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Interrelations of Age, Health, and Speed

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Latent construct structural equation modeling of the relations among age, self-rated health, and speed was conducted with two samples, each containing 372 adults between 18 and 87 years of age. The major results were confirmed in both samples. Self-rated health, sensory-motor speed, perceptual speed, and reaction time speed all decreased as age increased, but health only partially mediated the relationship between age and speed. There were direct effects of age on all types of speed in addition to the indirect effects of age on speed through the self-rated health measures, and there were direct effects of age on perceptual speed in addition to the indirect effects through sensory-motor speed.

THERE is growing evidence that speed is an important contributor to the decline in cognitive performance that occurs in many tasks with increased age (c.f., Salthouse, 1992, 1993a). Many reports now exist indicating that the age-related variance in a variety of cognitive tasks, including some memory tasks, is greatly reduced after statistical control of an index of perceptual speed (Hertzog, 1989; Lindenberger, Mayr, & Kliegl, 1993; Salthouse, 1993a, 1993b; Schaie, 1989).

Although speed appears to be important to the relationship between age and various measures of cognition, relatively little is yet known about the sources of the relationship between age and speed. Health status is one possible source, or mediating factor, because health presumably reflects biological factors that affect speed of processing. Evidence concerning the role of health in the relationship between age and cognitive performance has been mixed. Increased age has been reported to be associated with declines in self-rated health status (Perlmutter & Nyquist, 1990), and self-rated health status has been found to be related to cognitive performance, especially for older adults (Field, Schaie, & Leino, 1988; Hultsch, Hammer, & Small, 1993; Perlmutter & Nyquist, 1990). Salthouse, Kausler, and Saults (1990), however, found that statistically controlling for self-rated health status did not greatly attenuate the age-related variance in several cognitive tasks. One possible reason for the inconsistency regarding the influence of health in earlier research may be that the behavioral measures were at too high a level to exhibit direct health-related effects. More pronounced relations may be evident with simpler behavioral measures such as those reflecting the speed of performing elementary tasks. The goal of the present project was to examine this hypothesis using structural equation modeling (i.e., LISREL) methods.

Salthouse (1992, 1993a, 1993b, 1994) distinguishes between sensory-motor speed, reflecting the speed with which a person can perform the sensory-motor aspects of the task such as registering the stimuli and producing simple responses, and perceptual-cognitive speed, corresponding to the speed with which a person can perform tasks containing elementary cognitive components such as substitution or comparison. He found that the relationship between age and perceptual speed was still significant even after controlling for sensory-motor speed, and that the age-related variance in several cognitive measures was attenuated more after control of perceptual speed than after control of motor speed. This pattern is consistent with the view that perceptual speed is composed of sensory-motor processes plus cognitive processes, and that increased age is associated with a slowing of both types of processes.

Because reaction time tasks are frequently used to assess processing speed, this project also involved two reaction time measures in addition to the motor speed and perceptual speed measures derived from paper-and-pencil procedures. The reaction time measures were expected to be correlated with the other speed measures, but no specific direction of influence was hypothesized because of the different methods of assessment (i.e., computer administration of the reaction time tasks and paper-and-pencil administration of the other speed tasks).

If health status does contribute to the age-speed relations, then it is important to identify the factors responsible for this influence. In two large, population-based studies, age has been found to be associated with an increase in hypertension and cardiovascular disease (Dawber, 1980; Mittelmark et al., 1993). We, therefore, postulated that a major determinant of age-related variations in health status was cardiovascular functioning.

Although the use of medication to control hypertension may reduce or eliminate the effects of hypertension on cognition (Farmer et al., 1990), many studies have reported that hypertension and cardiovascular disease are negatively related to cognitive functioning (Elias, Robbins, Schultz, & Pierce, 1990; Elias, Wolf, D'Agostino, Cobb, & White, 1993; Farmer et al., 1990; Franceschi, Tancredi, Smirne, Mercinelli, & Canal, 1982; Hertzog, Schaie, & Gribbon, 1978; Schultz, Elias, Robbins, Streeten, & Blakeman, 1986), and to measures of perceptual speed (Boller, Vrtunski, Mack, & Kim, 1977; Light, 1978; Speith, 1964, 1965). There is also evidence that speed may be more affected by hypertension than are other cognitive abilities (Shapiro, Miller, King, Ginchereau, & Fitzgibbon, 1982; Wilkie, Eisdorfer, & Nowlin, 1976). Van Swieten et al. (1991) present evidence that hypertension in older adults may cause brain damage that causes cognitive decline, including declines in speed. We, therefore, postulated that health and cardiovascular disease would partially mediate the relation between age and speed.

To summarize, the goal of this project was to test hypothesized relations among age, health status, and several measures of speed. The data used in the analyses were originally collected from three studies reported by Salthouse (in press). Because complete data were available from 744 adults, two separate samples were created to cross-validate the model modification process (Breckler, 1990).

METHOD

Subjects

Participants were 744 adults age 18–87 from three separate studies. Two hundred and forty-six of the subjects participated in Study 1 of Salthouse (1994) and 258 participated in Study 2 of that project. An additional 240 subjects participated in Study 1 of Salthouse (in press). All participants were community-dwelling adults recruited through newspaper advertisements (requesting healthy adults) or through community contacts. They were each paid $20 for a 2–3 hour session involving a battery of cognitive tests including the ones discussed here. The total data set was divided into two samples of 372 adults, each containing half of the participants from each study. The mean age of the individuals in Sample 1 was 47.2 (*SD* = 16.5), with 140 subjects below age 40, 127 age 40–59, and 105 age 60 and above. The mean age in Sample 2 was 48.4 (*SD* = 16.8), with 127 adults below age 40, 129 age 40–59, and 116 age 60 and above. Women comprised 63.4% of Sample 1, and 60.2% of Sample 2. Participants in Sample 1 had a mean of 14.4 (*SD* = 2.5) years of education, and those in Sample 2 had a mean of 14.7 (*SD* = 2.4) years.

Measures

Only those measures used in the present study will be described here. (See Salthouse [1994] and Salthouse [in press] for a complete description of the other tasks.) Five constructs were measured: self-rated health, cardiovascular disease, sensory-motor speed, perceptual speed, and reaction time speed. (Gender and education were also included in initial analyses, but neither variable affected the age-speed relations, and thus results with these variables are not reported.) The variables are listed in Table 1.

Health. — Four measures of self-rated health were obtained. A paper-and-pencil demographics questionnaire included three health questions, similar to those used by Krause (1990), that were to be answered using a 5-point scale. These were: "In general, how satisfied are you with your health?" (1 = High, 5 = Low); "How would you rate your health at the present time?" (1 = Excellent, 5 = Poor); and "How much are your daily activities limited in any way by your health or health-related problems?" (1 = High, 5 = Low). Participants also rated their health on a 5-point scale (1 = Excellent, 5 = Poor) in a computer-administered task.

Cardiovascular disease. — The demographics questionnaire also included two questions about cardiovascular disease. These were: "Have you ever had surgery for cardiovascular (heart or artery) problems?" (0 = No, 1 = Yes); and "Are you currently taking medication or under dietary restrictions for high blood pressure, or have you been treated for this condition in the past?" (0 = No, 1 = Yes).

Table 1. Description of Variables

1 Age
2 Health rating 1 (1 = Excellent, 5 = Poor)
3 Health rating 2 (1 = Excellent, 5 = Poor)
4 Satisfaction with health (1 = High, 5 = Low)
5 Health-related activity limitations (1 = High, 5 = Low)
6 Surgery for cardiovascular problems (0 = No, 1 = Yes)
7 Medications or dietary restrictions for cardiovascular problems (0 = No, 1 = Yes)
8 Boxes (no. in 30 sec)
9 Digit Copy (no. in 30 sec)
10 Letter Comparison (no. correct – no. incorrect in 30 sec)
11 Pattern Comparison (no. correct – no. incorrect in 30 sec)
12 Digit Digit (reciprocal of median response time in msec multiplied by 10,000)
13 Digit Symbol (reciprocal of median response time in msec multiplied by 10,000)

Sensory-motor speed. — Sensory-motor speed was assessed with measures from two tests. (See top of Figure 1 for an illustration.) The Boxes Test was a paper-and-pencil test containing 100 open (i.e., three-sided) boxes, with subjects asked to draw a line to complete each box. The score was the number of boxes completed within 30 seconds.

The Digit Copy Test was also a paper-and-pencil test. The test page contained 100 pairs of boxes with a digit in the top box and nothing in the bottom box. The subject copied the digit in the top box into the bottom box, and the score was the number of digits copied in 30 seconds.

Perceptual speed. — Perceptual speed was assessed with the two tests illustrated in the bottom of Figure 1. The Letter Comparison Test contained 21 pairs of letter strings with 3, 6, or 9 items in each string. If the letter strings were the same, the subject was to write an S on the line between them, and if they were different (i.e., a change in the identity of one letter in one member of the pair), a D was to be written on the line. Thirty seconds were allowed for the test, and the score was computed by subtracting the number of incorrect responses from the number of correct responses, in order to correct for guessing.

The Pattern Comparison Test was similar to the Letter Comparison Test, except that the to-be-compared stimuli were pairs of line patterns. The test page contained 60 pairs of line patterns with 3, 6, or 9 line segments per pattern, and 30 seconds were allowed to work on the test. The task was to decide if the pairs were the same or different (i.e., a change in the identity of one line segment in one member of the pair), and to write an S (for same) or a D (for different) on the line between them. The score was the number of incorrect responses subtracted from the number of correct responses.

Reaction time speed. — Two measures of reaction time speed were also obtained from each research participant. (See

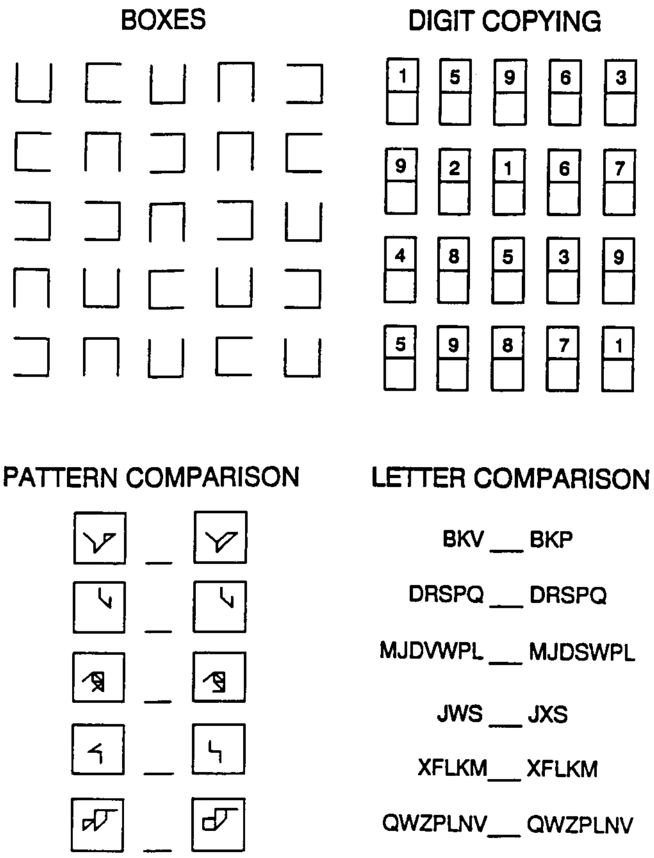

Figure 1. Samples of paper-and-pencil speed tasks. The top two tests were postulated to assess sensory-motor speed, and the bottom two tests perceptual speed.

Figure 2 for an illustration of a sample display in each task.) In the Digit Digit Test, a redundant code table containing pairs of identical digits was presented at the top of the screen, and a probe stimulus containing a pair of digits was presented in the middle of the screen. The subject pressed the "/" key if the digits matched and the "z" key if the digits did not match. Eighteen practice trials were followed by 90 experimental trials (i.e., 10 with each digit). Because average accuracy was over 95%, the dependent variable in both reaction time tasks was the median response time in msec.

In the Digit Symbol Test, the code table contained pairs of digits and symbols, and the probe stimulus contained a digit-symbol pair. If the digit and symbol matched according to the code table, the subject pressed the "/" key, and if they did not match according to the code table then the "z" key was pressed. As in the Digit Digit task, 18 practice trials preceded the 90 experimental trials.

Procedure

Participants were tested in a single session at mutually convenient locations such as a college campus, churches, or homes. The order of presentation for the tasks considered in the present analysis was: Questionnaire, Boxes, Letter Comparison, Pattern Comparison, Digit Copy, Digit Digit, Digit Symbol.

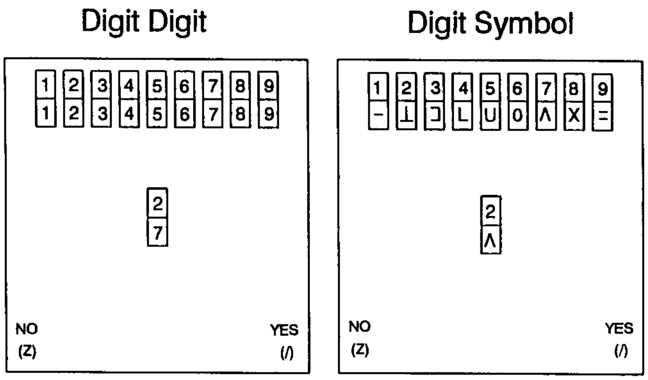

Figure 2. Illustration of sample displays in the reaction time tasks.

RESULTS

The mean, standard deviation, kurtosis, and skew for each variable in each sample are presented in Table 2, and the correlation matrices are contained in Table 3. Kurtosis and skew values are reported to test the assumption of multivariate normality. Kurtosis estimates were between −1.03 and 2.14 for all measures except the cardiovascular disease surgery measure, Digit Digit, and Digit Symbol. The Digit Digit and Digit Symbol reaction time variables were transformed by taking the reciprocal and multiplying by 10,000 in order to decrease the kurtosis and skew of the measures, therefore increasing normality of the distributions. After the transformation, the Digit Digit variable had a kurtosis of −.09 and a skew of −.46 for Sample 1 and a kurtosis of −.14 and skew of −.25 for Sample 2. The Digit Symbol variable had a kurtosis of .46 and a skew of .45 for Sample 1 and a kurtosis of .01 and skew of .34 for Sample 2. Because the measures of cardiovascular disease were dichotomous and had high kurtosis, this construct was not used in the initial model.

Estimates of the reliabilities of the speed measures are contained in Table 4. The immediate reliabilities were based on correlations between alternate forms of the tests administered in the same session for the 240 adults between 18 and 82 years of age in Study 1 of Salthouse (in press). The two-month reliabilities were based on a sample of 39 older adults (58 to 80 years of age) who were re-administered the same tests approximately two months after the original testing.

Age Relations

In order to illustrate the age trends for the speed measures, all measures were converted to z-scores and plotted as a function of age decade in Figure 3. Nonlinear age effects were examined in multiple regression equations with quadratic Age and cubic Age terms entered after the linear Age term. None of the nonlinear effects were significant ($p < .01$) for any of the measures in Sample 1, but the quadratic Age term was significant (and positive in direction) for the Boxes, Digit Copy, and Letter Comparison measures in Sample 2. Because the higher-order effects were restricted to a few measures in one sample, and were associated with rather small increments in variance (i.e., 1.5% for Boxes, 5.4% for Digit Copy, and 3.3% for Letter Comparison), only linear age effects were considered in subsequent analyses.

Table 2. Summary Statistics

	Sample 1				Sample 2			
Variable	Mean	*SD*	Kurtosis	Skew	Mean	*SD*	Kurtosis	Skew
1. Age	47.2	16.5	−1.03	0.29	48.4	16.8	−1.03	0.05
2. Health Rating 1	2.09	0.97	−0.32	0.62	2.07	0.96	−0.13	0.65
3. Health Rating 2	2.31	0.88	−0.26	0.30	2.27	0.90	−0.30	0.32
4. Health Satisfaction	2.34	0.84	0.65	0.51	2.24	0.81	0.66	0.50
5. Health Limit	1.56	0.87	2.14	1.61	1.59	0.86	1.78	1.48
6. Surgery	0.03	0.18	26.4	5.32	0.05	0.23	13.86	3.97
7. Medications	0.19	0.39	0.64	1.62	0.15	0.36	1.75	1.93
8. Boxes	48.8	13.8	0.41	0.22	48.3	13.1	0.02	0.06
9. Digit Copy	51.2	11.4	−0.02	−0.21	52.0	10.5	0.66	−0.43
10. Letter Comparison	9.9	3.3	1.11	−0.29	10.1	3.4	0.79	−0.06
11. Pattern Comparison	15.5	4.0	0.51	0.47	15.6	4.3	−0.16	0.42
12. Digit Digit[a]	822	281	6.88	2.30	791	235	5.98	2.08
13. Digit Symbol[a]	1636	446	1.34	1.06	1612	442	1.37	1.08

Note: Skew and Kurtosis were computed using SAS.

[a]Values reported are for median reaction times in msec before the transformation described in Table 1.

Table 3. Correlation Matrices for Sample 1 (above diagonal) and Sample 2 (below diagonal)

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	—	.19	.20	.14	.24	.06	.29	−.39	−.47	−.45	−.57	−.52	−.57
2	.09	—	.72	.65	.51	.01	.24	−.26	−.29	−.22	−.23	−.22	−.27
3	.12	.75	—	.80	.55	.02	.23	−.28	−.30	−.25	−.21	−.22	−.25
4	.07	.69	.79	—	.54	.00	.17	−.21	−.23	−.19	−.13	−.22	−.23
5	.21	.53	.55	.54	—	.02	.16	−.25	−.27	−.18	−.24	−.20	−.22
6	.25	.17	.22	.15	.22	—	.11	.01	−.12	−.03	−.09	−.07	−.04
7	.29	.23	.28	.21	.26	.30	—	−.24	−.27	−.27	−.23	−.27	−.29
8	−.45	−.19	−.18	−.16	−.15	−.14	−.18	—	.65	.45	.49	.31	.38
9	−.45	−.15	−.16	−.09	−.15	−.21	−.21	.67	—	.56	.51	.39	.42
10	−.38	−.08	−.09	−.02	−.18	−.14	−.20	.35	.46	—	.59	.50	.59
11	−.56	−.09	−.12	−.04	−.23	−.08	−.25	.50	.55	.50	—	.54	.61
12	−.49	−.14	−.17	−.11	−.22	−.14	−.26	.45	.44	.36	.51	—	.72
13	−.58	−.12	−.15	−.10	−.24	−.17	−.27	.44	.47	.47	.60	.72	—

Note: Numbers of variables correspond to those in Table 1. All correlations with an absolute value greater than .13 were significantly ($p < .01$) different from zero.

Table 4. Reliabilities of Speed Measures

	Immediate	2-Month
Boxes	.86	.73
Digit Copy	.86	.70
Letter Comparison	.58	.71
Pattern Comparison	.73	.64
Digit Digit Time	.61	.45
Digit Symbol Time	.93	.85

Note: Immediate reliabilities are correlations between alternate forms. Two-month reliabilities are test-retest reliabilities.

Covariance Structure Modeling

The variance/covariance matrix was analyzed using the LISREL VII maximum likelihood estimation procedure. For each model the chi-square value, degrees of freedom, *p*-value, adjusted goodness-of-fit index, and root-mean-square residual are reported as suggested by Raykov, Tomer, and Nesselroade (1991). The adjusted goodness-of-fit index is a measure of overall fit that takes into account the degrees of freedom, and the root-mean-square residual is based on the average of the unexplained residuals.

Measurement Model

A model with four factors (health, sensory-motor speed, perceptual speed, and reaction time speed) was fit to the data from Sample 1 by allowing covariances among all of the factors. The residual variances of the measures were also estimated, but the residual covariances were fixed at zero. The fit of this model (i.e., M1) was adequate, as indicated in Table 5.

Age was then added to the model. As in the first model (i.e., M1), all of the factors were allowed to intercorrelate. The residual variances were estimated, but the residual covariances were set to zero. As can be seen in Table 5, this model (i.e., M2) also had a satisfactory fit. Thus the hypothesized factor structure fit the data adequately.

Standardized covariances among health, speed, and age are in Table 6. It can be seen that age is associated with

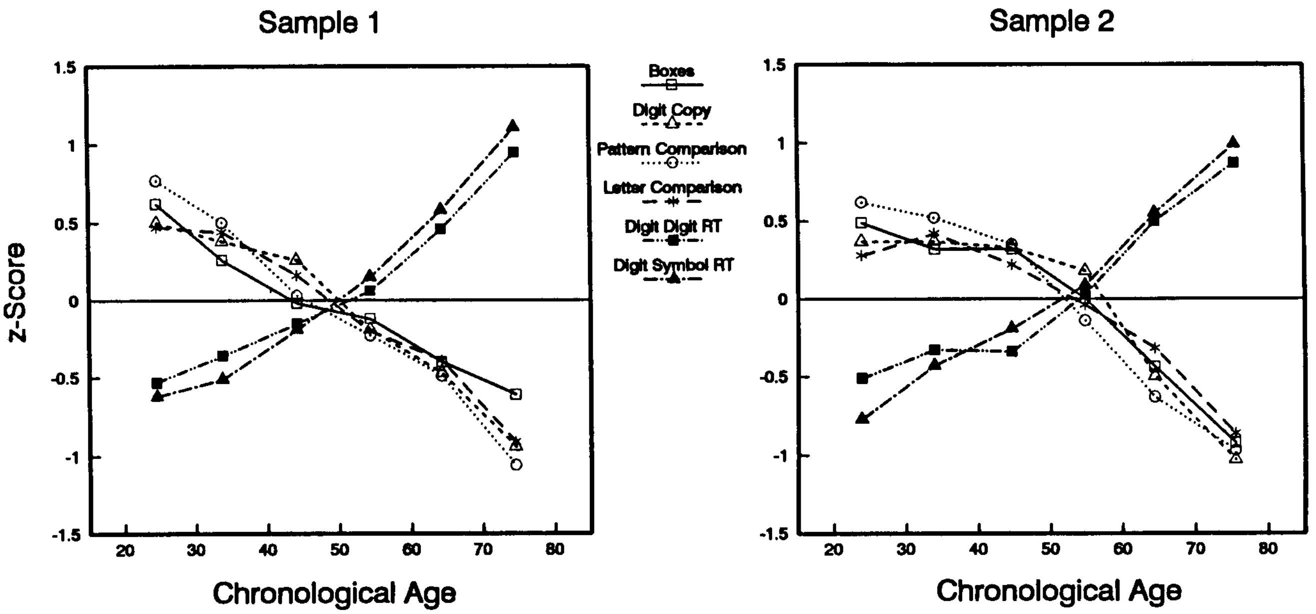

Figure 3. Mean z-scores by decade for the six speed measures in the current project. Each decade is represented by between 39 and 81 individuals in each sample.

Table 5. Summary of Model Fitting for Sample 1

Model	Description	χ^2	df	p-value	AGFI	RMR
M1	Intercorrelated factor structure	40.48	29	.076	.960	.382
M2	Addition of age	54.51	35	.019	.952	.791
N1	Null model	732.56	45	.000	.549	18.25
S1	Basic model (see Figure 4)	54.51	36	.025	.953	.793
	Compare to M2	0.0	1	>.01		
	Compare to N1	678.05	9	<.01		
S2	Add direct path from Health to Pspd	54.51	35	.019	.952	.791
	Compare to S1	0.0	1	>.01		
After Addition of Cardiovascular Disease Factor						
M3	Intercorrelated factor structure	58.38	44	.072	.956	.321
M4	Addition of age	73.23	51	.022	.949	.671
N2	Null model	808.31	66	.000	.576	15.55
S3	Basic model (see Figure 5)	78.60	56	.025	.950	.665
	Compare to M4	5.37	5	>.01		
	Compare to N2	729.71	10	<.01		
S4	Add direct path from Age to Health	75.36	55	.036	.952	.666
	Compare to S3	2.13	1	>.01		
S5	Add direct path from Health to Mspd	76.71	55	.028	.950	.677
	Compare to S3	3.48	1	>.01		
S6	Add direct path from Health to Pspd	78.59	55	.020	.949	.664
	Compare to S3	5.36	1	>.01		
S7	Add direct path from Health to RTspd	78.36	55	.021	.950	.665
	Compare to S3	5.13	1	>.01		
S8	Add direct path from CVD to Pspd	78.40	55	.021	.950	.657
	Compare to S3	5.17	1	>.01		

Notes: AGFI = adjusted goodness-of-fit index; RMR = root-mean-square residual; CVD = cardiovascular disease; Mspd = sensory-motor speed; Pspd = perceptual speed; RTspd = reaction time speed.

Table 6. Intercorrelations Among Age, Health, and Speed

Factor	Mspd	Pspd	RTspd	Health	CVD	Age
Mspd	—	.80	.54	−.38	−.43	−.54
Pspd	.80	—	.85	−.31	−.43	−.67
RTspd	.62	.81	—	−.32	−.44	−.64
Health	−.22	−.15	−.19	—	.33	.22
CVD	−.41	−.43	−.46	.47	—	.40
Age	−.55	−.67	−.63	.12	.48	—

Notes: Standardized covariance estimates of the final measurement model for Sample 1 (above diagonal) and Sample 2 (below diagonal). CVD = cardiovascular disease; Mspd = sensory-motor speed; Pspd = perceptual speed; RTspd = reaction time speed.

slower speed and lower self-rated health, and that the speed measures have high positive correlations with each other.

Structural Model

The basic hypotheses to be tested were that there is a direct effect of age on self-assessed health, and that health then influences sensory-motor speed, which in turn influences perceptual speed. Direct effects of age were also expected on all three speed measures. This structural model (i.e., S1) is shown in Figure 4. The variances of the factors as well as of the indicators were estimated by the model. Two covariances between factors were also estimated (i.e., sensory-motor speed with reaction time speed, and perceptual speed with reaction time speed). All other covariances between factors and between indicators were fixed at zero. The loading of one indicator of each factor was fixed at one (i.e., Digit Copy, Pattern Comparison, Digit Symbol, and Health Rating 2). It can be seen in Table 5 that the model had a satisfactory fit, and did not differ significantly from the measurement model (i.e., M2). The addition of a direct path from health to perceptual speed (i.e., S2) did not significantly improve the fit of the model. The basic model (i.e., S1) fit significantly better than did a null model (i.e., N1) in which all paths between latent constructs were fixed at zero.

Addition of Cardiovascular Disease

Measurement model. — The cardiovascular disease factor was then added to the model. This is a weak construct in the current project because it was assessed with two dichotomous variables in which the number of non-zero values was small (i.e., 12 for surgery and 69 for medical treatment). Furthermore, the surgery measure did not load significantly on the cardiovascular disease factor. Nevertheless, the intercorrelated factor-structure (i.e., M3 in Table 5) had a satisfactory fit, as did the factor structure including age (i.e., M4).

Structural model. — The basic cardiovascular disease model (i.e., S3) is similar to the basic health model (i.e., S1) and is illustrated in Figure 5. The only difference from the basic health model (i.e., S1) is that the effects of age on health and the effects of health on speed are hypothesized to be mediated by cardiovascular disease. As can be seen in Table 5, this model fit the data well. It is not significantly worse than the measurement model (i.e., M4), and it is sig-

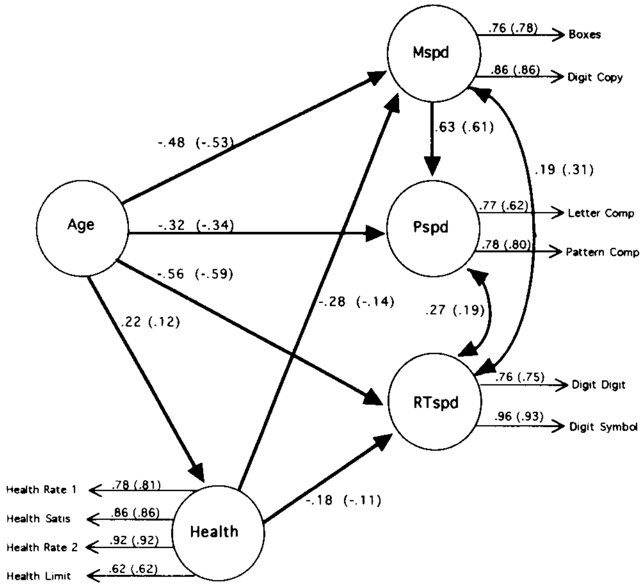

Figure 4. The structural model. Parameters for Sample 1 are on the left, and those for Sample 2 are on the right in parentheses. Path coefficients are from LISREL's completely standardized solution. All paths are significant at $p < .01$ except for the paths from age to health and health to RTspd for Sample 2, which are significant at $p < .05$.

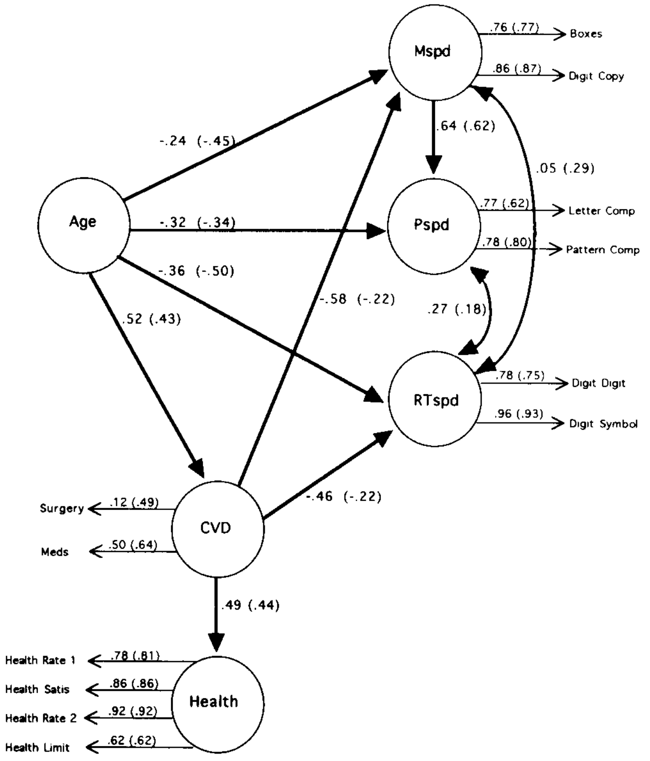

Figure 5. The structural model including cardiovascular disease. Parameters for Sample 1 are on the left, and those for Sample 2 are on the right in parentheses. All paths are significant at $p < .01$ except for the loading of surgery on CVD, the path from age to Mspd, and the covariance of Mspd and RTspd for Sample 1. The path from age to Mspd is significant at $p < .05$.

nificantly better than a null model (i.e., N2) in which all paths between latent constructs were fixed at zero. The only path that was not significant was the covariance between sensory-motor speed and reaction time speed. Furthermore, the path from age to sensory-motor speed was significant at $p < .05$ but not at $p < .01$

The addition of a direct path from age to health (i.e., S4 in Table 5) did not significantly improve the fit of the model. The addition of direct paths from health to the speed factors (i.e., S5, S6, and S7) also did not significantly improve the model. Finally, a direct path from cardiovascular disease to perceptual speed (i.e., S8) did not significantly improve the model. It can therefore be concluded that the model portrayed in Figure 5 cannot be substantially improved by the addition of omitted paths.

Cross-Validation

Following the recommendations of Breckler (1990), the results of Sample 1 were cross-validated using Sample 2. The same sequence of model modifications used for Sample 1 was used to test the models for Sample 2, with the results summarized in Table 7. The basic health model (i.e., S1) and the basic cardiovascular disease model (i.e., S3) fit the data well. As with Sample 1, no additions to either model significantly improved the fit of the model.

Examination of the coefficients in Figures 4 and 5 reveals that the pattern of relations was quite similar in the two samples. The strength of some of the relations varied across samples (e.g., Sensory-Motor Speed with Reaction Time Speed, Perceptual Speed with Reaction Time Speed, and Age with Health), but the discrepancies are quite minor.

Regression Analyses

An additional analytical method was used to confirm the inferences about the relative influence of health on age-related differences in speed. The method consisted of using hierarchical multiple regression equations to determine the proportion of age-related variance in the composite (average of z-scores) speed measure before and after control of the composite (average of z-scores) health index. The variance estimates for the composite sensory-motor speed index before and after control of the composite health index were .227 and .168 respectively for Sample 1, and .245 and .222 respectively for Sample 2, which correspond to reductions of 26.6% in Sample 1 and 9.4% in Sample 2. Comparable values for the composite perceptual speed index were .326 and .272 in Sample 1, and .293 and .276 in Sample 2, for reductions of 16.6% and 5.8%, respectively. Values for the composite reaction time speed index were .302 before control of health and .250 after control of health in Sample 1, and .294 and .270 before and after control of health in Sample 2, which correspond to reductions of 17.2% and 8.2%, respectively. It is apparent from these results that between 73% and 94% of the age-related variance in the composite speed measures was independent of the health measures.

Table 7. Summary of Model Fitting for Sample 2

Model	Description	χ^2	df	p-value	AGFI	RMR
M1	Intercorrelated factor structure	59.62	29	.001	.943	.508
M2	Addition of age	65.62	35	.001	.944	.863
N1	Null model	669.02	45	.000	.572	18.20
S1	Basic model (see Figure 4)	65.97	36	.002	.945	.878
	Compare to M2	.35	1	>.01		
	Compare to N1	603.05	9	<.01		
S2	Add direct path from Health to Pspd	65.62	35	.001	.944	.863
	Compare to S1	.35	1	>.01		
After Addition of Cardiovascular Disease Factor						
M3	Intercorrelated factor structure	80.38	44	.001	.942	.428
M4	Addition of age	89.84	51	.001	.939	.759
N2	Null model	773.70	66	.000	.590	15.51
S3	Basic model (see Figure 5)	95.97	56	.001	.940	.839
	Compare to M4	6.13	5	>.01		
	Compare to N2	677.73	10	<.01		
S4	Add direct path from Age to Health	91.64	55	.001	.942	.824
	Compare to S3	4.33	1	>.01		
S5	Add direct path from Health to Mspd	94.70	55	.001	.940	.773
	Compare to S3	1.27	1	>.01		
S6	Add direct path from Health to Pspd	95.72	55	.001	.940	.833
	Compare to S3	.25	1	>.01		
S7	Add direct path from Health to RTspd	95.71	55	.001	.939	.845
	Compare to S3	.26	1	>.01		
S8	Add direct path from CVD to Pspd	95.94	55	.001	.939	.840
	Compare to S3	.03	1	>.01		

Notes: CVD = cardiovascular disease; Mspd = sensory-motor speed; Pspd = perceptual speed; RTspd = reaction time speed.

DISCUSSION

Both health and speed were found to vary with age, but the age-speed relations were only weakly mediated by health. This is consistent with the results of Salthouse et al. (1990), who found only weak mediation by health of age-cognition relations. Even with a very basic ability (i.e., the speed with which elementary operations can be executed), therefore, health does not account for a large amount of the age-related variance in performance. Although health did have a moderate effect on sensory-motor speed, all of the effects of self-rated health on perceptual speed were indirect and mediated through sensory-motor speed.

Because substantial direct effects of age on speed were evident in addition to the effects mediated by health status, it can be concluded that factors other than self-rated health status are responsible for much of age-related slowing in relatively healthy adults. It is possible that, as Birren (1965; Birren, Woods, & Williams, 1979) has suggested, age-related slowing is a manifestation of primary aging, and is relatively independent of disease. The relations that do exist between self-assessed health status and measures of speed could: (a) reflect weak causal influences of health on speed; (b) be a consequence of a common influence of biological status on both sets of variables, or (c) represent an effect of basing the rating of one's health at least partially on assessments of one's speed of performance. Obviously, additional research is needed to distinguish among these alternatives.

An important feature of the current project was that (as recommended by Breckler, 1990) the model modification procedure was cross-validated in an independent sample to decrease the likelihood of capitalization on chance. Because the same pattern of results was evident in two moderately large samples, the reported relations appear quite robust. The hypothesized model fit the data adequately, and the only significant problem occurred when the cardiovascular disease construct was added to the model. This construct was weak in the current project because few subjects reported cardiovascular problems, and the indicators did not load highly on the factor.

There are several limitations concerning the manner in which health was evaluated in this project. First, one can question the validity of self-reported health status as a measure of objective health. However, it should be noted that self-rated health has been found to relate to physician assessments (LaRue, Bank, Jarvik, & Hetland, 1979), number of prescription medications (Salthouse, Kausler, & Saults, 1990), and longevity (Botwinick, West, & Storandt, 1978; see page 59 in Salthouse (1991) for more relevant citations). Thus, although self-ratings provide a much cruder evaluation of health status than do physician assessments, they are related to more objective measures of health status. Second, an attempt was made to recruit only healthy volunteers, and hence the range of health was undoubtedly restricted relative to the general population. Thus the results of the current study can only be generalized to the relatively healthy adult population. Nevertheless, because significant negative age relations were found with both the health and speed measures, an opportunity did exist for at least some mediational influence.

Although the results with the cardiovascular construct must be considered tentative because of weak assessment of this construct, cardiovascular status may be an important factor in the negative relations between age and self-reported health status, and between self-reported health and speed. Previous research suggested that cardiovascular disease was related to both perceptual speed (Speith, 1964) and higher cognitive functioning (Hultsch et al., 1993). In the current study, almost all of the effects of health on sensory-motor speed were mediated by cardiovascular disease, suggesting that cardiovascular disease may be the aspect of health that contributes to the negative relations between age and speed. This interpretation, however, needs to be investigated more directly with more sensitive and objective measures of health and cardiovascular status before it can be accepted with confidence.

In summary, self-rated health and speed were both negatively related to increased age. However, health only partially mediated the age-related variation in speed, and much of the relation that did exist between health and speed appears to have been mediated by cardiovascular status. The major conclusion from these analyses is that, within this relatively healthy sample of adults, health status was associated with only a relatively small portion of the age-related variance in speed. Additional mechanisms must therefore be identified to account for much of the negative relations between age and speed.

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