Journal of Gerontology: PSYCHOLOGICAL SCIENCES
1996, Vol. 51B, No. 6, P317–P330

Interrelations of Age, Visual Acuity, and Cognitive Functioning

Timothy A. Salthouse, Holly E. Hancock, Elizabeth J. Meinz, and David Z. Hambrick

School of Psychology, Georgia Institute of Technology.

It has recently been suggested that a large proportion of the age-related influences on many measures of cognitive functioning is mediated through a single common factor. This hypothesis has been supported by the discovery that much of the age-related variance in different cognitive measures is shared, and is not distinct or independent. These earlier results were replicated in this project, and it was also discovered that measures of corrected visual acuity and processing speed share a very large proportion of the age-related variance in measures of working memory, associative learning, and concept identification. The apparent implication is that the common factor that appears to contribute to age-related differences in many cognitive measures is quite broad and may reflect a relatively general reduction in central nervous system functioning.

RECENT research has established that age-related influences on many different cognitive variables are not independent, but instead that 50% or more of the age-related variance is shared with other variables (Salthouse, 1992b, 1994b, 1996a). This finding suggests that adult age differences in cognition are not exclusively attributable to task-specific processes but instead are determined at least partially by broader or more general factors. Variations in these broad factors are unlikely to be responsible for all of the observed age differences in cognitive functioning, but it is important to assess and understand the contribution of any general factors that might exist because the role of more specific factors cannot be accurately determined unless the general influences are first taken into consideration.

One approach that can be used to investigate the nature of the hypothesized common or general factor is to determine which variables "age together" in the sense that they share large portions of their age-related variance. That is, to the extent that a variable is found to have considerable overlap of its age-related variance with the age-related variance in other variables, then it can be inferred to be either a cause or a consequence of the hypothesized common factor.

For example, a number of studies have examined measures of how quickly simple comparison or substitution operations can be executed. Nearly everyone achieves perfect accuracy in these tasks if enough time is allowed, and thus performance is usually assessed in terms of how quickly the tasks can be completed. Because measures of performance in tasks of this type have been found to share 75% or more of the age-related variance from a variety of cognitive measures, speed of processing has been postulated to be centrally involved in the hypothesized common factor (Salthouse, 1993, 1994b, 1994c, 1996a, 1996b).

Recently, however, Lindenberger and Baltes (1994) have reported that measures of sensory ability also shared large proportions of age-related variance with several measures of cognitive functioning in a sample of adults between 70 and 103 years of age. Furthermore, the relations they reported were apparently not merely a consequence of difficulty registering the stimuli, because similar patterns were evident with measures from three different sensory modalities — vision, hearing, and balance. Among the possibilities discussed by these authors was that the sensory and cognitive measures were related because they were both indicators of the hypothesized common factor that has been postulated to contribute to adult age differences in many measures of cognitive functioning.

The goal of the current project was to investigate the role of sensory ability on age-cognition relations in healthy samples of adults from a younger age range — between approximately 18 and 80 years of age — than the sample studied by Lindenberger and Baltes (1994). (See Appendix, Note 1). Only measures of near visual acuity were examined because Lindenberger and Baltes (1994) found similar relations with measures from each sensory modality, and vision is the easiest sensory modality to assess. Moreover, visual acuity was assessed while the individuals were wearing their normal corrective lenses, because Lindenberger and Baltes (1994) found that this measure exhibited strong relations both with age and with measures of cognitive functioning.

Note that, because vision is assessed when the research participants were wearing corrective lenses, everyone might have been expected to have close to optimum acuity if the optical corrections were fully effective in remediating any visual defects. However, the research literature contains many reports of age-related declines in corrected visual acuity (e.g., Burg, 1966; Chapanis, 1950; Fozard, 1990; Gittings & Fozard, 1986; Pitts, 1982). There is some difference of opinion as to the primary factors responsible for the age-related acuity loss, because Kline and Schieber (1985, p. 31) claim that "Much of the slight to moderate loss in static visual acuity accompanying normal aging appears to be due to changes in the optic media of the eye," whereas Weale (1982, p. 167) suggests that optical factors are responsible for only some of the declines in visual acuity, with the rest attributable to loss of neural cells. When acuity is assessed at relatively close viewing distances, as was the case in the present studies, reductions in the effectiveness of accommodation probably also contribute to negative relations between age and visual acuity because of a decreased ability to focus on near objects. Regardless of the reasons for the age-related declines in corrected near visual acuity, however, the visual acuity measure is of interest if it is also related to measures of cognitive functioning because it might then be another reflection of the hypothesized common factor.

The primary analytical strategy in this project involved partitioning the variance among age, vision, and cognitive variables to determine how much variance is shared in various combinations. The goal was to find out which variables ''age together'' by, in effect, examining the correlations between the age-related effects on different variables. That is, the age-related effects can be expressed as the square of the correlation (i.e., the covariance), and then the degree of independence of the relations between age and different variables can be examined by inspection of the overlap of the age-variable covariances.

Commonality analysis (Pedhazur, 1982) was the principal method used to accomplish the variance partitioning. When there are two predictors (e.g., age and vision) of a measure of cognitive functioning, three variance proportions are of interest in commonality analysis. Two of these proportions represent unique contributions of age and of vision, respectively. They can be computed with hierarchical regression procedures and correspond to the increment in R^2 associated with one predictor variable after the variance in the other predictor variable has been controlled. The estimates therefore represent the variance in the criterion variable associated with one predictor that is independent of the other predictor. These unique variance estimates would be expected to be high if most of the influences of the predictor were distinct from the other predictor, but they would be expected to be low if most of the influences were shared. The third variance estimate represents the common variance in the criterion variable that is shared between the two predictors, and is not unique to either. It is computed by subtracting the estimate of the unique contribution of a predictor on the criterion variable from the total effects of the predictor on that variable. In the current context, this estimate of shared variance can be interpreted as the contribution of the hypothesized common or general factor on the age-related effects in the criterion variables.

An extension of commonality analysis proposed by Salthouse (1992b, 1994b) was also used to express the ratio of shared to total age-related variance in the form of a correlation coefficient. The traditional Pearson product-moment correlation reflects the square root of the ratio of shared to total variance for *all of the variance* in the variables, and the partial correlation controlling for age corresponds to the square root of the shared to total *age-independent variance* in the variables. In contrast, the quasi-partial correlation is the square root of the ratio of the shared to total *age-related variance*. It will be high if much of the relation between the variables is because of a common factor associated with both variables and with age, and it will be low if most of the age-related influences are unique.

Commonality and quasi-partial correlation analyses were conducted both with cognitive measures and with speed measures as the criterion variables. Speed measures are interesting because previous research has revealed that speed measures share a large proportion of the age-related variance with many cognitive measures (e.g., Bors & Forrin, 1995; Bryan & Luszcz, 1996; Graf & Uttl, 1995; Hertzog, 1989; Lindenberger, Mayr, & Kliegl, 1993; Nettelbeck & Rabbitt, 1992; Salthouse, 1992a, 1993, 1994a, 1994c, 1996a, 1996b; Schaie, 1989, 1990).

Analyses from three separate data sets are reported in this article. Two data sets were from studies conducted for other purposes, but some of those data were amenable to the present analyses because the participants spanned a wide age range and measures of visual acuity and speed were obtained from every participant. The other tasks in these studies were not traditional cognitive tasks and thus only the speed measures from those studies are reported here. The third data set is from a new study with the same four speed measures as in Studies 1 and 2 and also three measures of working memory and measures from an associative learning task and from a concept-identification task.

Studies 1 and 2

The purpose of the analyses in the initial two studies was to investigate the role of vision on the relations between age and relatively simple measures of processing speed. Of particular interest was whether strong negative relations between age and corrected near visual acuity would be found in samples of healthy adults between approximately 18 and 80 years of age and the degree to which the age-related variance in the measures of processing speed was shared with the age-related variance in the vision measure.

METHOD

Subjects. — Participants in these studies consisted of 77 and 127 adults, respectively, in Studies 1 and 2. Descriptive characteristics of the participants are summarized in Table 1, where it can be seen that nearly all of them reported themselves to be in good to excellent health. (More details about the participants are provided in the complete reports of these studies; Salthouse, Hambrick, Lukas, & Dell, in press; Meinz & Salthouse, 1996).

Procedure. — Visual acuity was assessed by means of a near-vision eye chart held at a distance of approximately 30 cm in a room with normal (uncontrolled) ambient illumination. The chart (Scalae Typographicae Birkhauseri, Birkhauser Verlag, Basel) contained both Landolt C and two-digit number stimuli in 10 different font sizes corresponding to Snellen acuity ratios of .1 to 1.0. The assessment consisted of asking research participants to read the numbers or state the direction of the gap in the C with each type of stimulus, first with the left eye covered and then again with the right eye covered. The Snellen ratio corresponding to the smallest font size at which this could be accomplished with fewer than two errors out of the 8 to 16 items at each font size was identified as the visual acuity estimate. Participants used any corrective lenses they had available during the testing,

Table 1. Characteristics of Participants in Studies 1 and 2

Variable	Study 1			Study 2		
	Mean	*SD*	Age *r*	Mean	*SD*	Age *r*
n	77	—	—	127	—	—
Age	50.5	16.7	—	45.9	15.5	—
% Female	53.2	—	—	66.1	—	—
Education	15.6	2.6	−.18	15.7	2.9	−.16
Health Rating 1	2.1	0.9	.17	1.9	0.9	−.06
Health Rating 2	2.4	0.9	.19	2.1	0.8	.05
Health Satisfaction	2.3	0.8	.17	2.2	0.7	−.02
Health-Related Limitations	1.6	0.8	.24	1.5	0.7	.11
Cardiovascular Surgery	0.06	0.25	.16	0.04	0.20	−.11
Hypertension Medications	0.26	0.44	.53*	0.11	0.31	.32*
Head Injury	0.05	0.22	.01	0.05	0.21	.02
Neurological Treatment	0.08	0.27	−.10	0.04	0.20	−.14
Vision - Right Eye	0.48	0.22	−.56*	0.57	0.26	−.64*
Vision - Left Eye	0.50	0.24	−.62*	0.54	0.25	−.56*
Synonym Vocabulary	7.2	2.5	.22	6.9	2.6	.17
Antonym Vocabulary	6.5	3.1	.07	6.4	2.8	.06
Perceptual Speed						
Letter Comparison	9.7	2.4	−.36*	10.0	2.8	−.46*
Pattern Comparison	16.2	3.4	−.54*	17.2	3.7	−.43*
Reaction Time						
Digit-Digit	742	203	.35*	750	164	.42*
Digit-Symbol	1552	394	.61*	1523	335	.57*

Note: Education is number of years of formal education completed, and Health Rating, Health Satisfaction, and Health-Related Limitations are ratings on a 5-point scale where lower numbers indicate better health. Responses to the Cardiovascular Surgery, Hypertension Medications, Head Injury, and Neurological Treatment items were Yes/No, and thus the means correspond to the proportion of individuals reporting a positive response. Vision scores are the average of the Snellen ratios for the number and Landolt C stimuli. Scores in the Vocabulary and Perceptual Speed tests are number of items correct, and scores in the Reaction Time tasks are in msec.

*$p < .01$.

but we have no information about the recency, or accuracy, of their optical correction.

Although this particular visual acuity test has not been widely used in the United States, it has several advantages for the current purposes. First, and most important, the test is from the same set of acuity tables used by Lindenberger and Baltes (1994) and Baltes and Lindenberger (1995, in press), and therefore we can examine the replicability of their results with a very similar assessment instrument. Second, unlike many acuity tests, two types of stimulus (2-digit numbers and Landolt C) are presented, and therefore it is possible to determine whether the results are specific to a particular type of stimulus. Third, the stimuli are calibrated in equal Snellen ratios from 0.1 to 1.0 in steps of 0.1, and thus there is a wide range of sensitivity within the normal population. And fourth, the acuity estimates from this test were found to correlate .91 with the estimates from a more traditional visual acuity test (i.e., the Lighthouse Near Visual Acuity Test, Modified ETDRS with Sloan Letters) in a sample of 19 individuals.

Two of the speed tasks were administered with paper-and-pencil procedures. The letter comparison task consisted of the presentation of pairs of three, six, or nine letters, with approximately half of the pairs differing in the identity of one letter. The participant was instructed to write an "S" (for same) or a "D" (for different) on a line between the numbers of the pair and to work as many of the items as possible within 30 sec. The pattern comparison test was very similar except that the pairs consisted of patterns composed of three, six, or nine line segments. Each test began with a page containing several sample items, and then was administered in two separately timed (30 sec) sections. The score in each section was the number of items marked correctly minus the number of items marked incorrectly, and the average of the two scores served as the primary performance measure.

The digit-digit and digit-symbol reaction time tasks were administered on computers. Trials in each task consisted of the presentation of a code table at the top of the computer screen and a pair of probe items in the middle of the screen. In the digit-digit task, the code table contained nine pairs of identical digits and hence was superfluous, but in the digit-symbol task, it contained nine digits each paired with a different symbol. Probe items consisted of pairs of digits in the digit-digit task and pairs of a digit and a symbol in the digit-symbol task. Research participants were instructed to press the "/" key on the keyboard if the members of the probe pair were the same (i.e., either physically identical in the digit-digit task or associationally equivalent in the digit-symbol task), and to press the "Z" key on the keyboard if the members of the pair were different. A practice block of 18 trials preceded the experimental block of 90 trials in each task. Because accuracy averaged over 95%, the median reaction time served as the primary measure of performance in these tasks.

No constraints on viewing distance were imposed in any of the tasks. However, the visual angles at a viewing distance of 45 cm were approximately two degrees for the letter comparison and pattern comparison stimuli, and four degrees for the digit-digit and digit-symbol stimuli.

RESULTS AND DISCUSSION

Age-Vision Relations

The visual acuity scores with the Landolt C and with the two-digit number stimuli were highly correlated with one another (i.e., r's $> .7$), and thus the average of the two scores was used as the visual acuity estimate for each eye. The vision scores across the two eyes were also moderately to highly correlated with one another ($r = .82$ in Study 1, $r = .49$ in Study 2), and thus the average across the two eyes was used as a composite vision score (see Appendix, Note 2). Estimated reliability of the composite vision score was computed by determining the partial correlation between the scores for the two eyes controlling for age and then boosting that value by the Spearman-Brown formula. The resulting estimates were .87 in Study 1 and .59 in Study 2. Because the results of the analyses reported below were very similar with the visual acuity score in each eye serving as the vision measure, the aggregation across eyes primarily serves to increase the reliability of the vision measure (see Appendix, Note 3).

Figure 1 portrays the relations between age and the composite vision measure in Studies 1 and 2. It is apparent that there were strong negative age relations on the corrected near-vision acuity measure in samples ranging from 18 to 80 years of age.

Regression analyses revealed that the quadratic (age-squared) term was significant in both Study 1 and Study 2 and was responsible for an additional 6.6% of the variance in Study 1 and an additional 3.0% of the variance in Study 2. Separate analyses on the subgroups above and below the median age indicated that the nonlinear effects were attributable to a smaller age relation at older ages. Neither the gender main effect nor the interaction of Age × Gender was significant in either study.

The influence of health measures on the relation between age and vision was examined by conducting a principal components analysis on the eight health measures (see Table 1), and then controlling the variance in the component scores before examining the relationship between age and vision. The principal components analysis of the health variables in Study 1 indicated that two components had eigenvalues greater than 1.0. The first component had high loadings on all health variables except for reports of head injury and of treatment for neurological disorders and was correlated .29 with age. The second component had high loadings on the head injury and neurological treatment variables and was correlated −.14 with age. The R^2 associated with age in prediction of the composite vision index was .379, and this was reduced to .293 after control of factor 1 and to .376 after control of factor 2.

In Study 2 the principal components analysis revealed three components with eigenvalues greater than 1. The first had major loadings from the self-rated heath variables, the second had a high loading from the cardiovascular surgery variable, and the third had a high loading from the report of neurological treatment variable. Correlations of age with the components were .05, −.01, and −.10, respectively. The age-related variance in the composite vision measure was .510, and it was reduced to .507 after control of the first component; it was reduced to .509 after control of the second

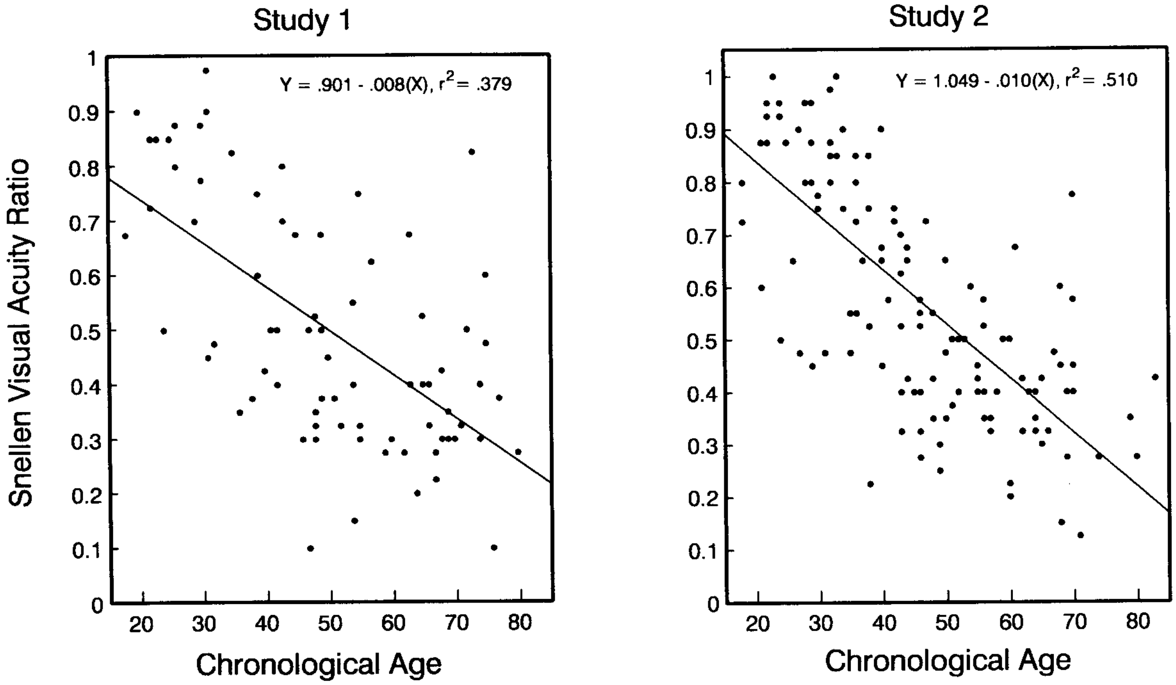

Figure 1. Relation between composite visual acuity score and age in Studies 1 and 2. Each point represents a different individual.

component, and it increased to .516 after control of the third component.

The results of the analyses just described suggest that the observed relations between age and vision are not mediated by poorer health, at least as health is assessed with the relatively crude self-report measures in these studies. Similar analyses with control of the variable of years of education also resulted in little reduction of the age-related variance in the composite vision measure. That is, after the amount of education variable was statistically controlled, the R^2 for age was reduced from .379 to .371 in Study 1, and from .510 to .479 in Study 2.

Age-Speed Relations

The initial analysis on the speed measures consisted of computing correlations, partial correlations, and quasi-partial correlations between pairs of speed measures. In Study 1 the absolute magnitude of the correlations ranged from .34 to .65, the range for the partial correlations was .24 to .59, and the range for the quasi-partial correlations was .71 to .86. In Study 2 the ranges of the absolute values were .27 to .63 for the correlations, .10 to .54 for the partial correlations, and .58 to .91 for the quasi-partial correlations. The relatively large values of the quasi-partial correlations indicate that a substantial proportion of the shared variance between pairs of speed variables was also related to age. However, it should be noted that one reason the quasi-partial correlations are larger than the other correlations is that all of the age-related variance was reliable, whereas some of the total variance and of the age-independent variance was due to error and hence was not systematic.

A composite speed index was created by subtracting the average z-score for the digit-digit reaction time and digit-symbol reaction time measures ($r = .65$ in Study 1 and $r = .50$ in Study 2) from the average z-score for the letter comparison and pattern comparison measures ($r = .49$ in Study 1 and $r = .63$ in Study 2). Note that the subtraction reflects the fact that the reaction time measures are scaled in time per item, whereas the comparison measures are scaled in items per time. This composite speed index served as an additional speed measure in the subsequent analyses.

Influence of Vision on Age-Speed Relations

Tests for the Age × Vision interaction were conducted by entering the cross-product term after the age and vision terms in the multiple regression equations with the five speed measures as criterion variables. Only one of the interaction terms (i.e., on Digit Symbol Reaction Time in Study 2) was significant at the specified ($\alpha = .01$) significance level, and therefore there is little evidence that the relations between vision and speed varied as a function of age.

Table 2 contains commonality estimates of the proportions of variance in the speed measures associated with different predictors. Note that the proportion of variance in the speed measures unique to vision was near zero for all five speed measures. This indicates that there was little age-independent relation between vision and speed and implies that almost all of the relation between vision and speed was attributable to the age variation.

The estimates of the variance unique to age ranged from 46 to 66% of the total age-related variance in Study 1, and from 38 to 61% in Study 2. The percentage of the total age-related variance common to vision averaged 43% in Study 1 and 53% in Study 2. It can therefore be concluded that approximately half of the age-related variance in the current speed measures is shared with a measure of near-vision acuity.

Although only about 50% of the age-related influences on speed were shared with the vision measure, it is nevertheless important to note that there were strong negative relations between age and corrected near-visual acuity, and moderate correlations between the visual acuity measure and speed measures obtained under high visibility conditions. The next study was therefore conducted to determine whether similar, or possibly even larger, relations of vision would be evident with measures from higher-order cognitive tasks.

Study 3

Previous research has indicated that processing speed is a major factor in the age relations on any cognitive measures (e.g., Bors & Forrin, 1995; Bryan & Luszcz, 1996; Graf & Uttl, 1995; Hertzog, 1989; Lindenberger, Mayr, & Kliegl, 1993; Nettelbeck & Rabbitt, 1992; Salthouse, 1992a, 1993, 1994a, 1994c, 1996a, 1996b; Schaie, 1989, 1990). The question of interest in this study was whether the age-related variance that is shared with speed is unique or whether it is also shared with measures of vision. If the latter is the case, this would suggest that a common factor reflecting relatively broad central nervous system functioning may be responsible for the mediation of age-related cognitive differences.

The tasks administered in this study consisted of the same four speed tasks used in Studies 1 and 2 and, in addition, three working memory tasks and two tasks assessing higher-order cognitive functioning. Two of the working memory tasks, reading span and computation span, have been used in several previous studies (Salthouse & Coon, 1994; Salthouse & Meinz, 1995). The *n*back task was based on a task originally described by Kay (in Welford, 1958) and Kirchner (1958). It consisted of the presentation of a series of randomly selected digits with the participant asked to report the digits *n* back in the sequence. Values of *n* equal to 0, 1, and 2 were used in this study.

The two higher-order cognitive tasks were associative learning (Salthouse, 1994a) and a computer-administered version of the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993). These particular cognitive tasks are of special interest because both yield measures of perseveration responses that have been found to increase in frequency with increasing age. Although the increase in perseveration responses with increased age seems well established, particularly for the WCST, there are two important questions about this phenomenon. First, are perseveration measures from different tasks highly correlated, as would be expected if they reflect a common construct? And second, are the age differences in perseveration responses mediated by age-related differences in working memory, as might be expected if they are attributable to a failure to effectively process feedback information (cf., Salthouse, 1994a)? It should be possible to answer these

Table 2. Commonality Estimates for Speed Measures, Studies 1 and 2

Criterion	Predictor	Unique to Age	Unique to Vision	Common to Age & Vision	Total
		Study 1 (n = 77)			
Letter Comparison					
	Age	.080		.051	.131
	Vision		.000	.051	.051
Pattern Comparison					
	Age	.166		.128	.294
	Vision		.001	.128	.129
Digit-Digit Reaction Time					
	Age	.055		.065	.120
	Vision		.005	.065	.070
Digit-Symbol Reaction Time					
	Age	.250		.125	.376
	Vision		.000	.126	.126
Composite					
	Age	.201		.144	.345
	Vision		.000	.144	.144
		Study 2 (n = 127)			
Letter Comparison					
	Age	.080		.130	.210
	Vision		.003	.130	.133
Pattern Comparison					
	Age	.040		.142	.182
	Vision		.019	.142	.161
Digit-Digit Reaction Time					
	Age	.056		.122	.178
	Vision		.006	.122	.128
Digit-Symbol Reaction Time					
	Age	.197		.132	.329
	Vision		.004	.132	.136
Composite					
	Age	.144		.233	.377
	Vision		.005	.233	.238

questions with data from a study in which the participants performed a battery of working memory and associative learning tasks in addition to the WCST.

The data in this study were examined with two sets of commonality analyses. The first set of analyses was identical to those in Studies 1 and 2, with age and vision as predictors of the speed measures. The second set of analyses involved three predictors (i.e., age, vision, and speed) of the working memory and cognitive measures. The goal in these analyses was to determine whether the age-related variance shared with speed and cognition was the same as the age-related variance shared with vision and cognition. If so, then this result would be consistent with the common factor interpretation. If not, then separate speed and vision influences on the age differences in cognition would presumably need to be postulated.

METHOD

Subjects. — The sample consisted of 197 adults between 18 and 92 years of age. None of the individuals had participated in either of the previous studies. Descriptive characteristics of the participants are summarized in Table 3, where it can be seen that most of the participants reported themselves to be in good to excellent health, and had attended college for an average of two to three years.

Procedure. — All participants performed the following sequence of tasks in a single session of approximately two hours. The tasks included letter comparison, pattern comparison, synonym vocabulary, antonym vocabulary, digit-digit reaction time and digit-symbol reaction time (in counterbalanced order), sentence span, computation span, *n*back with *n* equal to 0, 1, and 2 (in counterbalanced order), computer-administered WCST, and associative learning.

The letter comparison, pattern comparison, digit-digit reaction time, and digit-symbol reaction time tasks were identical to those administered in Studies 1 and 2. The same vocabulary tests from the earlier studies were also used in this study and consisted of 10 four-alternative multiple choice items for both the synonym and antonym tests.

The reading span and computation span tasks were identi-

Table 3. Characteristics of Participants in Study 3

Variable	Age Group 18–39	40–59	60–92	Age r
n	67	68	62	—
Age	30.0 (6.4)	50.5 (6.0)	69.8 (7.0)	—
% Female	64.2	61.8	46.8	—
Education	14.8 (2.3)	15.1 (2.3)	14.8 (3.2)	–.03
Health Rating 1	2.0 (0.9)	2.1 (0.9)	2.0 (0.9)	.00
Health Rating 2	2.2 (0.9)	2.3 (0.8)	2.3 (0.8)	.11
Health Satisfaction	2.3 (0.8)	2.4 (0.7)	2.3 (0.8)	.04
Health-Related Limitations	1.5 (1.0)	1.7 (0.8)	1.8 (0.9)	.20*
Cardiovascular Surgery	0 (0)	0.01 (0.12)	0.13 (0.34)	.28*
Hypertension Medications	0.03 (0.17)	0.16 (0.37)	0.37 (0.49)	.39*
Head Injury	0.04 (0.21)	0.12 (0.32)	0.11 (0.32)	.11
Neurological Treatment	0.09 (0.29)	0.09 (0.29)	0 (0)	–.15
Visual Acuity — Right Eye	0.69 (0.22)	0.45 (0.23)	0.35 (0.15)	–.59*
Visual Acuity — Left Eye	0.72 (0.20)	0.46 (0.21)	0.34 (0.16)	–.62*
Synonym Vocabulary	5.3 (2.8)	6.8 (3.0)	7.3 (2.9)	.28*
Antonym Vocabulary	4.8 (3.0)	6.1 (3.4)	6.1 (3.3)	.16

Note: Education is number of years of formal education completed, and Health Rating, Health Satisfaction, and Health-Related Limitations are ratings on a 5-point scale where lower numbers indicate better health. Responses to the Cardiovascular Surgery, Hypertension Medications, Head Injury, and Neurological Treatment items were Yes/No, and thus the means correspond to the proportion of individuals reporting a positive response. Vision scores are the average of the Snellen ratios for the number and Landolt C stimuli. Scores in the Vocabulary tests are number of items correct.

*$p < .01$.

cal to those used in earlier studies by Salthouse and Coon (1994) and Salthouse and Meinz (1995). Each consisted of a practice set of trials followed by two experimental blocks with different items in each set. Trials in the reading span task involved the presentation of a short sentence accompanied by a question and three alternative answers. The research participant was instructed to use the arrow keys on the keyboard to position an arrow in front of the correct answer to the question while also remembering the last word in the sentence. After selecting the answer to the questions, a prompt appeared, requesting the participant to recall the target words by typing them on the keyboard. The number of sentences (and to-be-remembered words) increased to a maximum of nine as long as the participant was correct on both the comprehension question and the recall on at least two of the three trials at each list length. The span estimate was the largest number of items at which the participant was correct on both the comprehension and the recall on at least two of three trials. The computation span task was very similar to the reading span task, except that it consisted of arithmetic problems instead of sentences, and the items to be remembered were digits instead of words.

The *n*back task involved the presentation of a sequence of 10 to 12 (i.e., $n + 10$) digits on the computer screen with the participant instructed to type the digit 0, 1, or 2 items back in the sequence. Each digit appeared for 1.5 sec, and the appropriate response had to be entered within that interval to be counted as correct. Participants received practice in each of the three conditions (i.e., $n = 0$, 1, and 2) before performing a total of six trials in each condition, with the conditions presented in a counterbalanced order (i.e., 0-1-2-2-1-0). The $n = 0$ condition was primarily a control condition because there was no storage requirement when the digit to be typed was currently on the screen. Performance could be less than maximum (100%) in this condition because of confusion about the instructions and/or difficulty in locating the response keys and responding within the 1.5-sec interval. The influence of these factors on performance in the other conditions was examined by computing the residuals in prediction of the $n = 1$ and $n = 2$ scores from a multiple regression equation after controlling for the $n = 0$ score. However, because these residuals were highly correlated with the raw scores (i.e., .83 for $n = 1$ and .90 for $n = 2$), only the raw scores were used in subsequent analyses.

A computer-administered version of the Wisconsin Card Sorting Test was used to present the WCST. (The computer program was developed by John L. Woodard, who kindly allowed us to use it in this study). The standard version of this test consists of a set of four stimulus cards and 128 response cards, which are to be sorted into the appropriate stimulus category according to principles (i.e., on the basis of color, form, and number) that had to be discovered, and which changed throughout the test. Instead of presenting the stimulus and response items as cards, in the computer-administered version they were displayed as boxes on the computer screen. A response card was sorted into the appropriate category by typing a number from 1 to 4 corresponding to the stimulus item below which the response card should be placed. The response card then appeared underneath the stimulus card and both auditory (i.e., tones of different frequencies) and visual (i.e., "Right" or "Wrong") feedback was presented. The two measures of primary interest in this test were the number of categories (out of a maximum of six) successfully completed, and the percentage of perseverative errors in which the participant continued to respond to a previous category after the sorting principle had changed.

The associative learning task was very similar to the tasks