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Age-related effects on cognition between 20 and 50 years of age

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Abstract

Data from 5391 adults between 20 and 50 years of age were analyzed to determine the magnitude of cross-sectional age-related effects on a set of cognitive variables within this age range, and to examine the degree of independence of age-related influences on different variables. Scores on a test of vocabulary increased about 0.05 standard deviation units per year across this age range, while scores on factors representing memory and space/reasoning decreased about 0.02 standard deviation units per year. Correlational analyses revealed that only small proportions of the age-related effects on different cognitive variables were unique, in the sense that they were independent of the cross-sectional age-related effects on other variables.

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There were two major goals of the current project. First we wanted to investigate the existence, and magnitude, of cross-sectional age differences in a variety of cognitive abilities between 20 and 50 years of age. Cognitive differences within this age range have been ignored in typical extreme-group comparisons of young and old adults, and studies with continuous distributions of ages seldom have had enough participants between these ages for powerful analyses. However, if they were to exist, age differences in cognitive abilities under the age of 50 could have important implications for job performance because cognitive ability has been found to be related to job performance (e.g. Hunter, 1986; Schmidt & Hunter, 1992, 1998), and unlike older ages a very high proportion of people within this age range are in the labor force.

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Our second goal in the project was to investigate the structure of any age-related influences that are found. That is, are the effects associated with increasing age on different cognitive variables completely independent of one another, or are they partially shared? This issue is important for theoretical reasons because it is relevant to the nature and number of explanations that will eventually be needed to account for age-related effects in cognitive functioning. For example, a large number of separate explanations would be required if age-related influences on different cognitive variables were largely independent of one another, but fewer distinct explanations would be necessary if large proportions of the age-related influences on some cognitive variables were found to be shared with the age-related influences on other cognitive variables.

The data used in the project were obtained from clients of the Johnson O'Connor Research Foundation in 1996 and 1997. Each individual paid a fee for vocational aptitude assessment, and thus all of the participants can be assumed to have been motivated to perform at a high level. The analyses are restricted to data from individuals between 20 and 50 years of age who completed at least 14 of the 18 perceptual-motor and cognitive tests.

1. Method

1.1. Sample

The 5391 individuals were grouped into six 5-year bands, with between 476 and 1791 people in each age group. Characteristics of the six age groups are summarized in Table 1. About 95% of the participants had between 12 and 20 years of formal education, but age and years of education were correlated 0.39 with each other. At least part of this correlation is likely attributable to many of the individuals in the younger groups having not yet completed their formal education.

1.2. Variables

The variables, which were obtained from a proprietary commercial assessment battery, are briefly described in Table 2. The reliability estimates were obtained from analyses of earlier data from similar, but independent, samples (Schroeder, 2001). The reliabilities are internal-

Table 1
Characteristics of the sample across five-year age intervals

Age range	*n*	Age (S.D.)	Educ (S.D.)	% females
20–24	1791	21.75 (1.46)	14.57 (1.37)	44.3
25–29	1146	26.82 (1.41)	15.92 (1.52)	48.7
30–34	775	31.88 (1.42)	16.43 (1.86)	47.9
35–39	648	36.95 (1.42)	16.28 (2.04)	49.4
40–44	555	41.97 (1.37)	16.49 (2.09)	56.9
45–50	476	47.32 (1.79)	16.61 (2.26)	55.9
All	5391	30.45 (8.62)	15.71 (1.92)	48.7

Table 2
Description of variables

Variable	Reliability	Description
Number Checking (Numchk)	0.96	Rapid (same/different) comparison of pairs of numbers
Idea Fluency (Ideaflu)	0.97	Generation of ideas on a particular topic
Inductive Reasoning (Indreas)	0.84	Quickness in detecting relationships among elements
Analytical Reasoning (Analreas)	0.75	Arrangement of elements in logical sequence
Numerical Reasoning (Numreas)	0.87	Number series completion
Arithmetic (Arith)	0.82	Rapid solution of simple arithmetic problems
Wiggly Block (Wigblk)	0.73	Assembly of 3-D blocks
Paper Folding (Papfld)	0.82	Rotate 2-D surface through 3-D space
Tonal Memory (Tonemem)	0.92	Memory for sequences of tones (Identify the different tone in two sequences)
Pitch Discrimination (Pitchdis)	0.80	Perception of differences in pitch
Rhythm Memory (Rhymem)	0.73	Memory (recognition) for complex rhythmic patterns
Memory for Design (Memdes)	0.80	Memory (reproduction) for line patterns
Associative Learning (AssocLrn)	0.92	Associative memory for verbal material (words and nonsense syllables)
Number Memory (Nummem)	0.82	Memory (recall) for numbers
Recognition Memory (Recmem)	0.62	Recognition memory for object identity and position
Finger Dexterity (Fingdex)	0.86	Speed and accuracy of manipulating small objects with one's fingers
Tweezer Dexterity (Twzdex)	0.93	Speed and accuracy in handling small objects with tweezers
Vocabulary (Vocab)	0.96	Identification of the best definition from a set of alternatives

consistency or split-half values, and for the speeded tests, they are derived from the correlations among separately timed subparts.

Less than 1% of the data was missing for all variables except for the associative learning variable, for which there were 2% missing values. In all cases, the missing value for the individual was replaced with the variable mean.

2. Results

All variables were converted to the same z-score metric, with a mean of 0 and a standard deviation of 1, to facilitate comparisons across variables.

Correlations of age, sex (coded 0 for males and 1 for females), and years of education, and the proportions of variance associated with linear and quadratic age trends, are summarized in Table 3. It can be seen that although several variables had statistically significant quadratic trends, most of the nonlinear trends were fairly small. Almost all of the nonlinear trends were in the direction of larger negative effects of age at older ages. The major exception was with the vocabulary variable in which the age trends were positive, but progressively smaller at older ages.

Females tended to perform at higher levels than males on finger dexterity, memory, and fluency variables, but at lower levels on spatial ability variables. Most of the variables were positively correlated with amount of education, with the strongest relation evident on the vocabulary variable.

Analyses were conducted to determine whether the age effects were moderated by either sex or education. That is, hierarchical regression analyses were conducted with age-by-sex or age-by-

Table 3
Linear and non-linear age-related effects and correlations of sex and education on the variables and factors

Variable	Age r	Linear R^2	Quadratic R^2	Sex	Educ.
Numchk	−0.044*	0.002*	0.007*	0.148*	0.133*
Ideaflu	0.009	0.000	0.000	0.231*	0.238*
Indreas	−0.108*	0.012*	0.000	0.046*	0.009
Analreas	−0.057*	0.003*	0.002*	0.018	0.155*
Numreas	−0.032*	0.001*	0.002*	−0.029*	0.250*
Arith	−0.095*	0.009*	0.003*	−0.006	0.140*
Wigblk	−0.091*	0.008*	0.003*	−0.222*	0.026
Papfld	−0.135*	0.018*	0.000	−0.166*	0.049*
Tonemem	0.002	0.000	0.003*	−0.001	0.084*
Pitchdis	−0.048*	0.002*	0.000	−0.088*	0.068*
Rhymem	−0.026	0.001	0.001	0.011	0.079*
Memdes	−0.222*	0.049*	0.000	−0.067*	0.009
Assoclrn	−0.112*	0.012*	0.000	0.218*	0.156*
Nummem	−0.184*	0.034*	0.002*	0.016	0.074*
Recmem	−0.123*	0.015*	0.000	0.150*	−0.055*
Fingdex	0.014	0.000	0.008*	0.365*	0.038*
Twzdex	−0.068*	0.005*	0.008*	0.061*	−0.027
Vocabulary	0.449*	0.201*	0.016*	0.052*	0.515*
F1 (Space/Reas)	−0.156*	0.024*	0.002*	−0.208*	0.053*
F2 (Num/Fluency)	−0.032	0.001	0.005*	0.158*	0.282*
F3 (Memory)	−0.199*	0.040*	0.000	0.154*	0.075*
F4 (Auditory)	−0.015	0.000	0.001	−0.019	0.126*
F5 (Motor)	−0.045*	0.002*	0.006*	0.291*	−0.054*

*$P < 0.01$.

education cross-product terms entered after the two main effects. Although the slightly higher proportion of females at older ages could bias the magnitude of the age relations, only one age-by-sex interaction, on the Wiggly Block variable, was statistically significant. The increment of R^2 associated with the cross-product term after partialling age and sex was 0.002, and reflected a greater age-related decline in block assembly performance for females than for males. Significant interactions of age and education were apparent on seven variables, with increments in R^2 ranging from 0.002 to 0.010. Lower education was associated with larger negative age relations for arithmetic, associative learning, and number memory, and with smaller negative age relations for number checking, finger dexterity, and tweezer dexterity. Surprisingly, greater education was associated with somewhat smaller age-related increases in vocabulary.

The vocabulary variable was treated separately from the other variables because it represented the products of processing carried out in the past whereas the other variables represented efficiency or effectiveness of processing at the time of assessment. Furthermore, because it seemed likely that the remaining 17 variables did not all represent distinct entities, an exploratory factor analysis was conducted to identify meaningful groupings of variables for later analyses. A principal-components factor analysis, with a promax (oblique) rotation, was conducted on all variables except vocabulary. The scree plot indicated a large discrepancy between one and two factors, but five factors seemed interpretable and had eigenvalues greater than one, and thus a five-factor solution was extracted. Results of the analysis are summarized in Table 4, where it can be seen that the factor pattern was relatively complex, with many of the variables having salient loadings on several factors and moderate correlations among the factors.

Confirmatory factor analyses were next conducted to determine whether the hypothesized pattern of interrelations among the variables could be verified in separate analyses. The sample was first randomly divided into two subsamples of equal size (*N*s = 2695 and 2696) to allow cross-validation. The inductive reasoning variable was dropped from these analyses because the exploratory factor analysis revealed that it had a complex pattern with moderate loadings on several different factors but no high loadings on any factor (cf. Table 4). Most of the remaining variables were hypothesized to be primarily influenced by a single factor, with others influenced

Table 4
Loadings of variables and factor intercorrelations from the exploratory factor analysis

	Space/Reas	Num/Fluency	Memory	Auditory	Motor
	F1	F2	F3	F4	F5
Variable					
Papfold	*0.835*	−0.128	0.017	0.125	−0.029
Wigblk	*0.900*	−0.059	−0.177	−0.009	0.097
Memdes	*0.528*	−0.173	*0.463*	0.060	0.070
Analreas	*0.524*	*0.336*	0.004	−0.024	0.107
Numchk	−0.157	*0.757*	0.058	−0.032	0.113
Arith	*0.351*	*0.662*	−0.019	−0.117	−0.093
Numreas	*0.384*	*0.477*	0.087	0.117	−0.252
Ideaflu	*−0.320*	*0.552*	0.041	0.165	0.280
Nummem	0.022	0.117	*0.767*	−0.009	−0.167
Assoclrn	−0.236	0.173	*0.825*	0.039	−0.098
Recmem	0.127	−0.191	*0.667*	−0.102	*0.318*
Tonemem	0.007	−0.004	−0.065	*0.864*	0.055
Rhymem	−0.004	0.028	0.105	*0.723*	0.042
Pitchdis	0.153	−0.004	−0.046	*0.711*	−0.023
Fingdex	−0.006	0.203	0.017	0.023	*0.683*
Twzdex	0. 105	−0.029	−0.106	0.061	*0.695*
Indreas	*0.312*	*0.304*	−0.013	−0.118	*0.373*
% Variance	28.80	9.62	8.44	6.97	6.03
Correlations					
F1	1.00	0.337	0.483	0.254	0.148
F2	0.337	1.00	0.397	0.222	0.140
F3	0.483	0.397	1.00	0.256	0.236
F4	0.254	0.222	0.256	1.00	0.022
F5	0.148	0.140	0.236	0.022	1.00
Age	−0.156	−0.032	−0.199	−0.015	−0.045
Educ	0.053	0.282	0.075	0.126	−0.054
Sex	−0.208	0.158	0.154	−0.019	0.291

Values in italic represent salient loadings of 0.300 or greater. Sex is coded as 0 for males and 1 for females.

by up to three factors. The relations between variables and factors were altered on the basis of modification indices in sample 1, but then were not further modified in the analysis of sample 2. Table 5 reveals that the model provided a reasonable fit to both sets of data, and that the factor loadings and factor correlations were very similar in the two samples.

Age trends on the five factors (based on the factor scores obtained from the exploratory factor analysis) and on the vocabulary variable are plotted in Fig. 1. It can be seen that there were very strong age-related increases in vocabulary, and small but systematic age-related decreases for the memory and space/reasoning factors. Statistically significant quadratic age trends were apparent on the numeric/fluency and motor factors (see Table 3), in both cases in the direction of larger age-related effects at older ages. Interactions of age-by-sex or age-by-education were examined, and the only two that were significant (both with an increment in R^2 of 0.004) were in the direc-

Table 5
Measurement model based on confirmatory factor analysis (Sample 1 / Sample 2)

	Space/Reas F1	Num/Fluency F2	Memory F3	Auditory F4	Motor F5
Variable					
Papfold	0.839/0.829				
Wigblk	0.699/0.712				
Memdes	0.522/0.528		0.466/0.446		
Analreas	0.468/0.462	0.359/0.370			
Numchk		0.586/0.620			
Arith	0.279/0.317	0.542/0.577			
Numreas	0.424/0.440	0.479/0.465			
Ideaflu		0.415/0.372			
Nummem	0.115/0.178	0.315/0.274	0.465/0.469		
Assoclrn		0.339/0.321	0.435/0.473		
Recmem	0.099/0.138		0.461/0.430		0.270/0.223
Tonemem				0.767/0.760	
Rhymem				0.663/0.643	
Pitchdis				0.591/0.583	
Fingdex					0.707/0.654
Twzdex					0.429/0.345
Factor intercorrelations (Sample 1/Sample 2)					
F1–F2	0.178/0.158				
F1–F3	0.381/0.324				
F1–F4	0.401/0.388				
F1–F5	0.320/0.272				
F2–F3	0.303/0.310				
F2–F4	0.313/0.244				
F2–F5	0.414/0.425				
F3–F4	0.231/0.287				
F3–F5	0.269/0.242				
F4–F5	0.168/0.159				

χ^2 (df = 80, N = 2695/2696) = 793.245/738.090. CFI = 0.939/0.941. RMSEA = 0.058/0.055.

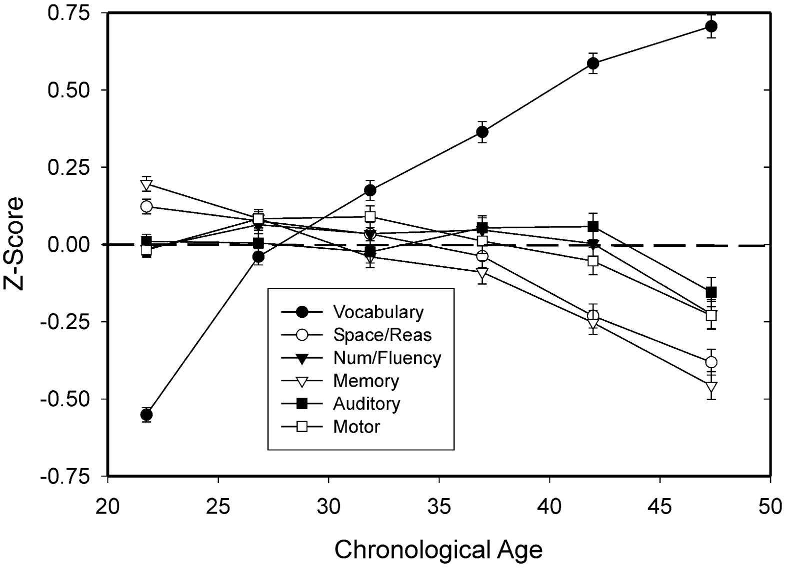

Fig. 1. Means (and standard errors) by five-year age intervals of factor scores and vocabulary.

tion of higher education associated with a smaller age-related decline for the numeric/fluency factor, and a larger age-related decline for the auditory factor.

Estimates of annual change per year were obtained by computing linear regression slopes (in units of standard deviations per year) for the vocabulary variable and for the memory and space/reasoning factors, which were the factors with the largest linear age relations in Table 3. The annual difference was 0.052 (95% confidence interval of 0.049–0.055) for the vocabulary variable, −0.023 (95% confidence interval of −0.026 to −0.021) for the memory factor, and −0.018 (95% confidence interval of −0.021 to −0.015) for the space/reasoning factor. These values lead to estimated age differences across the 30-year interval from 20 to 50 of about +1.56 standard deviations for vocabulary, −0.69 standard deviations for memory, and −0.54 standard deviations for space/reasoning. If the age range was 50 years, as in a typical comparison of adults between 20 and 70 years of age, and the linear trends could be extrapolated to that interval, the effects would correspond to about −0.90 standard deviations for the space/reasoning factor and about −1.15 standard deviations for the memory factor.

In order to examine interrelations among the age differences in the variables and factors, a structural model was examined in which all of the factors were postulated to be influenced by a common second-order factor that was negatively related to age, and by a knowledge factor represented by the vocabulary variable (cf. Fig. 2). Although this model is very simple, it has the virtue of being capable of empirical investigation. For example, the hypothesis that each factor will be significantly related to the second-order common factor can be tested by examining the statistical significance of the relevant path coefficient. Furthermore, direct relations from age to individual factors can be tested to determine whether they are significantly different from zero, and result in a significant improvement in overall fit.

As in the confirmatory factor analyses, the model was fit separately to the two subsamples. In both cases the fit was satisfactory (cf. Table 5), and there was no indication from the Lagrange

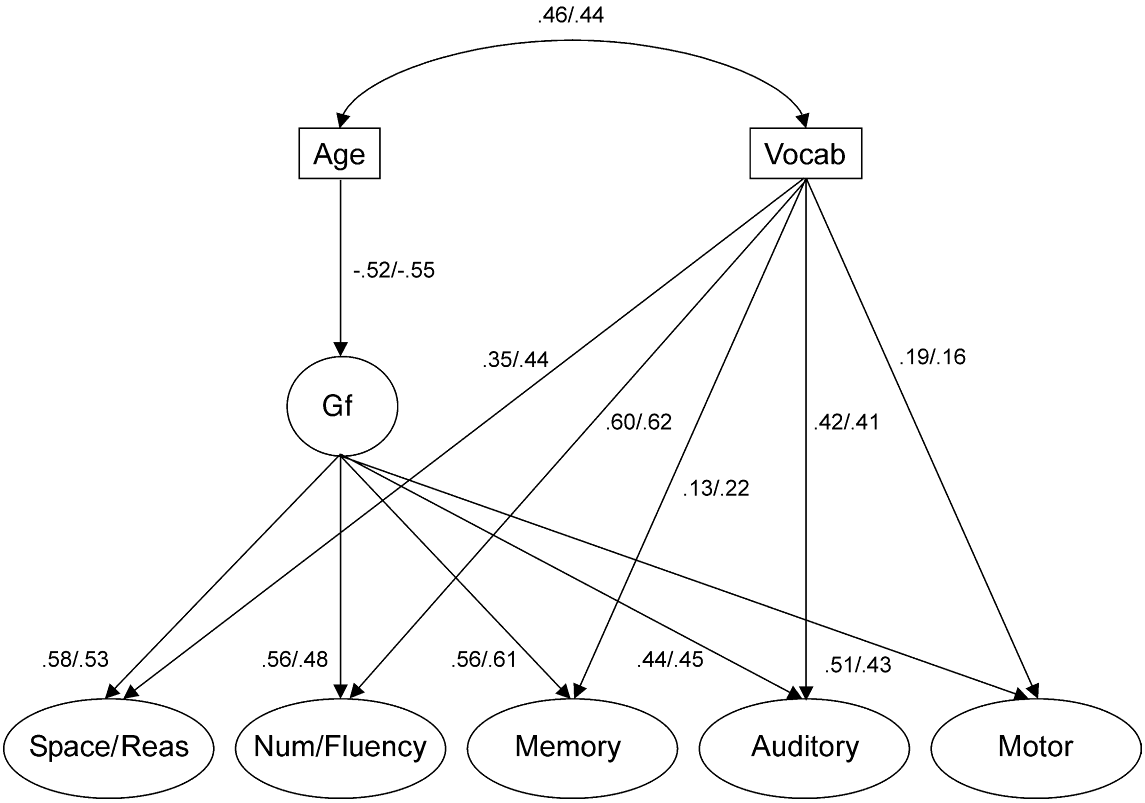

Fig. 2. Structural model portraying relations of age and vocabulary on the five factors. Fit statistics and coefficients for two independent samples. Variables loading on each factor are indicated in the measurement model in Table 5. Fit statistics were: χ^2 (df = 116, N = 2695/2696) = 1448.37/1438.84; CFI = 0.903/0.901; RMSEA = 0.065/0.065.

Multiplier Test or from inspection of the residuals that the addition of direct age relations to any of the factors would improve the fit in either sample.

Because all of the age-related effects in the model operate through a common factor, the model assumes that the age-related effects on the first-order factors are completely shared with one another. This is obviously a very strong assumption that is unlikely to be completely valid, but the fact that there was no evidence for additional direct age relations at the factor level suggests that it is not completely implausible. All of the factors were also influenced by knowledge (vocabulary), with the largest knowledge effects on the numeric/fluency factor, and the smallest effects on the memory and motor factors.

A final set of analyses was conducted to determine whether there was a systematic relation between the degree to which variables are related to one another and the magnitude of the age relation on the variables. Results from studies with a broader range of ages have found evidence for such a systematic relation (e.g. Salthouse, 2001a, 2001b), but there have been no reports of this phenomenon in samples between 20 and 50 years of age. The systematic relations have been designated AR functions because they represent the relation between the effects of age (A) on a variable and the relatedness (R) of the variable to other variables.

Because there was a large influence of vocabulary that may have obscured the relations of the variables to age, vocabulary was first partialled from all variables prior to subsequent analyses. Next a principal components analysis was conducted on the vocabulary-partialled residuals, with the first principal component serving as an estimate of what all the variables have in common. Finally, for each variable the loading on the first principal component was plotted against its correlation with age. This plot is portrayed in Fig. 3, where it can be seen that there was a significant positive relation between the two sets of values, such that the age effect was larger when the variable was more closely related to other variables.

Before one attempts to interpret the systematic AR relation, it is important to consider two possible artifacts. First, the values of the relatedness estimates might have been at least partially attributable to the relation that each variable had to age. This does not appear to be the case in these data, however, because there was a very high correlation (i.e. 0.99) between the first principal component loadings for the entire sample and the loadings for a subsample between 20 and 24 years of age. Furthermore, the correlation of the age relations from the entire sample with the first principal component loadings from the age 20–24 sample was 0.70 ($\rho = 0.80$), which is very similar to the value (i.e. $r = 0.75$, $\rho = 0.83$) obtained with the loadings from the entire sample.

A second possible artifact is that the systematic relation could originate simply because the variables differed in reliability, and hence in their ability to be related to either age or other variables. However, it is unlikely that the relation in Fig. 3 is an artifact of differential reliability of the variables because partialling estimates of the reliability (summarized in Table 2) from the relation between age and the first principal component loadings actually increased the correlation, from 0.75 to 0.78.

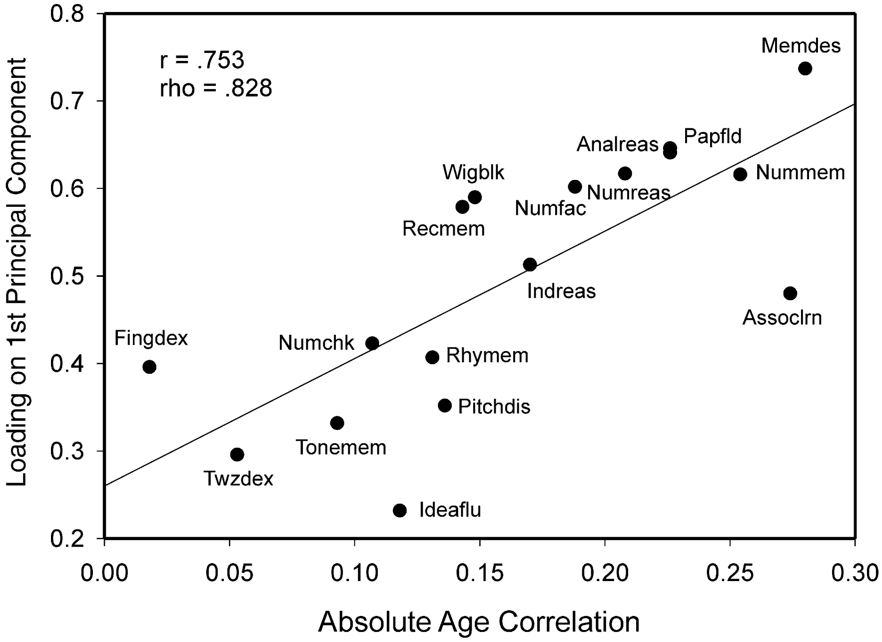

Fig. 3. Plot of loadings on the first principal component against absolute age correlations for vocabulary-partialled residuals of the 17 variables.

3. Discussion

Significant age-related differences were found in a vocabulary variable, and on memory and spatial/reasoning factors across a 5-to-15 year interval beginning from age 22. The differences are equivalent to an increase of about 0.05 standard deviation units per year for vocabulary, and to a decrease of approximately 0.02 standard deviation units per year for the memory and space/reasoning factors. These findings imply that aging has an important influence on cognitive performance in the range from 20 to 50 years of age, and not merely from age 50 to 80 as is sometimes assumed (also see Verhaeghen & Salthouse, 1997). Furthermore, these results do not appear to be attributable to an unusual sample of research participants because age-related increases in vocabulary over this range were similar to those frequently reported in the literature.

A question that immediately arises is why are these effects not more noticeable, perhaps in terms of consequences on job performance since other research has established significant relations between cognition and job performance (e.g. Hunter, 1986; Schmidt & Hunter, 1992, 1998). One reason why prior research has failed to document relations between age and job performance (e.g. McEvoy & Cascio, 1989) may be that job performance has often been measured rather crudely, with weak sensitivity and low reliability. Another likely reason is that most variables are influenced by both age and knowledge, and the two influences may tend to cancel one another (see Charness, 2000). An even larger contribution of knowledge, and particularly occupation-specific knowledge, may be operating with work-related activities to further obscure the consequences of any age-related cognitive declines that may be occurring. That is, it is likely that performance of many jobs is heavily dependent on the quantity and quality of relevant knowledge, and based on the age trend for vocabulary, knowledge appears to increase at least to age 50. Results from knowledge tests in standardized test batteries such as the Wechsler Adult Intelligence Scale and the Woodcock–Johnson Psychoeducational Test Battery suggest that declines in knowledge may begin at around age 50 (see Salthouse, 2003), but at least up to that age the pattern is of a consistent increase.

For many jobs, therefore, knowledge may become progressively more important and other cognitive abilities less important, with increased age and experience (also see Murphy, 1989). This could be manifested as a difference in the weightings of knowledge versus other cognitive abilities at different levels of age or experience, or as a difference in the absolute level of the variable with the same weighting in the prediction of job performance (see Salthouse, 1993). In neither scenario, however, would it mean that there are no effects of age on cognitive abilities, but rather that the consequences of these effects may be small when the corpus of relevant knowledge is large.

The preceding interpretation implies that consequences of age-related effects on cognitive abilities may be more salient if the knowledge advantage of older adults is eliminated. This could occur either by virtue of the individual being placed in novel situations in which his or her knowledge does not transfer, or if electronic data bases or information retrieval systems were developed that would make relevant knowledge equally available to individuals of all ages.

Two sets of findings suggest that a large proportion of the age-related effects observed on different cognitive variables within the range from 20 to 50 years of age are shared. First, the structural model with a single common age-related influence provides a plausible fit to the data. Evidence of this type is not definitive because many alternative models might also fit the data, but it is clearly consistent with the idea that only small proportions of the cross-sectional age-related effects on different cognitive variables are independent of one another. And second, after one partials for the effects of vocabulary there is a strong systematic relation between the magnitude of age-related effects on a variable and the degree to which the variable is related to other variables.

It is not yet clear what is responsible for the shared age-related effects inferred to operate in these and other data (e.g. Salthouse, 1998, 2001a, 2001b; Salthouse, Hambrick & McGuthry, 1998). Inspection of Fig. 3 reveals that variables in the upper right of the AR function tend to represent performance in tasks of memory, reasoning, and spatial abilities, whereas variables in the lower left of the function tend to represent perceptual and motor abilities. This pattern is consistent with the idea that the dimension underlying the AR function represents the amount of controlled processing required to perform the task. However, this is not a very satisfying interpretation without a detailed specification of what is meant by controlled processing. At the present time no such explanation can be provided because controlled processing may reflect aspects of working memory, attentional capacity, processing speed, or almost any other characteristic of processing that is not specific to a particular type of cognitive variable.

In conclusion, the results of the analyses reported here suggest two important goals for future research. One is to discover why both unique and shared age-related effects occur on many cognitive variables beginning as early as the 20s, and the second is to explain how increased knowledge might operate to offset the negative consequences of declining cognitive abilities to maintain a high level of functioning in select domains.

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