dysfunction. *Psychology and Aging, 7,* 290-298.

Perlmutter, M., & Nyquist, L. (1990). Relationships between self-reported physical and mental health and intelligence performance across adulthood. *Journal of Gerontology, 45,* 145-155.

Pillon, B., & Dubois, B. (1992). Cognitive and behavioral impairment. In I. Litvan & Y. Agid (Eds.), *Progressive Supranuclear palsy, clinical and research approaches*. (pp. 221-239). New York: Oxford University Press.

Reitan, R. (1958). Validity of the Trail Making Test as an indicator of organic brain damage. *Perceptual and Motor Skills, 8,* 271-276.

Reitan, R. (1985). *The Halstead-Reitan neuropsychological test battery: Theory and clinical interpretation*. Tucson, AZ: Neuropsychology Press.

Rothstein, H., Cohen, J., Schoenfeld, D., Berlin, J, & SPSS.(2000). *Power and precision* (ver. 2.0). Englewood, NJ: Biostat.

Salthouse, T. A. (1987). Age, experience, and compensation. In C. Schooler & K. W. Schaie (Eds.), *Cognitive functioning and social structure over the life course* (3rd ed., pp. 142-157). Norwood, NJ: Ablex Press.

Salthouse, T. A. (1991a). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. *Psychological Science, 3,* 179-183.

Salthouse, T. A. (1991b). *Theoretical perspectives on cognitive aging*. Hillsdale, NJ: Erlbaum.

Salthouse, T. A. (1992a). Why do adult age differences increase with task complexity? *Developmental Psychology, 28,* 905-918.

Salthouse, T. A. (1992b). Working-memory mediation of adult age differences in integrative reasoning. *Memory and Cognition, 20,* 413-423.

Salthouse, T. A. (1993). Speed mediation of adult age differences in cognition. *Developmental Psychology, 29,* 722-738.

Salthouse, T. A. (1994). The nature of the influence of speed on adult age differences in cognition. *Developmental Psychology, 30,* 240-259.

Salthouse, T. A. (1994b). The aging of working memory. *Neuropsychology, 8,* 535-543.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403-428.

Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology, 27,* 763-776.

Salthouse, T. A., Mitchell, D. R. D., Skovronek, E., & Babcock, R. L. (1989). Effect of adult age and working memory on reasoning and spatial abilities. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 507-516.

Schaie, K. W. (1989). Perceptual speed in adulthood: Cross-sectional and longitudinal studies. *Psychology and Aging, 4,* 443-453.

Schaie, K. W. (1990). The optimization of cognitive functioning in old age: Predictions based on cohort-sequential and longitudinal data. In P. B. Baltes & M. M. Baltes (Eds.), *Successful Aging: Perspectives from the behavioral sciences* (pp. 94-117). Cambridge, UK: Cambridge University Press.

Schaie, K. W. (1994). The course of adult intellectual development. *American Psychologist, 49,* 304-313.

Schaie, K. W. (1995). *Intellectual development in adulthood:The Seattle Longitudinal Study*. New York: Cambridge University Press.

Schaie, K. W. (1996). Intellectual development in adulthood. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (4th ed., pp. 266-286). San Diego, CA: Academic Press.

Schooler, C. (1984). psychological effects of complex environments during the life span: A review and theory. *Intelligence, 8,* 259-281.

Schooler, C. (1990). Psychosocial factors and effective cognitive functioning in adulthood. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (3rd ed., pp. 347-358). San Diego, CA: Academic Press.

Shimamura, A. P. (1990). Aging and memory disorders: A neuropsychological analysis. In M. L. Howe, M. J. Stones, & C. J. Brainerd (Eds.), *Cognitive and behavioral performance factors in atypical aging* (pp. 37-65). New York: Springer-Verlag.

Shimamura, A. P., Berry, J. M., Mangels, J. A., Rusting, C. L., & Jurica, P. J. (1995). Memory and cognitive abilities in university professors: Evidence for successful aging. *Psychological Science, 6,* 271-277.

Siegler, I. C., & Botwinick, J. (1979). A long-term longitudinal study of intellectual ability of older adults: The matter of selective subject attrition. *Journal of Gerontology, 34,* 242-245.

Smith, A. D. (1996). Memory. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (3rd ed., pp. 236-250). San Diego, CA: Academic Press.

Spreen, O., & Strauss, E. (1998). *A Compendium of psychological tests: Administration norms and commentary* (2nd ed.). New York: Oxford University Press.

Stine, E. L., & Wingfield, A. (1987). Process and strategy in memory for speech among younger and older adults. *Psychology and Aging, 2,* 272-279.

Stoltzfus, E. R., Hasher, L., & Zacks, R. T. (1996). Working memory and aging: Current status of the inhibitory view. In J. T. E. Richardson, R. W. Engle, L. Hasher, R. H. Logie, E. R. Stoltzfus, & R. T. Zacks, *Working memory and human cognition* (pp. 66-88). New York: Oxford University Press.

Storandt, M. (1976). Speed and coding effects in relation to age and ability level. *Developmental Psychology, 12,* 177-178.

Sward, K. (1945). Age and mental ability in superior men. *American Journal of Psychology, 58,* 443-479.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task independent? *Journal of Memory and Language, 28,* 127-154.

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale-Revised.* New York: Psychological Corporation.

Wechsler, D. (1987). *Wechsler Memory Scale-Revised*. San Antonio, TX: Psychological Corporation.

White, L., Katzman, R., Losonczy, K., Slaive, M., Wallace, R., Berkman, L., Taylor, J., Fillenbaum, G., & Havlik, R. (1994). Association of education with incidence of cognitive impairment in three established populations of epidemiologic studies of the elderly. *Journal of Clinical Epidemiology, 47,* 363-374.

Williams, J. D., & Klug, M. G. (1996). Aging and cognition: Methodological differences in outcome. *Experimental Aging Research, 22,* 219-244.

Zelinski, E. M., & Gilewski, M. J. (1988). Memory for prose and aging: A meta analysis. In M. L. Howe & C. J. Brainerd (Eds.), *Cognitive development in adulthood: Progress in cognitive development research*. New York: Springer-Verlag.

Zelinski, E. M., Gilewski, M. J., & Schaie, K. W. (1993). Individual differences in cross-sectional and 3-year longitudinal memory across the adult life span. *Psychology and Aging, 8,* 176-186.