

## Shared Age-Related Influences on Cognitive and Noncognitive Variables

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Analyses of new data and of previously published data were conducted to examine the degree to which age-related variance was shared across cognitive and noncognitive variables and to investigate possible alterations in the composition of a factor common to all variables as a function of age. The results indicated that measures of visual acuity, grip strength, and blood pressure shared age-related variance with measures of perceptual speed, episodic memory, spatial visualization, and inductive reasoning. However, although the cognitive variables shared similar amounts of variance in age-restricted and age-partialled analyses, the variance shared between cognitive and noncognitive variables was substantially reduced after controlling the influence of age.

There have been many reports of correlations between cognitive variables and physical variables such as blood pressure, grip strength, and peak expiratory volume in samples of older adults (e.g., Cook et al., 1995; Elias, D'Agostino, Elias, & Wolf, 1995). However, recently there have also been several reports that moderate to large proportions of the age-related variance in assorted cognitive variables are shared with noncognitive variables such as visual acuity, proprioceptive sensitivity, and lower limb strength (e.g., Anstey, Stankov, & Lord, 1993; Anstey, Lord, & Williams, 1997), and measures of vision, hearing, and balance (e.g., Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994; Salthouse, Hancock, Mainz, & Hambrick, 1996).

These latter findings are intriguing in part because the measurement of the noncognitive variables in these studies was often not very sophisticated, and thus the sensitivity may have been low. To illustrate, in the Baltes and Lindenberger (1997), Lindenberger and Baltes (1994), and Salthouse et al. (1996) studies visual acuity was assessed with a near vision chart under ambient light conditions and while the individual was wearing his or her corrective lenses. This type of measure might not be expected to have strong relations with age or with other variables because of the crude manner of assessment. Nevertheless, these measures have been found to be significantly correlated with age (reflecting lower acuity or strength with increasing age) and with measures of cognitive functioning (in the direction of higher cognitive scores when acuity and strength are high). This combination suggests that there may be what Baltes and Lindenberger refer to as a common cause contributing to the age-related differences in both cognitive and noncognitive variables.

One way in which the common cause hypothesis can be investigated is with an analytical model in which the variance that all variables have in common is determined first, and then an estimate of that common factor is controlled when examining relations of age to individual variables (see McArdle & Prescott, 1992). This procedure is conceptually analogous to determining the first principal component in a principal-components analysis based on all variables, and then controlling that component when examining the relations of age to each variable. Although the analyses are conducted within a structural equation framework, the method is probably best viewed as an exploratory technique for distinguishing between shared and unique age-related influences because there is no attempt to account for the interrelations among variables except those involving age. This latter feature also means that the overall fit statistics for the model are not particularly informative because they reflect the degree to which the model represents all of the relations among variables and not simply those involving age.

The top panel of Figure 1 illustrates this model in structural equation terms. The solid lines represent relations that are estimated and are then fixed when examining relations corresponding to the dotted lines. All variables included in the analysis are expected to be related to age, but within this type of model there are three interesting possibilities for individual variables. One possibility is that the variable has a moderate to high loading on the common factor, and no independent age-related effects. An outcome such as this would suggest that all of the age-related influences on the variable are shared with other variables. A second possibility is that the variable has a significant loading on the common factor, and also has independent (direct) age-related influences. This type of outcome would suggest that there is a mixture of both common and unique age-related effects on the variable. Finally, a third possibility is that the variable does not have a significant loading on the common factor, and all of the age-related effects on the variable are direct, and independent of the effects on other variables. If this type of outcome were to be found it would imply that there are no shared age-related influences between that variable and other variables.

Because noncognitive variables have seldom been included

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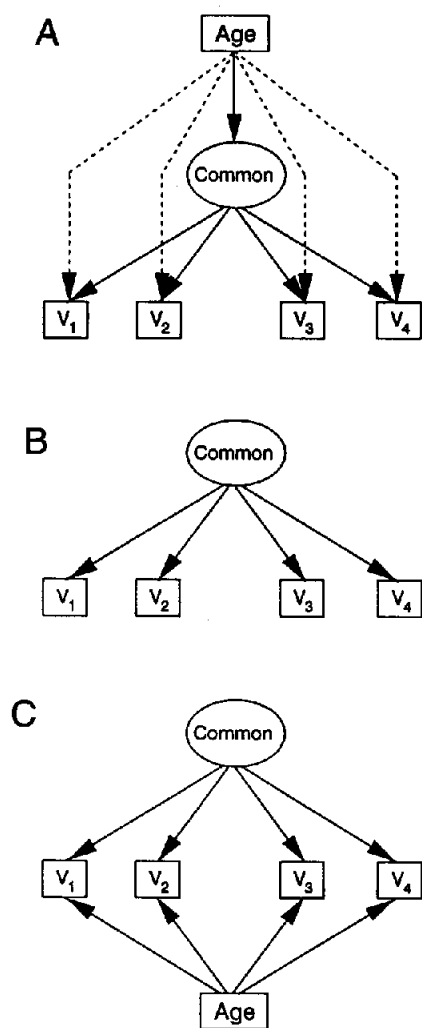


Figure 1. Schematic illustration of a single common factor model (A), a model with only a common factor ignoring age (B), and a model with a common factor after influences of age are partialled out (C). V = variable.

in studies of cognitive aging, many cognitive aging researchers seem to have assumed that separate and independent age-related influences are operating across cognitive and noncognitive variables. In other words, on the basis of the current research practices, it appears that a majority of researchers are operating as though the factors responsible for age-related effects on visual acuity or grip strength are distinct from those responsible for age-related effects on memory, reasoning, and spatial abilities. However, results from several recent studies seem more consistent with the second alternative described previously in that a number of noncognitive variables have been found to share age-related variance with cognitive variables. This phenomenon has recently been reported by Anstey et al. (1993, 1997), Baltes and Lindenberger (1997), and Lindenberger and Baltes (1994). An example within the single common factor analytical framework just described is a study by Salthouse et al. (1996) in

which measures of visual acuity were found to share age-related variance with several different types of cognitive variables.

Because it is not logically necessary that any variable related to age must share age-related variance with other variables that are also related to age, determining which combinations of variables have age-related variance in common is likely to be informative about the primary determinants of age-related effects on many types of variables. Baltes and Lindenberger (1997; Lindenberger & Baltes, 1994) suggested that sensory variables shared age-related variance with cognitive variables because they were additional indicators of brain integrity. Anstey et al. (1997) suggested that strength variables were related to cognitive variables because they also have central nervous system involvement. However, both the sensory and motor assessments used in those studies involve some cognitive aspects in order to comprehend and comply with the instructions and produce an appropriate response. It is therefore possible that at least some of the relations that have been reported are attributable to a cognitive component in all of the variables.

One manner in which this possibility can be investigated is to examine other noncognitive variables, such as blood pressure, that are both age-related, and which can be assessed without any effort on the part of the individual. If cognitive effort or conscious attention is an important factor contributing to the shared age-related effects, then these variables should not be expected to share as much variance with the cognitive measures as sensory and strength variables. A major purpose of the analyses reported here was to explore the range of noncognitive variables that share age-related variance with cognitive variables, and to examine the magnitude of the shared and unique age-related effects in a variety of different variables.

Another goal of the current project was to investigate possible shifts in the composition of the common factor as a function of age. Because the initial studies in which correlations were found between cognitive and noncognitive variables consisted of samples of adults 60 years and older, it is possible that this phenomenon is limited to the period of older adulthood. Indeed, Lindenberger and Baltes (1994) speculated that the connection between sensory and cognitive variables might emerge only in late adulthood.

There are at least two different ways in which possible shifts in the nature of the common factor across age might be investigated. One way is indirect and involves comparing the common-variable relations when age is ignored and also when age is partialled from all variables. These two situations are portrayed in the bottom two panels of Figure 1, with the former in Figure 1B and the latter in Figure 1C. The rationale for this method is that if some of the variables are associated with the common factor merely because of the relation that they and the other variables all have with age, then that association should be greatly reduced by partialing age from each variable. In a sense, then, this method can be viewed as a means of examining the extent to which the common factor might be a third-variable artifact in that the variables are related to one another only because each is related to age.

The second method of investigating possible shifts in the common factor across age consists of directly comparing the coefficients of structural models based on data from groups of

adults of different ages. That is, when the total sample is large enough it can be divided into subsamples on the basis of age and then the magnitudes of the age-common, common-variable, and age-variable relations can be compared to determine which are significantly different from one another. Lindenberger and Baltes (1994) found that the relations were very similar in adults from 70 to 84 and from 85 to 103, but no younger adults were available in that study to examine the comparability of the relations across earlier portions of adulthood.

A two-group comparison of the fit of single common factor structural models for adults under and over the age of 50 was recently reported by Verhaeghen and Salthouse (1997). The data used in those analyses were based on meta-analytically derived correlations extracted from prior studies. The only significant differences in the structural coefficients between the under-50 and 50-and-over groups were: (a) a larger age-common path in the older group, (b) a stronger common-speed path in the older group, and (c) a direct age-speed relation only in the group of younger adults. These results suggest that whatever is contributing to the common factor is operating throughout most of the adult years, and not merely during the period of late adulthood. This is a rather surprising conclusion, and thus another aim of the current project was to attempt to replicate these results with a new sample and different combinations of variables.

Analyses from a number of different data sets are reported in this article. The primary data to be analyzed were obtained from two recent studies primarily designed for other purposes. In addition to the tasks specific to each study, the participants performed four paper-and-pencil speed tests, and tests of matrix reasoning, cube assembly, and free recall. Measures of systolic and diastolic blood pressure were also obtained at both the beginning and end of the testing session, and measures of grip strength in each hand, and near visual acuity in each eye, were collected at the end of the session.

Because several sets of previously published data can be analyzed in a similar manner, the results of those analyses are also reported. One of the data sets was from a study conducted by Salthouse et al. (1996), and four are from studies by Clark (1960), Dirken (1972), and Heron and Chown (1967).

## Method

### Participants

A total of 380 adults between 18 and 87 years of age served as participants. Their descriptive characteristics are summarized in Table 1. It can be seen that there was little age-related variation in self-reported health or educational level, but that scores on the vocabulary tests were higher with increased age. Most of these individuals also performed several computer-administered tasks that are described in two other reports (i.e., Salthouse, Fristoe, McGuthry, & Hambrick, 1998; Salthouse, McGuthry, & Hambrick, 1998).

### Procedure

Each participant had his or her blood pressure assessed before performing the paper-and-pencil tests. After completing the paper-and-pencil tests and some computer-administered tests not described here, blood pressure was assessed again, followed by a test of grip strength and an assessment of visual acuity.

The blood pressure measurements were obtained with a Lumiscope (Model 1090; available from The Lumiscope Company, Edison, NJ) electronic automatic wrist monitor while the participant was seated with his or her left arm resting on a table. The cuff was placed on the left wrist so that it fit snugly, and the air tube was positioned so that it was over the participant's middle finger. After automatically inflating the cuff, the monitor registered heart rate, and systolic blood pressure and diastolic blood pressure in units of mmHg.

The paper-and-pencil tasks were administered in the same order to all participants: background health and education questionnaire, synonym and antonym vocabulary, pattern comparison, letter comparison, number matching, pattern matching, free recall, matrix reasoning, and cube assembly. All but the free-recall test were developed locally. The vocabulary tests consisted of synonym and antonym multiple-choice questions (10 each) with 5 alternatives for every question. A total of 5 min was allowed to complete both tests.

The perceptual speed tests (i.e., pattern comparison, letter comparison, number matching, and pattern matching) all consisted of an instruction page with several examples, and two test pages for each test. A time limit of 30 s was used for each page. The pattern comparison test consisted of 30 pairs of patterns composed of 3-to-9 line segments, and the letter comparison test consisted of 21 pairs of letters with 3-to-9 letters in each member of the pair. Approximately one-half of the pairs

Table 1  
*Descriptive Characteristics of Research Participants*

Variable	Age range (years)											
	18-29 (N = 60)		30-39 (N = 75)		40-49 (N = 77)		50-59 (N = 67)		60-69 (N = 62)		70-87 (N = 39)	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Age (years)	23.4	3.2	34.5	3.0	44.4	2.8	54.1	2.7	65.2	2.7	74.6	4.1
Percentage females	71.7	—	56.0	—	66.2	—	68.7	—	50.0	—	61.5	—
Self-rated health	2.3	0.8	2.2	0.7	2.4	0.8	2.3	0.9	2.2	0.8	2.3	0.8
Educational level	3.5	0.9	3.5	1.1	3.5	1.1	3.6	1.1	3.6	1.1	3.3	1.4
Synonym vocabulary	4.9	2.6	4.8	2.8	6.1	2.8	6.7	2.9	7.2	2.5	7.7	2.7
Antonym vocabulary	4.4	2.5	4.4	3.0	5.4	3.1	5.7	3.4	6.3	3.1	6.2	3.2

Note. Health ratings were made on a 5-point scale where 1 = excellent and 5 = poor. Educational level was reported on a 5-point scale where 1 refers to less than 12 years of education, 2 refers to a high school graduate, 3 refers to 1 to 3 years of college or vocational school, 4 refers to a college graduate, and 5 refers to a graduate degree. Dashes indicate data were not reported.

on each test page were identical, and one-half differed by a single element. The participants were asked to write an *S* on the line between the pairs that were the same, and to write a *D* on the line if the paired items were different. They were instructed to perform the tasks as rapidly and as accurately as possible. The number-matching and pattern-matching tests both consisted of 30 items with a single target and five alternatives. The participants were required to scan the choices, and mark the matching two-digit number or pattern as rapidly and as accurately as possible.

The free-recall test was based on the Rey Auditory Verbal Learning Test (Schmidt, 1996). The test consisted of five study-test trials of a list of 15 words (i.e., *drum, curtain, bell, coffee, school, parent, moon, garden, hat, farmer, nose, turkey, color, house, river*). The words were read by the examiner, in the same order on each trial, at a rate of one word every 2 s. A total of 45 s was allowed for each recall attempt, which was written on a separate page in a booklet.

The matrix reasoning test was similar to the Raven's Progressive Matrices Test (Raven, 1962), and has been described in several earlier articles (i.e., Salthouse, 1993, 1994). Each of the 20 test problems contained a  $3 \times 3$  matrix with geometric patterns in all but the lower right cell, which was blank. Immediately below the matrix was a set of eight response alternatives. The task for the participant was to select the best completion of the matrix from the set of alternatives. Two practice problems were provided with answers, and then 10 min was allowed to complete as many of the 20 problems as possible.

The cube-assembly test consisted of a set of six connected squares that could be assembled into a cube, and was based on a test originally described by Shepard and Feng (1972). One of the six unfolded squares was shaded to represent the base of the cube, and two of the remaining squares contained arrows. The participants were required to decide whether the arrows would point at one another after mentally assembling the cube, and to indicate their decision by marking *Y* for yes and *N* for no. After completing the two illustrated practice problems, 10 min was allowed to complete the 24-item test.

Grip strength was measured using a Smedley Hand Dynamometer (available from The Stoelting Company, Wood Dale, IL). The dynamometer was adjusted for each participant so that the lower joint of the second phalanx of the participant's hand was resting on the edge of the inner stirrup. The participants were instructed to take the dynamometer in their designated hand, point it towards the ground, and squeeze as tightly as possible. After releasing their grip, they were asked to do the same thing with the other hand. This process was repeated for a total of three measurements, recorded in units of kg of force, with each hand.

Visual acuity was assessed using the second edition of the Lighthouse Near Visual Acuity Test, modified ETRDS with Sloan letters (available from Lighthouse Low Vision Products, Long Island City, NY). The testing distance was 40 cm and was maintained with a distance string attached to the stimulus card. The participant was instructed to hold the ball on the end of the distance string between the fingers of his or her left hand, which was also used to cover the left eye. Once the left eye had been covered, the participant was instructed to start by reading the first line of letters on chart one with his or her right eye. Reading continued until two or more errors were made on any line, and the acuity was recorded as the smallest type font (largest Snellen ratio) in which fewer than two errors were made. The card was then turned over, the right eye covered, and chart two was read with the left eye in a similar manner. The participants were also asked how long since their eyes had been checked by an optometrist. The average response was between 12 and 24 months, but this value was not significantly correlated (i.e.,  $r = .08$ ) with the assessed visual acuity.

## Results and Discussion

The primary dependent variables were the number of correct minus the number of incorrect items for the perceptual speed

and cube-assembly variables, the number of correct items in the matrix reasoning test, and the average number of correctly recalled words across the five trials in the free-recall test. Blood pressure and heart rate measures were the average of the values obtained at the beginning and end of the session. The measure of grip strength was the average strength across three measurements with the stronger hand, and visual acuity was assessed in terms of acuity in the better eye.

Table 2 contains a correlation matrix of all variables (with reliabilities in parentheses along the main diagonal). Notice that there were significant age relations on all variables except for the heart rate variable, which consequently was not included in the subsequent analyses of these data. The age correlations were moderately large for the perceptual speed, matrix reasoning, and free-recall variables. The age relations were smaller for the cube-assembly variable, probably because many participants found this test to be quite difficult and had adjusted scores (i.e., number correct minus number incorrect) close to zero. The age correlation for the visual acuity variable was  $-.58$ , which is similar to the correlation of  $-.64$  in the Salthouse et al. (1996) study based on an independent sample of participants and a different vision chart.

Gender effects were also examined on all variables. Men had significantly higher systolic and diastolic blood pressure, grip strength, and cube-assembly scores than women, but women had faster heart rates and higher scores on the number-matching and free-recall tests than men. Most importantly for the current purposes, none of the interactions of age and gender were statistically significant, and thus the age relations can be inferred to be nearly equivalent for men and women.

Figure 2 illustrates the age relations for all variables after conversion to standard score units. The left panel portrays the four noncognitive variables, and the right panel the seven cognitive variables. It can be seen that the age relations were very pronounced for the visual acuity variable, but were less dramatic for the blood pressure and grip strength variables. Among the cognitive variables, the cube-assembly score had smaller age relations than the speed, recall, and reasoning variables. Some of the age relations in Figure 2 appear non-linear. For example, visual acuity appears to remain stable (at a Snellen ratio of approximately .65) from about age 50 on. Non-linear age relations were therefore investigated by entering the age-squared and age-cubed terms after age in regression equations predicting each variable represented in Figure 2. The quadratic (age-squared) relation was significantly different from zero for the systolic and diastolic blood pressure variables and the visual acuity and pattern-matching variables. Only the cube-assembly variable had a significant cubic (age-cubed) age trend. However, because for most variables the proportion of variance associated with the non-linear age trends was fairly small relative to the linear trends, only the linear age trends were considered in the subsequent analyses.

A two-step procedure was followed in the single common factor analysis. First the common-variable and age-common relations were estimated, deleting any relations with coefficients differing from zero by less than two standard errors. Next these parameters were fixed to the estimated values and all age-variable relations were examined, with the relation kept in the model

Table 2  
Correlation Matrix and Estimates of Reliability (N = 380)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Age	—												
2. Systolic BP	.23	(.73)											
3. Diastolic BP	.18	.93	(.77)										
4. Heart rate	-.03	.01	.07	(.97)									
5. Grip strength	-.16	.23	.19	-.17	(.59)								
6. Visual acuity	-.58	-.12	-.13	-.08	.22	(.65)							
7. Pattern comparison	-.50	-.13	-.13	.01	.13	.43	(.79)						
8. Letter comparison	-.48	-.11	-.13	.08	.04	.37	.58	(.80)					
9. Number matching	-.41	-.19	-.18	.05	-.05	.38	.58	.60	(.91)				
10. Pattern matching	-.52	-.11	-.12	-.00	.14	.48	.74	.64	.67	(.83)			
11. Matrix reasoning	-.44	-.10	-.11	-.02	.12	.41	.60	.49	.49	.68	(.86)		
12. Cube assembly	-.23	.02	-.03	-.06	.25	.23	.32	.20	.14	.36	.44	(.72)	
13. Free recall	-.40	-.12	-.14	.02	-.11	.33	.51	.50	.54	.55	.58	.24	(.93)
M	47.3	119.7	80.3	75.4	34.8	0.85	15.7	10.1	26.3	14.6	8.2	4.1	10.4
SD	16.5	13.4	11.7	12.9	11.5	0.34	3.8	3.1	3.9	4.1	4.7	6.9	2.0

Note. Correlations with an absolute magnitude greater than .13 are significantly ( $p < .01$ ) different from zero. Numbers in parentheses along the diagonal are estimated reliabilities. Reliability estimates were derived by boosting the correlation between the two scores by the Spearman-Brown formula for the systolic blood pressure (BP), diastolic blood pressure, heart rate, pattern comparison, letter comparison, pattern matching, and number matching variables. Coefficient alphas were used for the cube assembly and matrix reasoning variables, and the formula  $n(\text{avg. } r)/(1 + [n - 1] \text{ avg. } r)$  was used for the grip strength and free-recall variables, where  $n$  is the number of trials. The reliability estimate for visual acuity was the correlation between the two eyes.

if the coefficient differed from zero by more than two standard errors. The results of this analysis are illustrated in Figure 3 where it can be seen that all variables were related to the common factor. The relations were weak for the grip strength and blood pressure variables, but all of the common-variable relations were significantly different from zero. Only the visual

acuity and systolic blood pressure variables had age-related effects that were independent of the influences through the common factor. In both cases the independent age-related effects increased the magnitude of the age relations on the variable compared to the effect mediated through the common factor. For example, the predicted age-vision relation through the common

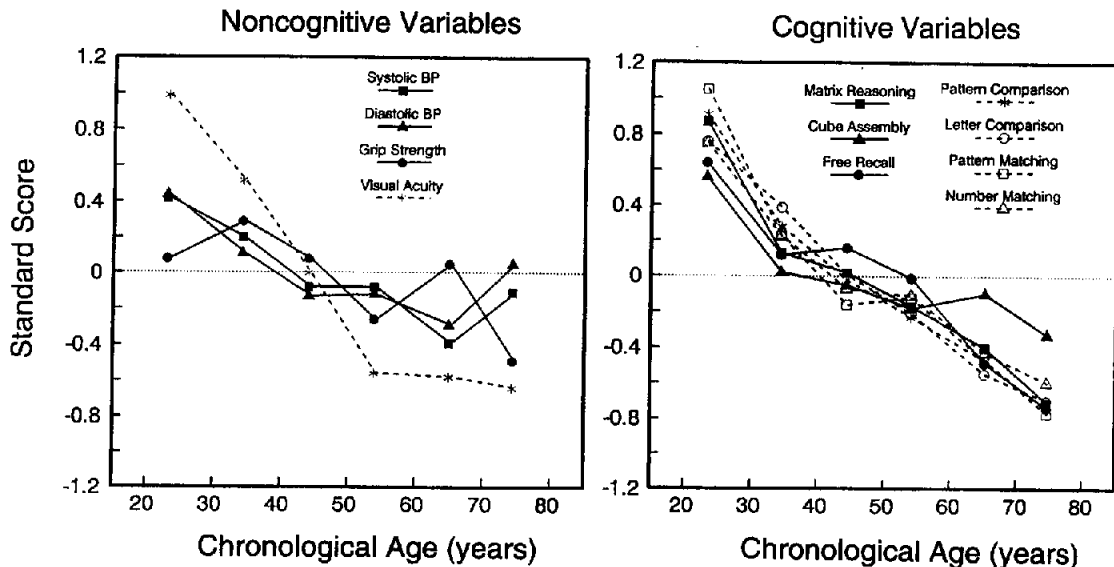


Figure 2. Mean standard scores for the four noncognitive (left panel) and seven cognitive (right panel) variables as a function of age. Because blood pressure (BP) increased with age, the signs of the scores for the blood pressure measures were reversed so that the direction of the age trends would be the same for all variables.

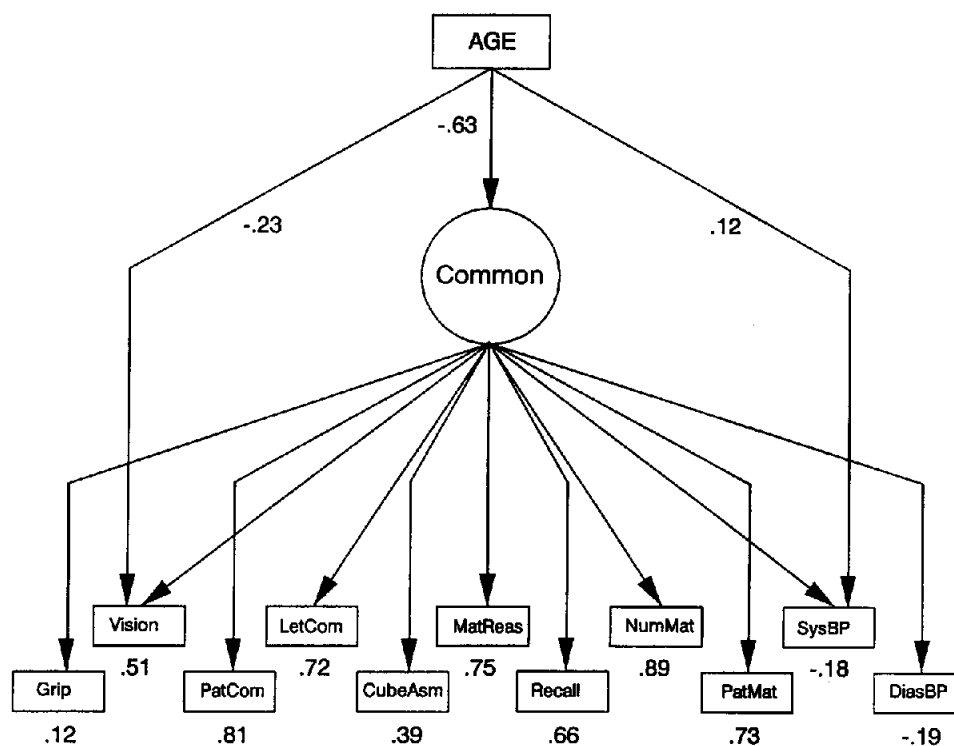


Figure 3. Single common factor structural model for the primary data. PatCom = pattern comparison; LetCom = letter comparison; CubeAsm = cube assembly; MatReas = matrix reasoning; NumMat = number matching; PatMat = pattern matching; SysBP = systolic blood pressure; DiasBP = diastolic blood pressure.

factor was  $-.32$  (i.e.,  $-.63 \times .51$ ), but with the addition of the direct age–vision path of  $-.23$  the total predicted age-related effect of  $-.55$  closely approximated the actual age–vision correlation of  $-.58$ .

The fit statistics for the model represented in Figure 3, and all other models examined in this article, are summarized in Table 3. It can be seen that the model had a poor fit to the entire data set, which was not unexpected because all relations among variables except those involving age were ignored. In order to examine a model with a more complex structure among variables an exploratory factor analysis (promax rotation) was carried out on the variables represented in Figure 3. The results of this analysis are summarized in Table 4, where it can be seen that three factors emerged, which can be tentatively labeled Cognitive, Blood Pressure, and Sensory-Motor. The pattern of loadings on the variables was a little surprising because the cube-assembly spatial test had a higher loading on the Sensory-Motor factor than on the Cognitive factor, and the vision variable had nearly equal loadings on the Cognitive and Sensory-Motor factors. Nevertheless, the structure seemed reasonably coherent and thus these results formed the basis for the hierarchical model illustrated in Figure 4. Note that three first-order factors are postulated to be responsible for the variation in the observed variables, and the first-order factors are in turn postulated to be influenced by the common factor. (Other relations among variables and first-order factors suggested by the results in Table 4 were tested but found not to be significant.)

Two major points should be noted about the model portrayed in Figure 4. The first is that when a greater amount of structure is allowed among the variables, the fit of the model is substantially better than when the models only represent relations involving age (cf. Table 3). As noted previously, this is not surprising because the fit statistics indicate the degree to which the model accounts for all of the observed covariances and not merely the subset involving age. The second important point to note about Figure 4 is that even with this elaborated structural model a very large portion of the age-related influences is shared among all of the variables. In fact, in this model none of the direct relations from age to any of the first-order factors or to any of the observed variables were significantly different from zero.

The next set of analyses compared the fit of separate single common factor models for adults between 18 and 49 years of age ( $n = 212$ ) and adults between 50 and 88 years of age ( $N = 168$ ). The coefficients for these models are portrayed in Figure 5, with those for the younger group to the left or above those for the older group. The models for the separate age groups differed in two respects from the model for the entire sample (portrayed in Figure 3). Neither the relation between the common factor and grip strength nor that between the common factor and systolic blood pressure was significantly different from zero in the samples with a narrower age range. A simultaneous two-group analysis was conducted to determine which coefficients differed significantly between groups (see Byrne,

Table 3  
Fit Statistics for Structural Equation Models

Model	$\chi^2/df$	CFI	NNFI	Std. RMR
Current study				
Figure 3	987.28/63	.63	.62	.13
Figure 4	213.92/50	.94	.91	.07
Two-group model	1,047.51/117	.56	.50	.16
Age-ignored	932.11/44	.61	.51	.13
Age-partialed	943.97/44	.64	.47	.12
Salthouse et al. (1996)				
Two-group model	434.44/141	.68	.65	.13
Age-ignored	393.34/54	.69	.62	.10
Age-partialed	330.14/54	.78	.68	.08
Clark (1960)				
Figure 6	207.42/63	.72	.70	.13
Age-ignored	158.15/44	.70	.63	.11
Age-partialed	140.14/44	.81	.72	.08
Dirken (1972)				
Figure 6	643.02/130	.70	.69	.11
Age-ignored	461.94/104	.71	.67	.08
Age-partialed	322.38/104	.87	.84	.06
Heron & Chown (1967) males				
Figure 7	304.22/61	.86	.85	.10
Age-ignored	225.76/44	.87	.84	.06
Age-partialed	199.64/44	.91	.86	.05
Heron & Chown (1967) females				
Figure 7	314.92/60	.81	.80	.13
Age-ignored	274.75/44	.80	.75	.09
Age-partialed	215.97/44	.88	.81	.06

Note. CFI = Comparative Fit Index; NNFI = Non-Normed Fit Index; Std. RMR = standardized root mean square residual.

1994). This was done by first constraining all coefficients corresponding to the relations illustrated in Figure 5 to be equal across the two groups, and then using the Lagrange Multiplier Test to determine which constraints were implausible in the sense that the fit of the model was significantly improved by allowing the coefficients to be freely estimated in each group. The results revealed that only the age-vision coefficient could not be constrained to be equal in the two groups without a loss in fit. It can be seen in Figure 5 that the direct relation between age and vision was  $-.34$  in the 18-to-49 group, but only  $.03$  (not significantly different from zero) in the 50-to-88 group. This difference is probably attributable to the smaller relation between age and visual acuity after age 50 evident in Figure 2.

The final analyses of the primary data consisted of comparing the magnitude of the common-variable relations when age was ignored (as in Figure 1B), and when the age influence was partialled from every variable (as in Figure 1C). The standardized coefficients from the two analyses along with the percentage reductions in absolute value and in proportions of variance are presented in Table 5. There are two important features to note in this table. The first is that three of the variables, grip strength and the two blood pressure variables, no longer had a significant relation to the common factor after partialling the influence of age from all variables. The second interesting point to note in Table 5 is that all of the noncognitive variables, including the visual acuity variable, had substantially larger reductions in the common-variable relations after partialling age than did the

cognitive variables. That is, the percentage reductions of the absolute values ranged from 16.8% to 24.9% for the cognitive variables, but from 57.8% to 84.5% for the noncognitive variables (i.e., visual acuity, grip strength, systolic blood pressure, and diastolic blood pressure). The percentage reductions in terms of proportions of variance, corresponding to the differences between the squared coefficients, ranged from 30.8% to 43.6% for the cognitive variables, but from 82.2% to 97.4% for the noncognitive variables. These two sets of results therefore suggest that although the cognitive variables tend to have a similar relation to the common factor independent of age, moderate to large proportions of the relation for noncognitive variables seem to be attributable to the relation that all variables have to age.

A major finding of this study was that all of the variables that were related to age were also related to the factor representing what the variables had in common, and when that common factor was controlled there were few independent age-related effects on any variables. The cognitive variables generally had similar, albeit somewhat weaker, relations to the common factor when age was partialled, and when the analyses were based on samples with narrower age ranges. However, this was not the case for the noncognitive variables because the common-variable relations for the systolic and diastolic blood pressure and grip strength variables were substantially reduced in the two sub-samples with smaller age ranges, and in the analysis on the age-partialed data. A similar trend was evident in the visual acuity variable, but it was not as pronounced as the other noncognitive variables.

Table 4  
Results of Exploratory Factor Analysis (Promax Rotation) on Variables From Primary Data

Variable	Factor		
	Cognitive	BP	Sensory-Motor
Pattern matching	.872	-.141	.365
Pattern comparison	.800	-.157	.322
Number matching	.780	-.194	.039
Letter comparison	.774	-.131	.120
Free recall	.770	-.152	.060
Matrix reasoning	.762	-.117	.443
Cube assembly	.347	-.021	.707
Systolic BP	-.180	.973	.126
Diastolic BP	-.184	.978	.078
Grip strength	-.015	.228	.801
Vision	.532	-.183	.488
Proportion of variance	.397	.182	.106
Cumulative proportion of variance	.397	.579	.684
Correlations			
Age	-.567	.237	-.348
Cognitive	—	-.210	.253
BP	—	—	.089

Note. BP = blood pressure.

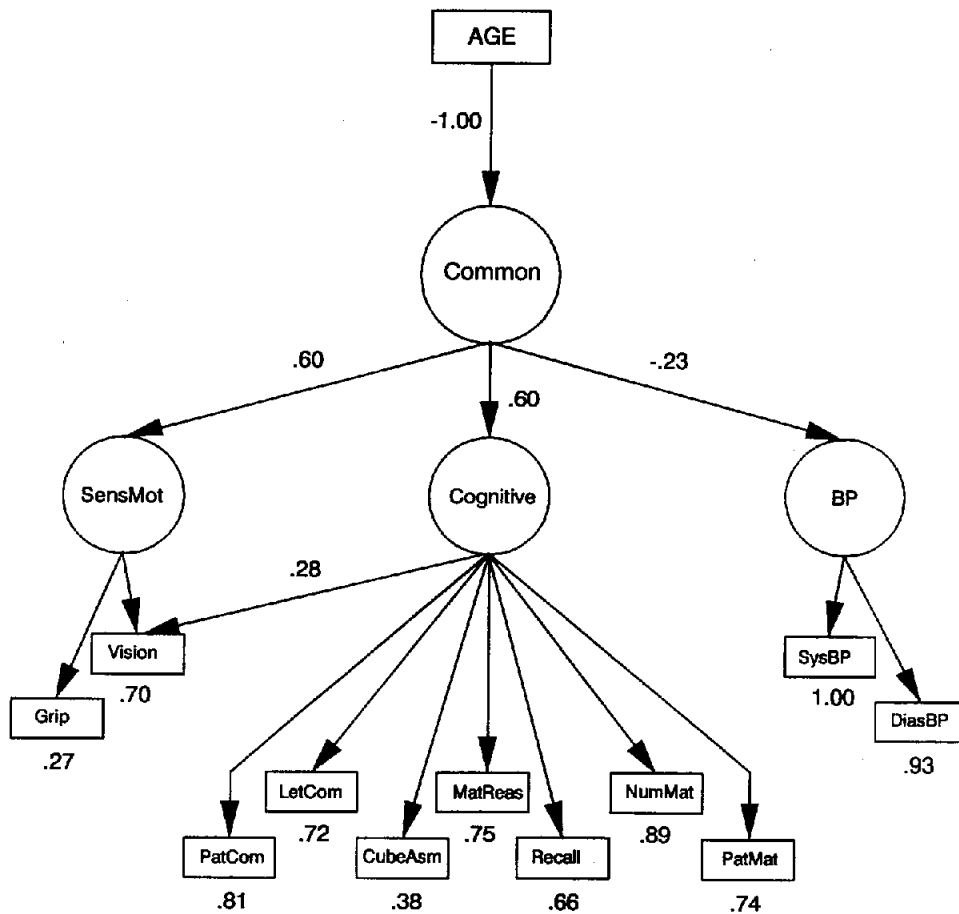


Figure 4. Hierarchical structural model for the primary data. SensMot = sensory-motor factor; PatCom = pattern comparison; LetCom = letter comparison; CubeAsm = cube assembly; MatReas = matrix reasoning; NumMat = number matching; PatMat = pattern matching; SysBP = systolic blood pressure; DiasBP = diastolic blood pressure.

Analyses of Other Data

The major goal of the analyses of data from other projects was to determine whether the results just described would be replicated in data from different samples of individuals and variables. Specifically, would the same pattern of robust common-variable relations for cognitive variables but attenuated relations for noncognitive variables after control of age be found in other data sets?

*Salthouse et al. (1996)*

The single common factor model reported in the Salthouse et al. (1996) article was based on the complete sample of participants from 18 to 87 years of age. However, because the raw data were still available it was possible to compare models based on adults under ( $n = 96$ ) and over ( $n = 101$ ) the age of 50. The two models were qualitatively similar, and in each the relations between the common factor and all variables were significantly different from zero. A simultaneous two-group

analysis following the same procedures described earlier revealed that the only significant difference between the models for each sample was that the direct age-vision relations were weaker, and not significantly different from zero, in the 50-and-over group (i.e.,  $-.12$  and  $-.07$ ) than in the under-50 group (i.e.,  $-.36$  and  $-.33$ ). It should be noted that this is the same pattern observed in the analyses of the primary data reported previously.

The common-variable coefficients before and after partialing age are presented in Table 6. It can be seen that the absolute reductions after partialing age were 61.5% and 63.8% for the two vision variables, but the median reduction was only 20.9% for the cognitive variables. Similar discrepancies were apparent in the reductions in variance as the reductions were 86.9% and 85.1% for the two vision variables, but the median for the cognitive variables was only 36.8%.

*Previously Published Correlation Matrices*

Some of these same kinds of analyses can be conducted on data reported as correlation matrices in previously published



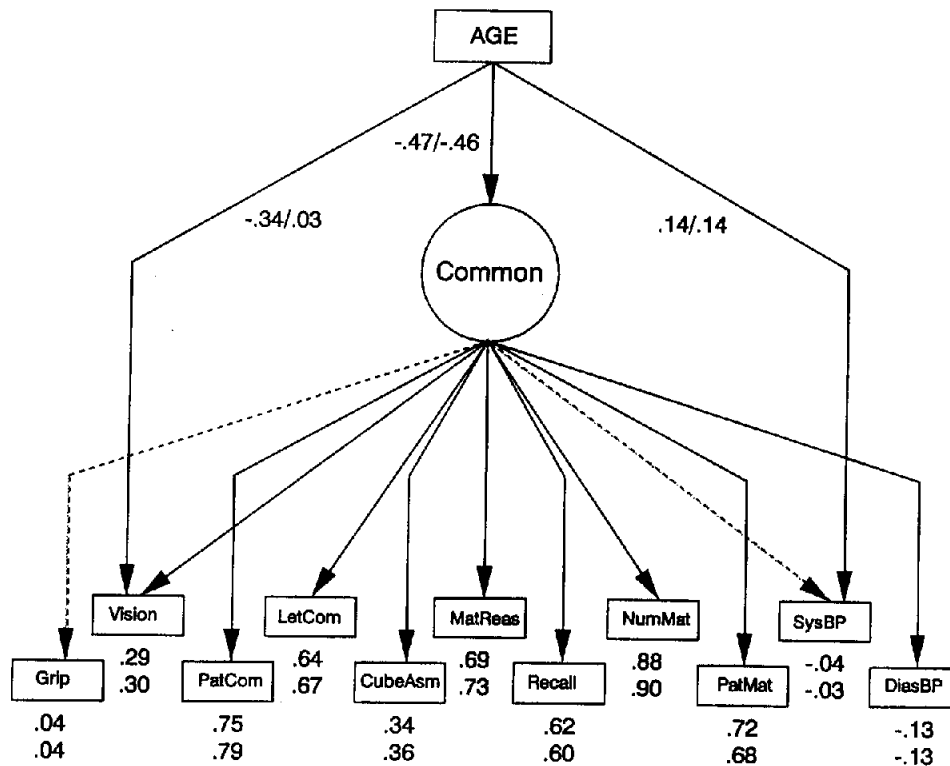


Figure 5. Single common factor structural model for adults between 18 and 49 years of age (first coefficient in each pair) and for adults between 50 and 87 years of age (second coefficient in each pair) in the primary data. The dotted lines represent paths that were significantly different from zero in the overall sample but not in either of the two groups with narrower age ranges. PatCom = pattern comparison; LetCom = letter comparison; CubeAsm = cube assembly; MatReas = matrix reasoning; NumMat = number matching; PatMat = pattern matching; SysBP = systolic blood pressure; DiasBP = diastolic blood pressure.

articles. Caution is needed when interpreting the results of structural equation analyses based on correlation matrices rather than on raw data or covariance matrices because the estimated relations in the models may be distorted and the fit statistics can be misleading (see Cudek, 1989), but they can still be informative when interpreted cautiously. Four data sets are particularly relevant for the current purposes; Clark (1960), Dirken (1972), and separate samples of men and women in Heron and Chown (1967). The samples, and variables included in the current analyses, are described in the Appendix.

The results of the single common factor analyses on these four data sets are portrayed in Figures 6 and 7. It can be seen that there was considerable shared age-related variance across all variables, as well as independent age-related influences on some variables. In the Clark (1960) data the measures of vision, hearing, grip strength, and systolic blood pressure were all related to the common factor, but only the vision and systolic blood pressure variables had independent age-related effects. In the Dirken (1972) data all variables were related to the common factor, and there were independent age-related effects on several cognitive variables as well as on the heart rate variable. There were no independent age-related influences

on the vision, hearing, grip strength, or systolic or diastolic blood pressure variables in this data set. All variables were related to the common factor in both the male and female data sets from the Heron and Chown (1967) study. Independent age-related effects were evident on the systolic blood pressure and forced expiratory volume variables in both data sets, and also on the vision and hearing variables in the female data. Although the results based on separate analyses of the men and women in the Heron and Chown (1967) study were slightly different, a simultaneous two-group analysis revealed that all of the coefficients could be constrained to be equal without a significant loss in fit.

The coefficients for the common-variable relations for the analyses before and after partialing age are presented in Table 6. As in the earlier analyses, statistical control of the age-related variance resulted in a greater reduction of the common factor relations for the noncognitive variables than for the cognitive variables. Specifically, the median percentage reduction of the absolute values after partialing age for the 27 cognitive variables in the Clark (1960), Dirken (1972), and Heron and Chown (1967) analyses was 20.1%, but it was 69.4% for the 22 noncognitive variables (i.e., vision, hearing, grip strength, forced expi-

Table 5  
Standardized Coefficients for Common-Variable Relations  
Ignoring Age and Partialing Age

Variable	Ignore age (Figure 1B)	Partial age (Figure 1C)	% Reduction	
			Absolute	Proportion of variance
Cognitive				
Number matching	.895	.731	18.3	33.3
Pattern comparison	.809	.635	21.5	38.4
Matrix reasoning	.751	.605	19.4	35.1
Pattern matching	.738	.614	16.8	30.8
Letter comparison	.719	.540	24.9	43.6
Free recall	.658	.528	19.8	35.6
Cube assembly	.385	.304	21.0	37.7
Noncognitive				
Vision	.531	.224	57.8	82.2
Diastolic BP	-.176	-.070*	60.2	84.2
Systolic BP	-.168	-.026*	84.5	97.6
Grip strength	.111	.018*	83.8	97.4

*Note.* The column labeled % *Reduction absolute* contains the difference between the third and second columns divided by the second column. The column labeled % *Reduction variance* is the difference in the variance estimates (i.e., squares of the coefficients) from the second and third columns divided by the square of the value in the second column. BP = blood pressure; \* = not significantly different from zero.

ratory volume, systolic and diastolic blood pressure, and heart rate). Medians of the percentage reductions in variance were 36.1% for the cognitive variables and 86.1% for the noncognitive variables. Furthermore, the age-partialled common-variable relation was not significantly different from zero for 9 of the 22 noncognitive variables, but for only 1 of the 27 cognitive variables.

### General Discussion

Consistent with several previous reports (e.g., Salthouse, 1993, 1994; Verhaeghen & Salthouse, 1997), the current analyses revealed that most of the age-related variance across many cognitive variables was shared. In fact, in the primary data set there were no independent age-related influences on any of the perceptual speed and cognitive variables, despite zero-order age correlations ranging in absolute magnitude from .23 to .52. These results suggest that after taking into consideration the age-related effects on what the variables have in common, there is little or no evidence of unique age-related effects on individual cognitive variables. The current results, and those of Verhaeghen and Salthouse (1997), also suggest that the common factor is surprisingly stable across most of the adult years. That is, because the loadings of the variables on what is common to all variables were qualitatively and quantitatively similar in groups under and over the age of 50, and before and after partialing age from the variables, it appears that the composition of what is shared among all variables changes little, if at all, as a function of age.

The finding that noncognitive variables also share age-related

variance with cognitive variables is similar to several recent reports (e.g., Anstey et al., 1993, 1997; Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994; Salthouse et al., 1996). There was some variation across data sets with respect to the specific variables with independent age-related influences, which could be related to the particular combination of variables included in the analyses, to characteristics of the sample, or to other unknown factors. Regardless of the reasons for the variation, however, it is important to note that a consistent finding across all of the analyses is that large proportions of the age-related effects on many cognitive and noncognitive variables are shared.

How is the phenomenon of large proportions of shared age-related influences across cognitive and noncognitive variables to be explained? Before accepting interpretations based on speculations about neurophysiological processes or neuroanatomical structures that might be involved in both types of variables, it is important to consider the possibility that at least some of the relations could be an artifact of the relation that all variables have with age. Two analyses in the primary data are relevant to this possibility. First, when the analyses were conducted on samples restricted to adults above and below the age of 50 years, the grip strength and systolic blood pressure variables no longer had significant relations with the common factor, and the strengths of the relations were reduced relative to those in the total sample for the diastolic blood pressure and vision variables. And second, when the common-variable relations were compared before and after partialing the age-related variance in the variables, the relations were substantially reduced for the noncognitive variables, and were no longer significantly different from zero for the grip strength and blood pressure variables. A similar pattern was apparent in the analyses of the other data sets. In particular, although the common-variable relations for the cognitive variables were reduced when age was partialled, the percentage reduction was much smaller than with the noncognitive variables.

A tentative conclusion from the results just described is that within the range of about 18 to 80 years of age much of the age-related influences of noncognitive variables that are shared with cognitive variables may be spurious, and attributable to the relation that all variables have with age. It is not clear whether this conclusion is true to the same extent for the vision variables as for the other noncognitive variables. On the one hand, the common-vision relations were still significantly different from zero in the samples with restricted age ranges and in the age-partialled analyses in the primary data and in the Salthouse et al. (1996) data. On the other hand, the percentage reduction in the common-vision relations after partialing age in all data sets was much larger than with the cognitive variables, and comparable to that with the other noncognitive (i.e., grip strength, forced expiratory volume, and blood pressure) variables.

Although there may be questions about the relation of the noncognitive variables to the common factor, the relations of the cognitive variables to the common factor were much less affected by controlling for variation in age. The question of why scores on quite different types of cognitive tests tend to be related to one another has puzzled researchers at least since

Table 6  
*Standardized Coefficients for Common-Variable Relations Ignoring Age and Partialing Age*

Variable	Ignore age (Figure 1B)	Partial age (Figure 1C)	% Reduction		Variable	Ignore age (Figure 1B)	Partial age (Figure 1C)	% Reduction	
			Absolute	Proportion of variance				Absolute	Proportion of variance
Salthouse et al. (1996)					Dirken (1972)				
Cognitive					Noncognitive				
Digit symbol RT	.835	.577	30.9	52.2	ExpirVol	.658	.168	74.5	93.5
Pattern comparison	.723	.425	41.2	65.4	Pitch	.593	.169	71.5	91.9
Letter comparison	.712	.504	29.2	49.9	Grip strength	.576	.247	57.1	81.6
N-back 1	.662	.757	-14.4	-30.8	Heart rate	.544	.026*	95.2	99.8
Digit digit RT	.646	.418	35.3	58.1	Audio	-.435	-.193	55.6	80.3
N-back 2	.626	.756	-20.8	-45.8	Vision	.411	.033*	92.0	99.4
Assoc. percentage correct	.573	.501	12.6	23.6	Diastolic BP	-.099	.015*	115.2	97.7
WCST	.489	.486	0.6	1.2	Systolic BP	-.067	.072*	207.5	-15.5
Noncognitive					Heron and Chown (1972) men				
Visual acuity-left eye	.578	.209	63.8	86.9	Cognitive				
Visual acuity- right eye	.550	.212	61.5	85.1	Matrices	.883	.596	32.5	54.4
Clark (1990)					Trails	.789	.597	24.3	42.7
Cognitive					DigCode	.769	.569	26.0	45.3
PMA reasoning	.791	.610	22.9	40.5	Mazes	.689	.425	38.3	62.0
RT	-.691	-.477	31.0	52.3	DspanA	.576	.596	-3.5	-7.1
PMA space	.677	.580	14.3	26.6	DspanV	.522	.562	-7.7	-15.9
Recall	.657	.525	20.1	36.1	Noncognitive				
Letter speed	.651	.433	33.5	55.8	Grip strength	.657	.396	39.7	63.7
Maze time	-.585	-.546	6.7	12.9	ExpirVol	.645	.211	67.3	89.3
Word latency	-.439	-.177*	59.7	83.7	Hearing	.513	.268	47.8	72.7
Noncognitive					Systolic BP	.435	.106	75.6	94.1
Vision	-.516	-.040*	92.2	99.4	Vision	.425	.176	58.6	82.9
Hearing	-.486	-.048*	90.1	99.0	Heron and Chown (1972) women				
Systolic BP	-.436	.071*	116.3	97.3	Cognitive				
Grip strength	.226	.201*	11.1	20.9	Matrices	.894	.739	17.3	31.7
Dirken (1972)					DigCode	.841	.696	17.2	31.5
Cognitive					Trails	.786	.604	23.2	40.9
CatMed RT	-.707	-.736	-4.1	-8.4	Mazes	.592	.503	10.5	19.8
RT4	-.632	-.332	47.5	72.4	DspanA	.503	.515	-2.4	-4.8
PictRec	.617	.365	40.8	65.0	DspanV	.475	.538	-13.3	-28.3
CatAcc	-.509	-.772	-51.7	-130.0	Noncognitive				
Concent	.508	.477	6.1	11.8	ExpirVol	.644	.272	57.8	82.2
DspanD	.389	.478	-22.9	-51.0	Grip strength	.601	.381	36.6	59.8
Tapping	.295	.210	28.8	49.3	Hearing	.481	.214	55.5	80.2
Position	.323	.117	63.8	86.9	Vision	.459	.221	51.9	76.8
					Systolic BP	.362	.042*	88.4	98.7

*Note.* The columns labeled % Reduction Absolute contain the difference between the third and second columns divided by the second column. The columns labeled % Reduction Variance are the difference in the variance estimates (i.e., squares of the coefficients) from the second and third columns divided by the square of the value in the second column. RT = reaction time; N-back = report item *N* back in the square; Assoc. = associative memory; WCST = Wisconsin Card Sorting Test; PMA = primary mental abilities; \* = not significantly different from zero; BP = blood pressure; CatMedRT = reaction time for classifying words into categories; PictRec = identification of incomplete drawings of familiar objects; Concent = seeing groups of three, four, or five dots, and instructed to do nothing with three dots, draw horizontal line with four dots, and draw vertical line with five dots (score is number completed in a fixed time); DspanD = Digit span (auditory pronunciation) with 15-s delay; ExpirVol = expiratory volume; DigCode = digit code; DspanA = digit span for auditorily presented digits; DspanV = digit span for visually presented digits.

the time of Spearman (1927). Among the possibilities for this phenomenon are that the commonality is attributable to particular neurotransmitters (e.g., quantity of dopamine, on the basis of similarities between deficits associated with aging and with Parkinson's disease; cf. Gabrieli, 1991), neuroanatomical struc-

tures (e.g., the frontal lobe, cf. West, 1996), or cognitive processes (e.g., controlled attention, cf. Hasher & Zacks, 1979; Jennings & Jacoby, 1993). The analyses reported here cannot distinguish among these alternatives, but along with other recent reports they provide a strong case that the level at which many

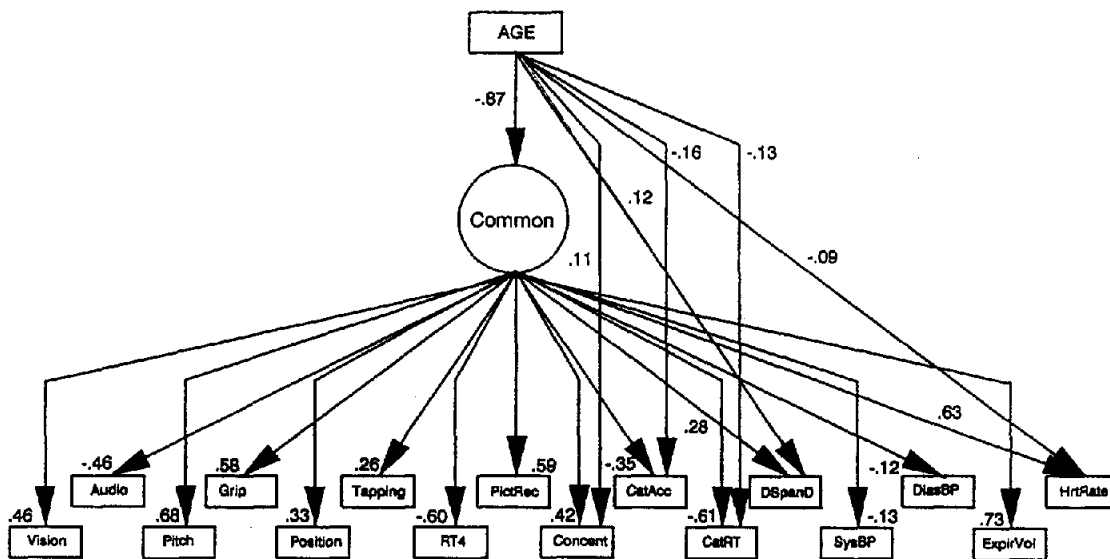
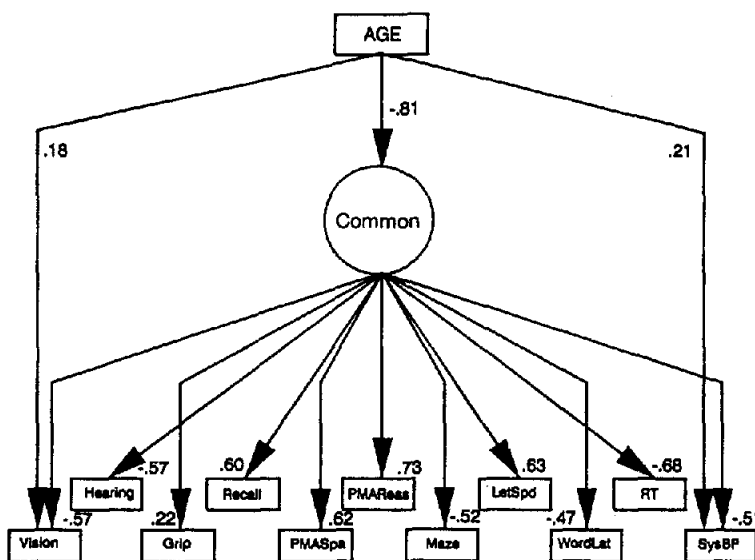


Figure 6. Single common factor structural model for data from Clark (1960; top) and Dirken (1972; bottom). PMA Spa = PMA Space Test; PMA Reas = PMA Reasoning Test; LetSpd = speed of letter comparison; WordLat = word association latency to 20 common words; RT = reaction time; SysBP = systolic blood pressure; RT4 = choice reaction time with four stimulus-response alternatives, median of five trials; PictRec = identification of incomplete drawings of familiar objects; Concent = seeing groups of three, four, or five dots, and instructed to do nothing with three dots, draw horizontal line with four dots, and draw vertical line with five dots (score is number completed in a fixed time); CatAcc = accuracy of classifying words into categories; CatRT = reaction time when classifying words into categories; DspanD = digit span (auditory pronunciation) with 15-s delay; DiasBP = diastolic blood pressure; ExpirVol = expiratory volume; HrtRate = heart rate.

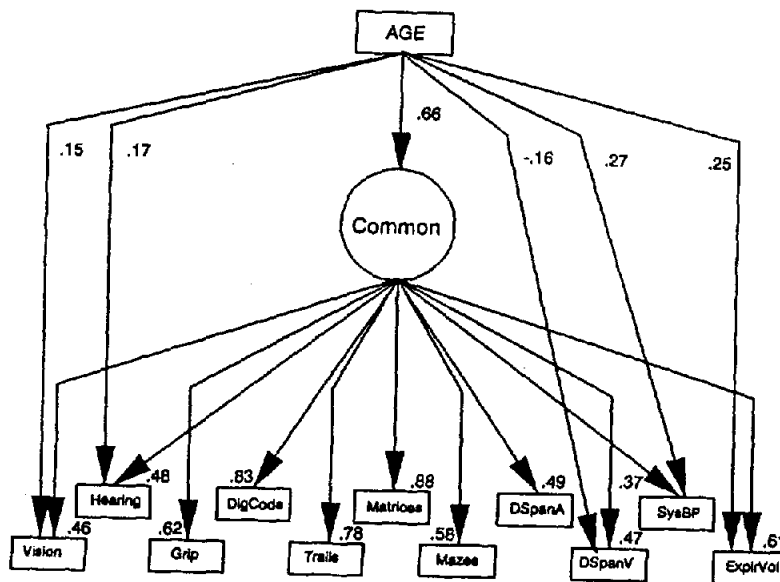
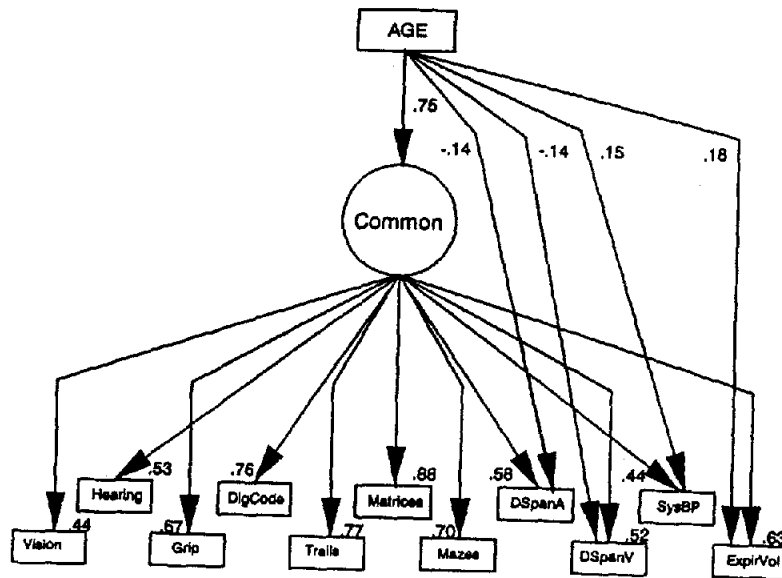


Figure 7. Single common factor structural model for data from men (top) and women (bottom) in Heron and Chown (1967). Note that because Heron and Chown recoded the variables such that all correlations with age were positive, the age-common paths in these models are positive. DigCode = digit code; DSpanA = digit span for auditorily presented digits; DSpanV = digit span for visually presented digits; SysBP = systolic blood pressure; ExpirVol = expiratory volume.

age-related influences are operating appears to be considerably broader than the individual variable.

In summary, the results of these analyses indicate that the finding that most of the age-related influences on a wide range of cognitive variables is shared appears to be robust. Not only

is it evident in different samples of adults and in different combinations of variables, but it also occurs in samples from different portions of the adult life span. However, the results also suggest that caution needs to be exercised when interpreting age-related influences that appear to be shared across cognitive and noncog-

nitive variables, because the relations involving noncognitive variables are substantially reduced by restriction of age and by partialing age from all variables.

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## Appendix

### Description of Samples and Variables in Other Studies

Clark (1960): 102 men and women ages 20 to 70 years  
 PMAREas = PMA Reasoning Test  
 PMASpa = PMA Space Test  
 RT = 5-alternative choice reaction time with movement time  
 LetSpd = Speed of letter comparison  
 Recall = Number of words recalled from a set of phrases  
 WordLat = Word association latency to 20 common words  
 MazeTime = Time to complete 5 mazes of varying difficulty  
 Vision = Near accommodation distance  
 Hearing = Absolute threshold for 3000-Hz tone  
 Grip = Hand strength with dynamometer  
 SysBP = Systolic blood pressure

Dirken (1972): 316 men, ages 30 to 69 years  
 Tapping = Number of taps in 5 s

Position = Inserting a pin in holes of progressively smaller diameters with touching sides, score is smallest hole without touching sides  
 RT4 = Choice reaction time with four stimulus–response alternatives, median of five trials  
 CatAcc = Accuracy of classifying words into categories  
 CatMedRT = Reaction time for classifying words into categories  
 DspanD = Digit span (auditory pronunciation) with 15-s delay  
 Concent = See groups of three, four, or five dots, and instructed to do nothing with three dots, draw horizontal line with four dots, and draw vertical line with five dots. Score is number completed in a fixed time.  
 PictRec = Identification of incomplete drawings of familiar objects  
 Grip = Hand grip strength  
 DiasBP = Diastolic blood pressure  
 SysBP = Systolic blood pressure  
 HeartRate = Frequency per minute

ExpirVol = Forced expiratory volume measured by amount of air forcibly expelled

Vision = Visual acuity without glasses at 4 m

Audio = Speech discrimination for monosyllables

Pitch = Highest detectable frequency

Heron & Chown (1967): 300 men, 240 women, ages 20 to 79 years

Matrices = 40-min Ravens Progressive Matrices

Mazes = Elithorn Perceptual Mazes

Trails = Time to complete both Parts A and B in Trail Making Test

DspanA = Digit span for auditorily presented digits

DspanV = Digit span for visually presented digits

DigCode = Digit coding substitution test

Grip = Hand dynamometer to measure hand grip strength for stronger hand

Vision = Landolt C at distance of 6 m, both eyes uncorrected

Hearing = Pure tone threshold for 1000 Hz

SysBP = Systolic blood pressure

ExpirVol = Forced expiratory volume in 1 s, using spirometer

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