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Speed and Knowledge as Determinants of Adult Age Differences in Verbal Tasks

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Two studies were conducted to determine the relative importance of processing speed and knowledge as predictors of performance in simple verbal tasks within samples of young and old adults. Eight different criterion tasks were investigated, and performance on each was found to be significantly related both to speed of processing and to quantity of word knowledge. It was also discovered that although young adults were faster than old adults and that old adults were equal or superior to young adults in relevant knowledge, the same regression equations could be used to predict criterion performance in both groups. These results therefore suggest that any age-related compensation that exists in these tasks is rather weak, in the sense that speed and knowledge appear to have the same importance in young and old adults, and only the average levels of the predictors differ as a function of age.

IT is well established that increased age is often associated with lower levels of processing efficiency, as reflected by slower responses, in many cognitive tasks (e.g., see Salthouse, 1985, for a review). However, increased age is also frequently assumed to be associated with greater amounts of experience, which might lead to broader and more extensive knowledge. An issue of considerable interest in light of these two trends is how processing speed and knowledge jointly influence performance on tasks involving both factors, and, in particular, whether there are age-related differences in the pattern of these influences.

Whenever there are two or more determinants of performance on a task, it is possible that the same level of performance could be achieved with different combinations of abilities. In the literature concerned with psychology and aging, this possibility is often discussed within the rubric of compensation. For example, if older adults have a greater amount of knowledge than young adults in a particular domain, then it might be expected that they would rely on this knowledge to compensate for any age-related declines in processing efficiency that might have occurred. Although this speculation seems reasonable, the mechanisms (i.e., particular combinations of abilities and processes) by which the presumed compensation takes place in a given task have not yet been identified. One possible exception is in the activity of transcription typing, where research suggests that older adults appear to rely on anticipatory processing to a greater extent than young adults when performing at the same overall level of speed (Salthouse, 1984). However, there is apparently no convincing evidence for age-related compensation in tasks with a greater cognitive component.

At least two possibilities can be proposed with respect to the nature of compensation in tasks involving both speed and knowledge. One possibility is that there is a change in the composition of the task, as reflected by an alteration in the relative importance of speed and knowledge as predictors of task performance. As an example, the speed of performing addition would almost certainly become less important in the solution of multiplication problems after one has learned the multiplication table. If the knowledge is procedural ("how-to" knowledge) in nature, then it may lead to alterations in the way the task is performed, and if the knowledge is declarative (factual information) in nature, then the individual may already have stored solutions from previous encounters with the task. In either case, efficiency of basic processing might be expected to be a less important determinant of individual differences in performance within a sample of people with high levels of relevant knowledge than in a sample with lower levels of knowledge.

A second possibility regarding compensatory mechanisms is that the relative importance of processing efficiency and knowledge may remain the same, but different groups of people may vary in the average values of each factor. That is, the same determinants of individual differences in performance may be important in samples of different ages, but the samples may vary in the average levels of those determinants. A relevant analogy here might be vocabulary knowledge and grammatical knowledge as predictors of overall linguistic competence. Knowledge of vocabulary and grammar could have the same relative importance in predicting linguistic competence in two groups who learned a language with different methods, even if one group had a higher average level on the measure of vocabulary knowledge and the other group had a higher average level on the measure of grammatical knowledge.

Distinguishing between the two alternatives outlined above requires tasks in which it is possible to assess two or more hypothesized determinants of performance, which in the present situation are relevant knowledge and processing efficiency. This is not often feasible in many naturalistic activities, because the activities are so complex that it is difficult to specify, much less to assess, the relevant knowledge. An assumption underlying the current research is that evaluation of the influence of both knowledge and processing efficiency may be more feasible with relatively simple verbal tasks. At least as a first approximation, it seems reasonable to assume that relevant word knowledge can be assessed in terms of performance on vocabulary tests, and that the efficiency of simple processing can be assessed in terms of performance on speeded perceptual comparison tests.

The criterion tasks used in the present studies are illustrated in Figure 1. Four different tasks were investigated in each of two studies in order to provide a relatively broad evaluation of the phenomenon. The measures of performance in the verbal tasks were not necessarily expected to be highly correlated, but the tasks were all of interest because word knowledge and processing efficiency or speed were postulated to be important in each. As an example, consider the anagrams task presented in Study 1. Performance on this task is expected to be facilitated with greater word knowledge because of better understanding of sequential constraints and probabilities of particular letter combinations in the language, and because recognition of words and word fragments is likely to be superior when there are more words in one's knowledge system. In fact, Hayslip and Sterns (1979) have reported moderate (.23 to .50) correlations between anagram performance and a composite measure of crystallized intelligence that included several measures of vocabulary knowledge.

STUDY 1

Nouns
Write as many 4-letter nouns as you can. (60 sec)

S-Words
Write as many words that begin with the letter S as you can. (60 sec)

Anagrams
Unscramble the following letters to make an English word. (10 minutes for 25 problems)
Examples: eisla, ghmit

Word Switch
Switch the first word into the second word by changing one letter at a time such that each intermediate set of letters also makes an English word. (10 minutes for 15 problems)
Examples: nine - camp, hall - sink

STUDY 2

Word Beginnings
Write as many words as you can that start with PRO (SUB). (60 sec for each word fragment)

Word Endings
Write as many words as you can that end with AY (OW). (60 sec for each word fragment)

Making Words
Write as many words as you can from the following letters. (60 sec each for BFHILNDRW and ACDGKMPTU)

Scrabble
Write letters in the boxes to make words, trying to connect words whenever possible. (60 sec for each of two diagrams each containing 106 boxes)

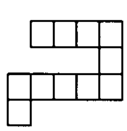

Figure 1. Description of criterion tasks used in Studies 1 and 2.

Anagram performance might also be expected to be enhanced among individuals who are faster at processing information because of more rapid processes of search, transformation, and exploration of letter permutations.

The same analytical strategy was used with each of the verbal tasks illustrated in Figure 1. The reasoning is as follows. If the relative importance of speed and knowledge differs in the two groups, then coefficients from the regression equations predicting performance on the tasks would be expected to have different values in samples of young and old adults. For example, word knowledge might have a larger regression weight for old adults than for young adults, whereas the opposite may be the case for processing efficiency or speed. However, if young and old adults differ primarily with respect to their average levels of word knowledge and speed, and not in terms of the relative importance of these factors for task performance, then the same regression equations should be found to apply in both groups.

The two studies in this project were very similar, and thus will be described together to conserve space and minimize redundancies. Word knowledge in both studies was assessed by performance in two relatively difficult multiple-choice vocabulary tests, one involving antonyms and the other synonyms. The same two measures of perceptual comparison speed, one involving pairs of letters and the other pairs of line patterns, were also used in both studies. Because of a desire to separate the influence of peripheral sensory and motor speed from the speed of performing more cognitively demanding operations, two tests of motor speed were also administered. Finally, in order to provide a comparison with another moderately complex task not expected to be sensitive to amount of word knowledge, the Digit Symbol Substitution Test (Wechsler, 1981) was also administered to all research participants.

METHOD

Subjects. — Characteristics of the samples of young and old adults participating in the two studies are summarized in Table 1. Young adults in both studies were college students participating in partial fulfillment of a course requirement. The older adults in Study 1 were recruited from an adult education program, whereas most of those in Study 2 were recruited from an adult community center. All of the older adults, or their designated organization, received a nominal payment for their participation.

Inspection of Table 1 reveals that the young adults in the two studies were very similar, but that the older adults in Study 2 were somewhat older than those in Study 1, with lower ratings of self-reported health and lower vocabulary and Digit Symbol scores. It can also be seen that the older adults reported more recent experience reading both books and magazines than did the young adults. Older adults reported more recent experience with word puzzles than did the young adults in Study 1, but there was no difference in this dimension across the samples of young and old adults in Study 2.

Procedure. — All participants within a given study performed the tasks in the same fixed order. The order for the

Table 1. Characteristics of Samples in Studies 1 and 2

	Study 1			Study 2		
	Young	Old	$t(198)$	Young	Old	$t(145)$
No.						
Males	46	28		29	22	
Females	54	72		48	55	
Age	21.0	70.1	−77.50*	20.0	74.1	−69.94*
	(2.0)[a]	(6.0)		(1.3)	(6.7)	
Education	13.7	14.0	−1.06	13.4	13.7	−.99
(Years completed)	(1.5)	(2.8)		(1.5)	(2.7)	
Health	2.0	2.3	−1.41	2.1	2.7	−3.29*
(1 = excellent, 5 = poor)	(1.1)	(1.2)		(1.0)	(1.2)	
Medications	.2	1.5	−4.02*	.3	2.6	−8.18*
(No./week)	(.5)	(3.1)		(.7)	(2.4)	
Hospitalizations	.3	.4	−.69	.05	.7	−4.56*
(No. in last year)	(1.6)	(1.4)		(.2)	(1.3)	
Antonym Vocabulary	10.0	12.7	−4.11*	9.9	9.4	.70
	(3.7)	(5.6)		(3.7)	(5.0)	
Synonym Vocabulary	11.0	15.4	−7.50*	10.8	12.7	−2.78*
	(4.0)	(4.4)		(4.2)	(4.6)	
Digit Symbol	73.0	49.7	12.33*	71.9	38.8	18.53*
	(11.3)	(15.2)		(10.7)	(11.4)	
Reading Books						
(Hours/month)	15.1	30.9	−5.62*	20.5	36.1	−3.32*
	(17.2)	(22.1)		(23.6)	(33.8)	
(Years with 15 hours/month)	5.8	40.6	−18.90*	6.4	41.3	−14.54*
	(4.3)	(17.9)		(4.4)	(20.2)	
Reading Newspapers and Newsmagazines						
(Hours/month)	17.9	32.6	−6.14*	13.8	29.9	−7.29*
	(14.2)	(19.1)		(9.7)	(16.8)	
(Years with 15 hours/month)	4.3	43.4	−23.59*	3.8	45.4	−20.76*
	(4.2)	(16.0)		(3.3)	(17.0)	
Working Word Puzzles						
(Hours/month)	5.2	10.3	−3.06*	7.3	6.6	.29
	(7.9)	(14.4)		(18.1)	(10.2)	
(Years with 15 hours/month)	3.0	16.3	−6.48*	2.1	12.5	−4.55*
	(4.0)	(20.1)		(3.2)	(19.4)	

[a]Standard deviations are in parentheses.
$*p < .01$.

tasks in Study 1 was Digit Symbol, Digit Copy, Letter Copy, Pattern Comparison, Letter Comparison, Nouns, S-Words, Antonym Vocabulary, Synonym Vocabulary, Anagrams, and Word Switch. The order for the tasks in Study 2 was Digit Symbol, Vertical Line Marking, Horizontal Line Marking, Pattern Comparison, Letter Comparison, Word Beginnings, Word Endings, Antonym Vocabulary, Synonym Vocabulary, Making Words, and Scrabble.

The Digit Symbol task was the Digit Symbol Substitution Test from the Wechsler Adult Intelligence Scale–Revised (Wechsler, 1981). The Digit Copy and Letter Copy tasks were similar in format to the Digit Symbol test in that they consisted of a series of pairs of boxes with a digit (or a letter) in the top box and nothing in the bottom box. Unlike the Digit Symbol task, however, in these tasks the research participant merely had to copy the character from the top box in the bottom box. Because there was very little cognitive requirement in these copying tasks, they were presumed to assess motor speed. The line marking tasks used in Study 2 were also intended to assess motor speed, because the individual merely had to create plus marks by drawing horizontal lines across vertical lines, or by drawing vertical lines across horizontal lines.

The Pattern Comparison and Letter Comparison tasks were very similar to those described by Salthouse and Babcock (1991), and consisted of pairs of line patterns or letters that were either identical or that differed by one element (position of a line or identity of a letter). The task for the participant was to classify the pairs as *same* or *different* as rapidly as possible by writing an S or a D on a line between the two members of the pair. All of the speed tasks were presented in a paper-and-pencil format and had a time limit of 30 sec, with the exception of the Digit Symbol test that had a time limit of 90 sec.

Items in the two vocabulary tests were adapted from assorted sources, such as commercially published practice tests for the Scholastic Aptitude Test. Pilot administrations and item analyses were used to select a set of 20 items, each with five alternative answers, for both a synonym test and an antonym test. The tests were administered with a time limit of 4 minutes, which was sufficient for nearly all participants to attempt every item.

Each of the criterion verbal tasks, portrayed in Figure 1, was preceded by an example illustrating a typical item in the task and a possible solution. The tasks were then administered for the time limits indicated.

RESULTS

An initial factor analysis (specifying three factors and a promax rotation with $k = 3$) was conducted on the six predictor variables (two each designed to measure motor speed, perceptual speed, and word knowledge) separately in each age group to determine whether the relations among variables were consistent with the hypothesized pattern. The results of these analyses, summarized in Table 2, indicate that the loading patterns were as expected in both age groups in each study. Composite predictor variables were therefore created by averaging the two measures of each construct, and these composites were used in the subsequent analyses.

It is noteworthy that the correlations between the factors (and between the composite scores) were considerably higher in the older adult samples than in the young adult samples. To illustrate, the correlations between the vocabulary and perceptual speed factors were .39 and .40 in the two older adult samples, but were only .05 and .06 in the two young adult samples. This suggests that the speed and knowledge predictors may not be as distinct in the older adult group as in the young adult group. Potential causes of this finding will be considered in the Discussion section.

Performance in the criterion verbal measures was represented in terms of the number of correct items produced in the specified time. [*Websters Ninth New Collegiate Dictionary* (1985) was used to verify the authenticity of the generated words.] Two alternative methods of scoring responses in the Scrabble task were examined, one in which the score represented the number of unique words produced, and the other in which the score represented the number of connections between words. The correlations between the two measures were very high in both young (.97) and old (.99) groups, however, and consequently the number of unique words served as the single performance measure in this task.

Figures 2 and 3 illustrate the age effects on the primary measures in each study by expressing the performance of older adults in terms of the standard deviations of young adults. As expected from previous research, the age differences were quite pronounced and favored young adults for the motor speed, perceptual speed, and Digit Symbol measures. Also consistent with past research is the finding that the age differences were smaller and favored older adults, rather than young adults, for the vocabulary measures. Finally, it should be noted that the age differences in the speeded verbal tasks were generally smaller than those in the Digit Symbol task in which there was assumed to be little or no influence of word knowledge.

Table 2. Factor Structure for Predictors (Promax Rotation)

	Factor					
	MotSpd		PerSpd		Vocab	
	Y	O	Y	O	Y	O
Study 1						
LCopy	.88	.88	−.16	.12	.02	.04
DCopy	.98	.98	−.12	.01	−.02	−.03
LetCom	−.06	.09	.92	.79	−.02	.10
PatCom	.06	.05	.86	.92	.01	−.07
Antonym	.05	.02	.07	−.02	.93	.96
Synonym	−.06	−.01	−.07	.02	.90	.96
Factor Correlations			Young	Old		
MotSpd-PerSpd			.32	.64		
MotSpd-Vocab			−.23	.33		
PerSpd-Vocab			.05	.39		
Study 2						
HMark	.92	.96	−.06	−.01	.00	.07
VMark	.97	.96	.07	.05	.00	−.07
LetCom	.08	−.02	.84	.89	.04	.10
PatCom	−.06	.08	.92	.91	−.04	−.06
Antonym	.01	.08	.10	.00	.92	.94
Synonym	−.01	−.07	−.10	.02	.94	.96
Factor Correlations			Young	Old		
MotSpd-PerSpd			.35	.50		
MotSpd-Vocab			−.04	.20		
PerSpd-Vocab			.06	.40		

Notes. Y, young; O, old; MotSpd, motor speed; PerSpd, perceptual speed; Vocab, vocabulary; LCopy, Letter Copy; DCopy, Digit Copy; LetCom, Letter Comparison; PatCom, Pattern Comparison; HMark, Horizontal Line Marking; VMark, Vertical Line Marking.

Correlations among the criterion verbal measures were in the low to moderate range (i.e., median of .33 in Study 1 and median of .47 in Study 2). Because this suggests that the criterion measures may represent somewhat different constructs, they are treated separately in all subsequent analyses.

Correlations were also computed between each of the criterion verbal measures and the health and experience measures summarized in Table 1. None of the correlations was significant in the young groups, but several correlations were significant ($p < .01$) in the older groups. For example, self-rating of health had a correlation of −.24 with the Word Beginnings measure in Study 2, indicating that the scores were lower for those individuals with poorer ratings of their own health. Reported recent experience with word puzzles had the following significant correlations in the older groups: .25 for Nouns, .36 for Anagrams, .41 for Word Endings, .48 for Making Words, and .40 for Scrabble. The available data do not allow a distinction between greater experience as the cause or the consequence of the higher performance on these verbal tasks, but it is nevertheless interesting that significant relations were apparent only in the older groups.

The primary method of investigating the relative importance of speed and knowledge in young and old adults consisted of comparing the parameters of regression equations predicting performance in the verbal tasks in the two

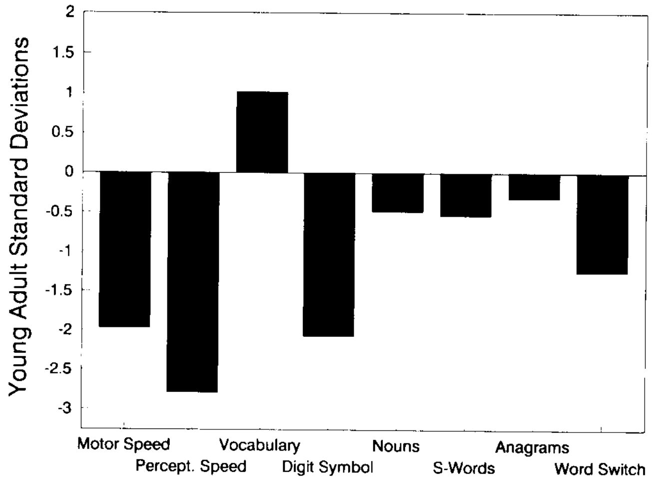

Figure 2. Mean performance of older adults in standard deviations of young adults (Study 1).

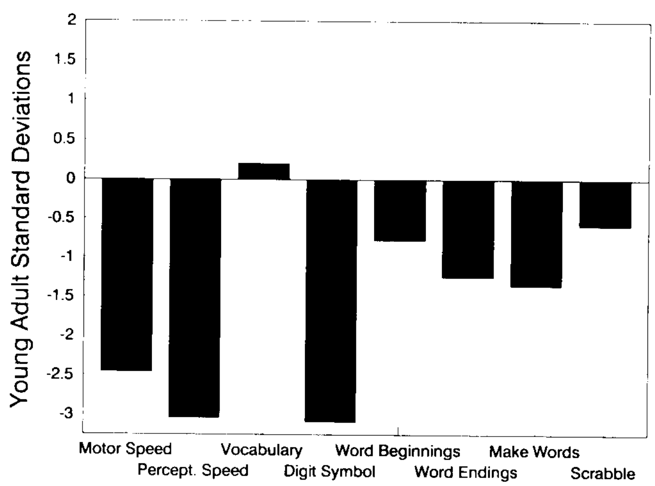

Figure 3. Mean performance of older adults in standard deviations of young adults (Study 2).

groups. Very similar patterns of results were evident when the data were analyzed in single regression equations including an Age × Predictor interaction term. That is, the interaction was significant ($p < .01$) in Study 1 only with the perceptual speed and vocabulary predictors with the Digit Symbol measure, and in Study 2 with the perceptual speed predictor for the Digit Symbol and Scrabble measures and with the vocabulary predictor for the Scrabble measure. Because the two analytical methods yielded comparable results, separate regression equations are reported to indicate the complete regression equations, and the percentage of variance accounted for, in each group. Initial analyses revealed that there was no significant influence of motor speed for any criterion measure in any group, and thus this predictor was deleted from subsequent analyses. Interactions of perceptual speed and vocabulary were also examined for each measure. The interaction was significant [i.e., $F(1,73) = 9.56$] for the older adults in the Scrabble measure. However, because this was the only measure with a significant interaction, and because the pattern was difficult to interpret (i.e., the effect of speed was greater among adults with higher levels of vocabulary), interactions of the predictor variables were ignored in subsequent analyses.

Results from the regression analyses are reported in Table 3 for Study 1, and in Table 4 for Study 2. A z-value testing the difference between the parameters for young and old adults is reported below the parameters of the two groups.

Table 3. Regression Parameters for Young and Old Adults (Study 1)

	Intercept	b(PerSpd)	b(Vocab)	R^2
Digit Symbol				
Young	38.664*	2.073*	−.462	.175*
Old	−5.684	3.538*	.697	.418*
z for difference	−3.78*	1.96	2.92*	
Nouns				
Young	4.513	.288	.027	.025
Old	−.509	.361	.294	.227*
z for difference	1.19	.29	1.92	
S-Words				
Young	5.580	.347	.309*	.117*
Old	2.388	.626*	.197	.199*
z for difference	.76	1.06	−.79	
Anagrams				
Young	−1.905	.688*	.490*	.191*
Old	−2.037	.906*	.345	.191*
z for difference	−.02	.56	−.72	
Word Switch				
Young	−3.969	.401*	.207*	.172*
Old	−4.568*	.289	.222*	.292*
z for difference	−.22	−.68	.17	

Notes. PerSpd, perceptual speed; Vocab, vocabulary.
*$p < .01$.

Table 4. Regression Parameters for Young and Old Adults (Study 2)

	Intercept	b(PerSpd)	b(Vocab)	R^2
Digit Symbol				
Young	36.786*	1.322*	.973*	.218*
Old	−3.401	3.178*	.540	.515*
z for difference	−7.92*	2.85*	−1.16	
Word Beginnings				
Young	.025	.267*	.224*	.310*
Old	.641	.317*	.147*	.301*
z for difference	.33	.39	−1.09	
Word Endings				
Young	2.201	.315*	.210*	.190*
Old	−.482	.336	.338*	.330*
z for difference	−.96	.10	1.19	
Making Words				
Young	1.409	.220	.221*	.171*
Old	−2.215	.327	.274*	.357
z for difference	−1.44	.63	.56	
Scrabble				
Young	4.171	.119	.126	.047
Old	−4.298*	.556*	.374*	.496*
z for difference	−2.97*	2.28*	2.33*	

Notes. PerSpd, perceptual speed; Vocab, vocabulary.
*$p < .01$.

Inspection of the tables reveals that the only significant age differences were in the Digit Symbol measures in both studies, and in the Scrabble measure in Study 2. In each case, the differences corresponded to the older adults having smaller intercept values, but larger regression coefficients, than young adults. The only significant differences evident in any of the criterion verbal tasks were therefore in the direction of larger influences of both vocabulary and perceptual speed for older adults than for young adults.

The results summarized in Tables 3 and 4 indicate that there is little evidence that the functions relating speed and knowledge to performance on simple verbal tasks are different for young and old adults. That is, the lack of differences in the regression equations for seven of the eight tasks suggests that the same regression equations serve to describe the relations among the predictor and criterion variables in each age group. This conclusion is admittedly based on the acceptance of the null hypothesis, but the samples within each study were fairly large, and the pattern was replicated across a variety of different tasks and two independent samples.

A final analysis was based on the relations among the primary variables in the combined data from both age groups in each study. The purpose of this analysis was to examine the influence of age on each of the predictor variables and on the criterion verbal measures. A model illustrating the relations of major interest is portrayed in Figure 4. Multiple regression procedures were used to estimate the (standardized) path coefficients for each of the lines represented in this diagram. Coefficients among age and the three predictors are represented on the diagram, and those for the paths labeled 1 through 4 are listed in Table 5.

Several points should be noted about the values in Table 5. First, there is little effect of motor speed on the criterion verbal measures, with a significant influence only evident on the S-Words measure in Study 1. Second, the effects of perceptual speed and vocabulary were moderately large, with significant influences of perceptual speed on all but two measures and significant influences of vocabulary on every measure. And third, the direct or unmediated effects of age were small and nonsignificant on all measures except the Digit Symbol task in both studies, and the Word Switch task in Study 1.

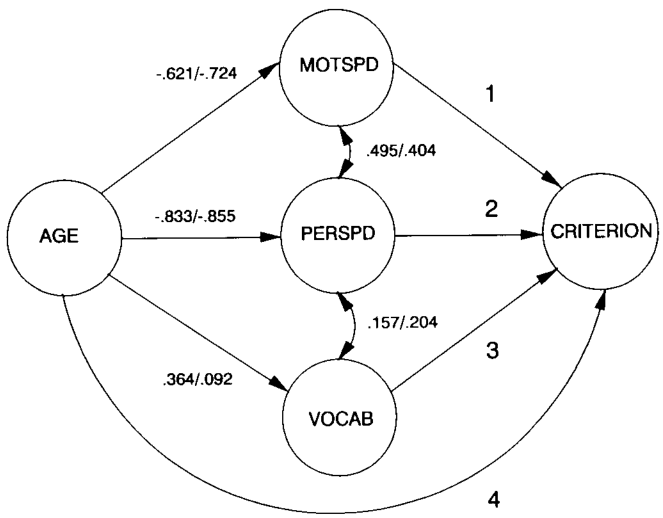

Figure 4. Model of relations among age, speed, word knowledge, and performance on the criterion tasks. Numbers adjacent to the paths are standardized path coefficients in the form (Study 1/Study 2). Values of the coefficients labeled 1 through 4 are presented in Table 5. MOTSPD, motor speed; PERSPD, perceptual speed; VOCAB, vocabulary.

Table 5. Standardized Path Coefficients for Model Illustrated in Figure 4

	Path			
	MotSpd 1	PerSpd 2	Vocab 3	Age 4
Study 1				
Digit Symbol	.257*	.403*	.083	−.221*
Nouns	.130	.222	.219*	−.073
S-Words	.203*	.209	.273*	−.081
Anagrams	−.093	.527*	.305*	.113
Word Switch	.043	.332*	.288*	−.363*
Study 2				
Digit Symbol	.172*	.306*	.182*	−.475*
Word Beginnings	−.119	.623*	.333*	.079
Word Endings	.174	.382*	.343*	−.043
Making Words	.131	.373*	.337*	−.131
Scrabble	.082	.437*	.392*	.160

Notes. MotSpd, motor speed; PerSpd, perceptual speed; Vocab, vocabulary.

*$p < .01$.

Discussion

As expected, the age differences in these studies were much smaller in tasks in which knowledge of words was relevant to task performance than in tasks in which word knowledge was not relevant. That is, the older adults averaged between two and three standard deviations below the mean of young adults on the perceptual speed and Digit Symbol variables, but were within about one standard deviation on most of the criterion tasks. Moreover, this was true in both studies, despite a less elite sample (as judged from scores on the vocabulary and Digit Symbol tests) of older adults in Study 2 than in Study 1. The results of these studies are therefore consistent with the view (e.g., Salthouse, 1988) that the magnitude of the age-related influences in a cognitive task depends on the balance of speed and knowledge required in the task. If successful performance is primarily dependent on speed, then the age effects can be expected to be quite large, as is evident in the Digit Symbol task. However, if knowledge is an important aspect of the task, as in most of the criterion verbal tasks examined in these studies, then the age effects can be expected to be much smaller. The data summarized in Figure 4 and Table 5 allow this argument to be made more specific. Consider the anagram task in which the regression coefficients were .527 for perceptual speed and .305 for vocabulary. If knowledge were not important in this task, then the total age effect would be expected to be −.44 total sample standard deviation units (i.e., −.833 × .527); but if only knowledge were important, then the total age effect would be expected to be

.11 total standard deviation units (i.e., .364 × .305). Both the direction and the magnitude of the age effects can thus vary as a function of the relative involvement of speed and knowledge in the task.

The results of these studies suggest that inconsistencies in earlier studies with tasks similar to those investigated here may be at least partially attributable to variations in the level of word knowledge or vocabulary ability among the research participants. That is, the studies in which the age differences in fluency were quite pronounced (e.g., Birren, 1955; McCrae, Arenberg, & Costa, 1987) may have had samples with zero or negative relations between age and word knowledge, whereas studies with small to nonexistent age relations (e.g., Davis et al., 1990; Mittenberg, Seidenberg, O'Leary, & DiGiulio, 1989; Schaie, 1983) may have had samples in which the older adults were equal to or superior to the young adults in word knowledge. The absence of significant age differences in anagram performance reported by Hayslip and Sterns (1979) may also be attributable to greater vocabulary knowledge for older participants relative to young participants in their study.

A major goal of the current studies was to determine the mechanism responsible for the reduced age effects in tasks in which knowledge is likely to have a substantial influence. Two possible mechanisms were identified. One is that knowledge could be more important in older adults, as reflected by a larger regression weight for vocabulary as a predictor of performance in the criterion tasks. An alternative possibility is that the determinants of performance may remain the same in the two groups, but that older adults have a higher average level of knowledge and a lower average value of speed. These two possibilities, although not mutually exclusive, have quite different implications about the role of knowledge in any age-related compensation that may be occurring. In the former case, knowledge might be considered to replace speed as a primary determinant of individual differences in performance, whereas in the latter case both speed and knowledge would be still important, and only the average values of each predictor might change with age.

The results across the eight tasks in the two studies were more consistent with the second, weak, form of compensation because there was little evidence that the regression equations predicting criterion performance differed across the two groups. This finding indicates that, even though young and old adults may differ in the average values of speed and knowledge, the two variables appear to have the same predictive importance in both groups. In other words, high levels of knowledge are just as advantageous to young adults as to older adults, and high levels of speed are just as advantageous to older adults as to young adults.

Another interesting result in these studies was the discovery that the correlations between the perceptual speed and vocabulary variables were substantially higher in the samples of older adults than in the samples of young adults. This type of "factor convergence" has been reported many times previously (e.g., Cunningham, 1980; Schaie, Willis, Jay, & Chipuer, 1989) and could have at least two potential origins. One possible cause of the higher correlations could be that the two abilities are more closely related with advancing age because people who experience declines in one ability also tend to have declines in other abilities that were once unrelated. This interpretation is consistent with the idea that there may be some type of common process underlying the age-related effects in different abilities, and that when it begins to deteriorate there are negative consequences for many abilities.

A second possible cause of the larger correlations among older adults is that, even though there may be age-related declines in perceptual speed, those individuals with the fastest speeds may have experienced larger increases in their verbal knowledge over the years of adulthood, and consequently the higher correlation may be a reflection of a greater increase in acquired vocabulary information from the period of young to old adulthood for those individuals with the fastest values of perceptual speed. That is, individuals with faster speeds may be quicker at integrating a word with its context to infer its meaning, faster at comprehending and integrating information while reading, or simply more effective at assimilating new information. This perspective thus suggests that the larger correlation between speed and knowledge among older adults is a reflection of many decades in which learning of word meanings was facilitated by faster speed of processing. Rather than representing differential *decline* across older adults with linked abilities, therefore, the higher correlation with increased age may represent differential *accumulation* of knowledge with speed having a causal influence on the rate of information accumulation or learning.

Unfortunately, both of these suggestions are merely speculations at the current time, and more research is needed to determine whether the existence of larger correlations among older adults for abilities that are unrelated in young adults reflects a global deterioration, or a selective increase in one ability that might be at least partially mediated by the other ability. Regardless of the explanation for the larger correlations between variables in older adults, however, the results of the present studies appear unequivocal in suggesting that speed and knowledge have the same importance as predictors of performance in simple verbal tasks among young and old adults. Age differences are reduced in tasks with moderate to large knowledge involvement not because of changes in the predictive value of different factors at different ages, but because the average level of one performance determinant (knowledge) tends to increase with age at the same time that the average level of the other performance determinant (speed) tends to decrease.

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References

Birren, J. E. (1955). Age changes in speed of responses and perception and their significance for complex behavior. In *Old age in the modern world* (pp. 235–247). Edinburgh: Livingstone.

Cunningham, W. R. (1980). Age-comparative factor analysis of ability variables in adulthood and old age. *Intelligence, 4,* 133–149.

Davis, H. P., Cohen, A., Gandy, M., Colombo, P., VanDusseldorp, G., Simolke, N., & Romano, J. (1990). Lexical priming deficits as a function of age. *Behavioral Neuroscience, 104,* 288–297.

Hayslip, B., & Sterns, H. L. (1979). Age differences in relationships between crystallized and fluid intelligences and problem solving. *Journal of Gerontology, 34,* 404–414.

McCrae, R. R., Arenberg, D., & Costa, P. T. (1987). Declines in divergent thinking with age: Cross-sectional, longitudinal, and cross-sequential analyses. *Psychology and Aging, 2,* 130–137.

Mittenberg, W., Seidenberg, M., O'Leary, D. S., & DiGiulio, D. V. (1989). Changes in cerebral functioning associated with normal aging. *Journal of Clinical and Experimental Neuropsychology, 11,* 918–932.

Salthouse, T. A. (1984). Effects of age and skill in typing. *Journal of Experimental Psychology: General, 113,* 345–371.

Salthouse, T. A. (1985). Speed of behavior and its implications for cognition. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (2nd ed., pp. 400–426). New York: Van Nostrand Reinhold.

Salthouse, T. A. (1988). Effects of aging on verbal abilities: Examination of the psychometric literature. In L. L. Light & D. M. Burke (Eds.), *Language, memory and aging* (pp. 17–35). New York: Cambridge University Press.

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

Schaie, K. W. (1983). The Seattle Longitudinal Study: A 21-year exploration of psychometric intelligence in adulthood. In K. W. Schaie (Ed.), *Longitudinal studies of adult psychological development* (pp. 64–135). New York: Guilford Press.

Schaie, K. W., Willis, S. L., Jay, G., & Chipuer, H. (1989). Structural invariance of cognitive abilities across the adult life span: A cross-sectional study. *Developmental Psychology, 25,* 652–662.

Webster's Ninth New Collegiate Dictionary. (1985). Springfield, MA: G & C Merriam & Co.

Wechsler, D. (1981). *Manual for the Wechsler Adult Intelligence Scale–Revised.* New York: The Psychological Corporation.

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