Processing Speed and Memory in Aging and Dementia

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We examined the role of processing speed (PS) as a mediator of age-related and dementia-related differences in cued recall and text memory. Consistent with previous research, statistical control of PS significantly attenuated or eliminated age differences on each of the memory measures. However, age-related decline in the ability to benefit from conditions of increased encoding specificity was not mediated by PS. In contrast to the results for age effects, statistical control of PS did not significantly attenuate dementia-related memory differences, suggesting that processing speed is not an important dementia-related memory impairment. The implications of these findings for interpreting residual age effects and the possible influence of preclinical dementia on studies of normal aging are discussed.

A TOPIC of recent debate in cognitive aging research concerns the role of process-specific and general influences in accounting for age effects on cognitive tasks. The existence of process-specific age effects is not in question: There are important exceptions to generalized age deficits involving different aspects of cognition, such as memory (e.g., Fisk & Rogers, 1991; Swearer & Kane, 1996), word recognition (e.g., Allen, Madden, Weber, & Groth, 1993; Madden, Pierce, & Allen, 1993), and arithmetic processing (e.g., Allen, Ashcraft, & Weber, 1992; Geary & Wiley, 1991). What is at issue is the minimum number of factors or dimensions that must be postulated to account for age differences on a wide number of cognitive variables. This issue is often addressed by examining the relative magnitude of age effects before and after statistical control of variables thought to reflect basic processing sources. One influential line of research has been the study of how individual differences in processing speed can account for cognitive age effects.

The role of speed as a mediator of adult age differences in memory and other cognitive abilities has been demonstrated repeatedly by Salthouse and his colleagues (Salthouse, 1993b, 1994b, 1996b; Salthouse & Babcock, 1991; Salthouse, Fristoe, & Rhee, 1996) as well as by numerous other investigators (Bryan & Luszcz, 1996; Hultsch, Hertzog, & Dixon, 1990; Lindenberger, Mayr, & Kliegl, 1993; Nettelbeck & Rabbit, 1992). Evidence for the mediating role of speed comes from analyses that demonstrate that statistical control of measures of simple processing speed substantially reduces or eliminates age-related variance in memory measures. This phenomenon has been reliably demonstrated for free recall (Bryan & Luszcz, 1996; Hultsch et al., 1990; Salthouse, 1993a; Salthouse et al., 1996), paired associates (Salthouse, 1994a), memory for text (Hultsch et al., 1990; Lindenberger et al., 1993), and for cued recall (Park et al., 1996).

Salthouse (1996a) has recently proposed the processing-speed theory of adult age-associated cognitive change, which postulates that increased age in adulthood results in a decrease in the speed with which many elementary processing operations can be executed; this in turn results in impairments of higher order cognitive functions, such as memory and reasoning. One implication of processing-speed theory and the research it is based on is that much of what were thought to be age-associated memory differences may only be apparent memory differences. That is, there seems to be little evidence to suggest that age-associated memory differences have much to do with age differences in processes specific to memory, such as encoding or retrieval, because these differences are substantially reduced by statistically controlling for processing speed. Although memory performance declines with advanced age, this decline in memory function may result from a more general deficit in processing speed, which can also account for age-associated impairments in other cognitive abilities (Fisk & Warr, 1996; Lindenberger et al., 1993; Salthouse et al., 1996; Salthouse, 1996a).

A second implication of processing speed theory is that to identify a specific (or genuine) age-related memory impairment, one must first determine to what extent the age difference in question is mediated by processing speed. Significant residual age effects (i.e., age differences that remain after statistical control of processing speed and other relevant covariates) have been observed in several previous studies of memory (Nettelbeck & Rabbit, 1992; Salthouse, 1993b; Salthouse et al., 1996) and might point to specific memory processes that are especially vulnerable to the aging process. By contrasting the residual age effects from different types of memory procedures, it may be possible to identify specific mechanisms underlying age-associated memory change that cannot be explained by a general (nonspecific) deficit in processing speed.

The current research has several aims, which will be addressed in two sets of analyses (Study 1 and Study 2). The first study compares a sample of young and older adults on several memory measures to examine the role of speed in
mediating age differences on different types of memory tasks. In particular, little is known about how individual differences in processing speed relate to age differences in cued recall tasks. Cued recall is important because it is necessary for maximum retrieval and accurate assessment of memory ability (Tulving & Pearlstone, 1966; Tulving & Osler, 1968; Tulving, 1979). One recent study by Park et al. (1996) examined the role of processing speed in accounting for age differences on cued recall. They found a strong correlation (.48) between latent constructs of processing speed and cued recall, and no direct effect of age on cued recall performance after controlling for speed. Therefore, one aim of the present study is to replicate the findings of Park et al. using a cued recall procedure developed by Buschke (Buschke, Sliwinski, Kuslansky, & Lipton, 1995, 1997).

A second related aim is to test whether the influence of processing speed is equivalent for different types of memory procedures (i.e., cued recall and text memory). Although statistically adjusting for processing speed reduces substantially age-related variance on a variety of memory measures, tests for equivalence of age-effects among different types of memory procedures before and after this adjustment are not usually conducted. That is, age-effects might be larger for some types of procedures that isolate memory processes especially susceptible to the effects of aging. If these differential age-effects were eliminated by adjusting for speed, then one could argue that they resulted from the differential influence of processing speed on each memory task. However, demonstrating differential age effects for certain types of memory procedures that remain even after controlling for processing speed and other relevant covariates would suggest the presence of age-associated impairment in specific memory processes (such as those required to benefit from conditions of increased encoding specificity).

A third aim of this study is to test whether age differences in the ability to benefit from conditions of enhanced encoding specificity are mediated by processing speed or whether this effect might reflect a genuine age-associated memory impairment. Encoding specificity is important for the study of memory because it is necessary for effective retrieval and accurate memory assessment (Thomson & Tulving, 1970; Tulving & Thomson, 1973). Buschke et al. (1995) introduced the Double Memory Test (DMT) procedure, which consists of two conditions, Category Cued Recall (CCR) and Item Cued Recall (ICR). The names of each condition (Category and Item) refer to the type of cue used during learning: in the CCR condition, category cues are used to search for and identify each to-be-remembered item, and in the ICR condition the items themselves are used to search for and identify each to-be-remembered word. The retrieval phases are identical: both conditions use cued recall of four items by each of 16 category cues (total of 64 words to be recalled for each condition). Table 2 from Buschke et al. (1995) shows that recall by both young and older adults was more than 100% higher in the CCR than in the ICR condition, but that the latter did not benefit as much from the use of category cues during learning. The present study will examine whether this possible age deficit in processes required to benefit from encoding specificity is mediated by processing speed measures shown to mediate age differences in other types of memory tasks.

There are at least two possible explanations of residual age-related memory differences. The first, which was mentioned above, is that age differences on memory tasks that remain after statistically controlling for processing speed might reflect genuine age impairments in cognitive processes specific to memory. An alternative explanation is that residual age effects are caused by an unidentified age-associated pathology, such as preclinical dementia (Crystal et al., 1996; Morris et al., 1996; Sliwinski, Lipton, Buschke, & Stewart, 1996), which may affect a significant proportion of presumably nondemented older adult samples. Therefore, before researchers can frame interpretations of residual memory effects, it is necessary to determine whether processing speed mediates dementia-related memory impairments as it does age-related memory impairments. The primary aim of Study 2 involves extending the questions posed in Study 1 to address the role of processing speed as a mediator of memory differences in dementia by comparing the sample of nondemented older adults from Study 1 with a sample of mildly demented older adults of similar age and education. In addition, testing whether the same mediational model that describes the relations among age, processing speed, and memory also describes the relations among dementia, processing speed, and memory can improve our understanding of the similarities and differences between age-related and dementia-related memory changes.

Figure 1 displays these mediational models in the form of path diagrams for age and dementia effects on memory, with processing speed as the candidate mediator. The coefficient for Path 1 would represent the direct effect of age or dementia on memory, while their indirect (or mediated) effects would be conveyed by the product of the coefficients for Paths 2 and 3. Previous research suggests that a large portion of the total age effect will be mediated and hence contained in Paths 2 and 3. However, there is no research suggesting how processing speed will function as a mediator.
mediator of dementia-related memory impairment. If memory is a primary deficit in dementia, that is, if the processes involved in memory function are directly affected by the disease, then one would predict that the majority of the total dementia effect would be direct (i.e., contained in Path 1). However, if memory is a secondary deficit in dementia, that is, if the disease influences memory function indirectly by affecting overall processing efficiency, then one would predict that the majority of the total dementia effect be indirect (i.e., mediated by processing speed).

If individual differences in processing speed can account for both age- and dementia-related memory impairment, then there would be evidence that the memory deficits in dementia differ in severity but not kind from memory deficits in nondemented elderly. If, on the other hand, processing speed does not mediate memory differences in dementia, then there would be evidence (at the functional level) to suggest that different mechanisms underlie age-related and dementia-related memory differences and that residual memory differences in studies using samples of presumably nondemented older adults might reflect, at least to some degree, the presence of preclinical dementia.

### Study 1

#### METHOD

##### Participants

All participants gave informed consent approved by the Committee on Clinical Investigations of Albert Einstein College of Medicine (AECOM). The 141 older adults (85 female and 56 male) were nondemented, healthy community-residing participants in a longitudinal study of memory and cognition (Project 2 of the Einstein Aging Study). The average age of the elderly participants was 81.5 (range 75–93). The 108 young adult (67 female and 41 male) subjects were healthy college students and nonfaculty staff at AECOM. The average age of the young adults was 22.9 (range 18–35). Younger adults had significantly more formal education than the older adults (15.1 vs 11.9 years, \( p < .01 \)). Participants were excluded if there was evidence of any of the following: disturbance of consciousness, medical or neurologic disease causing cognitive impairment, head injury with loss of consciousness for more than 1 hour, current psychiatric disorder, alcohol or drug dependence, endocrine or hematologic disease or malignancy not in remission for more than 2 years, or current use of psychotropic or antidepressant drugs. An additional criterion for the older participants was that they be diagnosed as "not demented" according to the procedures described in the Methods section for Study 2.

##### Testing Procedures

Cued Recall was measured using the DMT procedure that has been described in detail elsewhere (Buschke et al., 1995, 1997). The DMT consists of two tests that have identical retrieval conditions: both tests use cued recall of four items by each of 16 category cues (total of 64 words to be recalled for each test). The two tests differ only with respect to the controlled learning phase. For the CCR test, each trial consisted of the presentation on a computer screen of four words, each from a different category. Appropriate category cues were shown sequentially in the center of the screen. The subject was asked to find each item (e.g., eagle) and name it aloud when its category cue (e.g., bird) was shown. When all four items were identified, the next four items were presented, until one item from each of the 16 categories was presented. Category cues were not presented at acquisition for the ICR test. Instead, each word (i.e., item) was shown sequentially in the center of the screen. The participant was asked to point to each item (e.g., dog) and name it aloud when that item (dog) was shown in the center of the screen. After matching all four items, the next four items were presented, until all four items in each of the 16 categories were identified. Immediately after acquisition there was one trial of cued recall. The participant was asked to recall aloud in any order the four items from each category as each category cue was read aloud to the subject. Thirty seconds were allowed for recall of the items in each category. The same interval between acquisition and retrieval was maintained for all items by presenting the category cues in the order used for acquisition.

Text memory was assessed using the immediate recall from the Logical Memory I test, which is part of the Wechsler Memory Scale-Revised (Wechsler, 1987). Two stories (A and B) were read aloud to participants who were asked to recall as much of each story as possible as soon as it was completed. Two scores were used from this procedure, which reflect the total number of ideas recalled from each of the two stories.

Processing speed was measured by two tasks, the Digit Symbol Substitution Test from the WAIS-R (DSST, Wechsler, 1981) and a number copy task (Sliwinski et al., 1994). In the DSST, participants are presented with a sheet of paper that has a code table displaying pairs of digits and symbols. Beneath the code table are rows of double boxes with the digit in the top box and nothing in the bottom box. The participants are then asked to use the code table to determine which symbol is associated with each digit and to write as many symbols as possible in the empty boxes in a 90-second period. The number of correct symbols is the score for this task. In the number copy task, participants were presented with a two-digit number on the center of a computer screen and were required to copy the number by pressing the appropriate keys on the numeric keypad. Response time (RT) was measured as the time between stimulus presentation and the second keypress. Only correct responses were used to analyze RT.

Verbal knowledge was assessed using the Mill Hill vocabulary scale (Raven, Court, & Raven, 1986) and WAIS-R Vocabulary subtest from the WAIS-R (Wechsler, 1981).

#### RESULTS AND DISCUSSION

Descriptive statistics for all the cognitive measures are presented in Table 1. Independent samples \( t \)-tests confirmed that young adults outperformed the older adults (\( df = 247, p < .01 \)) on all measures of memory, verbal ability, and speed, except on the Mill Hill vocabulary test, for which performance was nearly identical in the two age groups. The ob-
correlated in both the young \(r = .55\) and elderly \(r = .51\) (related variance in three of the four memory measures was precipiable amount. However, controlling for processing speed resulted in considerable attenuation of age-related variance after adjusting for speed. Similar results were obtained for WAIS-R vocabulary measures. The Mill Hill vocabulary and WAIS-R vocabulary tests were well correlated in both the young \(r = .55\) and elderly \(r = .51\) samples. The same procedure was applied to the Mill Hill and WAIS-R vocabulary tests to compute a composite verbal ability measure. The Mill Hill and WAIS-R vocabulary measures were very well correlated in both the young \(r = .55\) and elderly \(r = .51\) samples. Because only extreme age groups were examined, age was treated as a dichotomous variable (0 = older adults, 1 = young adults). Both composite measures were scaled so that high values reflected better performance. A series of hierarchical regressions were then performed using standardized measures of cued recall (ICR, CCR) and text memory (Story A, Story B) as criterion variables and the dichotomous age, composite verbal ability, and composite processing speed measures of predictors.

Hierarchical Regression

Table 2 presents the results from the hierarchical regression analyses. The dichotomous age variable alone showed strong and significant relations to each of the memory measures, accounting for between 12 and 38% of the variance. Because all the memory measures were verbal, it was reasoned that verbal ability might play an important role in mediating age relations to memory. Column 2 of Table 2 suggests that this is not the case, as controlling for verbal ability did not attenuate the age-related variance by an appreciable amount. However, controlling for processing speed resulted in considerable attenuation of age-related variance in the memory measures. Specifically, the age-related variance in three of the four memory measures was attenuated by at least 95% by statistically controlling for processing speed (see Column 3 of Table 2). The effect of age remained statistically significant \(p < .01\) only for CCR, although there was still over a 90% reduction in the amount of age-related variance after adjusting for speed. Simultaneous adjustment for verbal ability and processing speed did not alter the pattern of results, although the age effect for Story B became statistically significant \(p < .01\). Because the two age groups differed significantly in terms of education, the above regressions were recomputed to determine whether including education altered the results. Although education significantly correlated with all memory measures, its inclusion in any of the models did not change the pattern of results reported in Table 2.

Table 2. Hierarchical Regression for Memory Measures Controlling on Composite Speed and Verbal Ability Measures, Study 1

<table>
<thead>
<tr>
<th>Criterion</th>
<th>B (Study 1)</th>
<th>(R^2) (Study 1)</th>
<th>B (Study 2)</th>
<th>(R^2) (Study 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCR</td>
<td>-1.25*</td>
<td>.38</td>
<td>-1.19*</td>
<td>.341</td>
</tr>
<tr>
<td>ICR</td>
<td>-0.94*</td>
<td>.22</td>
<td>-0.90*</td>
<td>.198</td>
</tr>
<tr>
<td>Story A</td>
<td>-0.72*</td>
<td>.13</td>
<td>-0.65*</td>
<td>.102</td>
</tr>
<tr>
<td>Story B</td>
<td>-1.01*</td>
<td>.25</td>
<td>-0.94*</td>
<td>.216</td>
</tr>
</tbody>
</table>

Notes: CCR = category cued recall, ICR = item cued recall, DigSym = digit symbol substitution test, CopyNm = number copy, Mhill = Mill Hill vocabulary, WVocab = WAIS-R vocabulary. *CopyNm is in seconds.

Served pattern of age differences is quite typical of comparisons between the performance of young and elderly adults.

The role of cognitive speed as a mediator of age differences in memory was examined by computing a composite speed index after converting the DSST and number copy measures into standard units and then averaging the \(z\)-scores. The DSST and number copy measures were well correlated in both the young \(r = .55\) and elderly \(r = .51\) samples. The same procedure was applied to the Mill Hill and WAIS-R vocabulary tests to compute a composite verbal ability measure. The Mill Hill and WAIS-R vocabulary measures were very well correlated in both the young \(r = .55\) and elderly \(r = .51\) samples. Because only extreme age groups were examined, age was treated as a dichotomous variable (0 = older adults, 1 = young adults). Both composite measures were scaled so that high values reflected better performance. A series of hierarchical regressions were then performed using standardized measures of cued recall (ICR, CCR) and text memory (Story A, Story B) as criterion variables and the dichotomous age, composite verbal ability, and composite processing speed measures of predictors.
The present results are quite consistent with previous studies that have demonstrated substantial reductions in age-related variance on memory measures after statistically controlling for speed. In some studies, all of the age-related variance in memory measures has been shown to be mediated through speed (Bryan & Luszcz, 1996; Lindenberger et al., 1993). However, some research has reported that significant relations between age and memory remain, even after controlling for processing speed (Nettelbeck & Rabbit, 1992; Salthouse, 1993b; Salthouse et al., 1996). Therefore, identifying reliable residual age effects (i.e., age differences in memory after controlling for speed and other covariates) is of particular interest because such effects might point to specific age-related memory changes that are not mediated by mechanisms related to cognitive slowing. The small but significant age effects for CCR that remained after adjusting for speed indicate the presence of residual age effects. This difference among age effects may not result only from the differential loading of the memory tasks on a common factor related to cognitive speed. Because this difference remains after partialling on speed, it may reflect a specific age-related impairment in processes related to the memory task.

**Encoding Specificity Analysis**

CCR coordinates acquisition and retrieval by using the same category cues in both phases of the test and results in a substantial improvement in the number of words recalled by young and older adults. Buschke and his colleagues (Buschke et al., 1995, 1997) have argued that recall is higher in CCR relative to ICR because the former condition optimizes encoding specificity, and that the failure of older adults to improve as much as the young suggests the presence of a specific age-associated impairment in processes needed to benefit from conditions of enhanced encoding specificity. The only procedural difference between CCR and ICR is that the former (but not the latter) uses the same category cues during acquisition and retrieval. Therefore, it is possible to obtain an estimate of the differential effect of using category cues during acquisition on recall performance of young and older adults by testing for age differences in CCR after partialling on ICR.

Because previous research (Buschke et al., 1995) has suggested a specific age deficit in encoding specificity as reflected in performance on the CCR-ICR residual, a path analysis was conducted to estimate the direct and indirect effects of age and to examine the role of processing speed in mediating age deficits in encoding specificity. The residual from the regression of CCR on ICR was used to represent the effect of encoding specificity (ES) in the model. The model also included the dichotomous age variable and the composite processing speed measure. Coefficients were simultaneously estimated for paths from age to speed and ES, and from speed to ES.

Figure 2 displays the results from this analysis. Solid lines indicate paths with significant coefficients, and dashed lines indicate paths whose coefficients failed to attain statistical significance. The standardized coefficient for Path 1 is significant, indicating a direct effect of age on ES. However, the more interesting finding from this analysis is that very little of the total age effect is mediated through processing speed. In fact, the path between processing speed and ES did not attain statistical significance, indicating that speed did not play an important role in accounting for age differences on the ES measure.

The present claim that performance on CCR after partialling for ICR reflects an effect of ES is somewhat complicated by the fact that using category cues during acquisition might promote deeper semantic processing (Craik & Lockhart, 1972) of the stimuli as well as enhance ES. Therefore, the overall effect might reflect a mixture of two effects: ES and depth of processing. Although the possible role of depth of processing in the present results cannot be conclusively determined, there are several lines of evidence to suggest that the primary effect is that of ES. First, existing research demonstrates that ES is a more powerful determinant of performance than depth of processing (Tulving, 1979), and that depth of processing effects can be eliminated (Fisher & Craik, 1977; McDaniel, Friedman, & Bourne, 1978) or even reversed (Morris, Bransford, & Franks, 1977) by manipulating encoding specificity. Second, the controlled search procedure of the DMT (see Method) ensured that all subjects recognized the semantic relation between cues and targets. Therefore, age differences in CCR could not be attributable to the failure of older participants to appreciate the semantic relations between cues and targets. And third, one could reasonably expect that the ability to benefit from deeper semantic processing might be related to verbal ability and, consequently, that adjusting for verbal ability might attenuate these age differences. The regressions described in Table 2 indicate that this is not the case. Specifically, age differences were relatively unchanged after controlling for verbal ability and the incremental variance attributable to age did not decrease, suggesting that verbal ability did not mediate the age effect.

**Summary of Study 1.** — There are three important results from Study 1. First, statistical control of speed was shown to reduce substantially or eliminate age differences in measures of cued recall and text memory. A substantial proportion of the age-related variance was shared between these memory measures, speed and verbal ability. Second, although speed mediated the entire effect of age on text recall and ICR, there remained unique age-related variance in cued recall in the CCR measure. Third, there was an age...
deficit that was not mediated by processing speed in the CCR-ICR residual, which might be a specific age-related impairment in processes required to benefit from ES.

Study 2

The primary purpose of Study 2 was to address the question of whether processing speed mediates dementia-related memory differences as it does age-related memory differences. The answer to this question is especially important in light of the recent study by Salthouse et al. (1996) that demonstrated that much of the age-related variance is shared among measures postulated to be sensitive to functioning in specific neuroanatomical regions of cortex. Specifically, Salthouse et al. (1996) showed that much of the age-related variance in tests thought to reflect impairment in frontal lobes (e.g., verbal fluency, sequencing, and concept identification), parietal lobes (e.g., visual-spatial ability), and temporal lobes (verbal memory) was shared, and that age differences were substantially reduced by statistical control of speed. To account for their findings, Salthouse et al. (1996) proposed that “something analogous to processing speed appears to play a key role in the age-related influences that have been found to be shared across different cognitive measures” (p. 283). The findings from Study 1 are certainly consistent with this proposal in that much of the age-related variance in cued recall and memory for text was shared with a composite measure of processing speed. If dementia-related variance in memory measures also is shared with processing speed, then one could argue that identifying the neuroanatomical and neurophysiological mechanisms responsible for diminished processing speed might facilitate the understanding of memory impairment observed in dementia as well as in normal aging. However, if little or no dementia-related variance in memory measures is shared with processing speed, then one could conclude that the construct of processing speed does not mediate memory deficits that result from dementia and that different mechanisms underlie age-associated and dementia-associated memory changes.

Method

Subjects. — The 140 older adult participants from Study 1 served as the nondemented control sample for this study. Twenty-nine older adult participants (19 female, 10 male) who were diagnosed as demented according to DSMIII-R criteria comprised the dementia sample (American Psychiatric Association, 1987). A trained clinician reviewed subject charts, which contained information about performance on neuropsychological tests, responses on medical/health questionnaires, and findings on neurologic examination. The average age of the demented sample was 81.3 years, and the average years in school was 11.0, neither of which differed from the nondemented sample (t = 1.0, n.s.). The demented sample made more errors than the nondemented sample (t[167] = 12.6, p < .01) on the Blessed Mental Status exam (Roth, Tomlinson, & Blessed, 1967), but were only mildly impaired (mean number of errors = 9.7).

Procedure. — See Study 1.

Results and Discussion

Independent sample t-tests of the means displayed in the second and third columns of Table 1 indicated that the demented subjects performed worse on nearly all the cognitive measures (df = 167, p < .01). Demented subjects, on average, could identify one fewer word on the Mill Hill vocabulary test, but this difference did not reach statistical significance (p = .10). Calculating standardized effects (d = [mean age-mean dementia]/pooled SD) for the two speed measures (d = 1.09, 1.51 for DSST and number copy, respectively), the DMT memory measures (d = 2.22, .96 for CCR and ICR, respectively), and Logical Memory (d = 1.23, 1.13 for Story A and B, respectively) shows comparable effect sizes for all measures except the CCR, which is much larger than the other memory and speed measures. This is consistent with other analyses, which show that the CCR is more sensitive to dementia-related memory impairment than some other commonly used memory tests (Buschke et al., 1997).

Hierarchical regression. — The results are reported in Table 3 from a series of regressions conducted to examine the effect of dementia on measures of cued recall and memory for text before and after controlling for processing speed and verbal ability. The demented subjects performed significantly worse on the measures of cued recall (R2 = .36 and .10 for CCR and ICR, respectively) and text memory

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Dementia After Verbal Ability</th>
<th>Dementia After Speed</th>
<th>Dementia After Speed + Verbal Ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCR</td>
<td>B</td>
<td>ΔR2</td>
<td>B</td>
</tr>
<tr>
<td>ICR</td>
<td>-1.87*</td>
<td>.41</td>
<td>-1.62*</td>
</tr>
<tr>
<td>Story A</td>
<td>-0.77*</td>
<td>.12</td>
<td>-0.72*</td>
</tr>
<tr>
<td>Story B</td>
<td>-0.91*</td>
<td>.15</td>
<td>-0.88*</td>
</tr>
</tbody>
</table>

F(3,165) = 14.7, p < .01 F(3,164) = 10.5, p < .01 F(3,164) = 8.7, p = .01 F(3,163) = 7.5, p = .01

Note: F-tests are multivariate contrasts for equality of Bs across criterion variables. ΔR2 = increment in R2; CCR = category cued recall; ICR = item cued recall.
*p < .01.
Comparing the dementia-related variance in Columns 1 and 2 indicates that control of verbal ability did little to reduce the effect of dementia on cued recall and text memory.

Column 3 displays the proportion of dementia-related variance in memory after controlling for processing speed. Controlling for processing speed results in only a modest attenuation of dementia-related variance: 40% for CCR, 26% for ICR, 49% for Story A, and 50% for Story B. This is in marked contrast with the results from Study 1, which showed over 90% attenuation of the age-associated variance in these memory measures by statistical control on the composite processing speed measure. It is unlikely that the failure of statistical control of processing speed to attenuate dementia-related memory differences is due to a peculiarity of the speed measures used, because the same composite measure substantially reduced the age-related differences described in Study 1. Controlling for processing speed and verbal ability together did not alter the pattern of results, as a large proportion of dementia-related variance remained. These results indicate that controlling for processing speed does not eliminate or reduce dementia-related memory differences as it does age-related memory differences.

Comparison of direct age- and direct dementia-related memory differences. — So far the results indicate that speed mediates a large proportion of age- but not dementia-related memory differences. To provide a systematic comparison of the role of processing speed in mediating age and dementia memory differences, the results from the regression described in Tables 2 and 3 are displayed graphically in Figure 3. The largest age ($R^2 = .38$) and dementia ($R^2 = .41$) differences were observed for CCR, and CCR was the only memory test for which age differences remained significant after adjusting for processing speed ($\Delta R^2 = .035$). In contrast to the substantial attenuation of age differences, dementia differences remained significant for every memory test after controlling on the composite speed measure.

Another useful means of displaying this dissociation is to decompose the total age and dementia effects into their direct and indirect (mediated) components. For example, the total effect for age is equal to the regression coefficient for age when age alone is in the model, the direct effect is equal to the regression coefficient for age when both age and speed are in the model, and the indirect effect is the difference between total and direct effects. Figure 4 summarizes the decomposition of the total age and total dementia effects into their direct (solid bars) and indirect (light bars) components. For three of the four memory measures, the indirect age effect is larger than the direct age effect. In contrast, the direct dementia effect is much larger than the indirect effect for all four memory measures. Another feature of the data in Figures 3 and 4 is that the degree of attenuation in dementia differences by controlling for speed is...
roughly equivalent on each test, which suggests that amount of attenuation does not appear to differ between memory tests that are most sensitive (i.e., CCR) and least sensitive (i.e., ICR) to dementia impairment as indicated by $R^2$.

**General Discussion**

This discussion focuses first on the three major findings of the first study: (1) processing speed mediates age difference in cued recall; (2) there are differences in residual age effects for different types of memory, the largest being for cued recall; and (3) processing speed does not mediate the age deficit in the CCR-ICR residual (ES). Then the finding from Study 2 that processing speed does not mediate dementia-related memory differences and the implications this finding has for understanding age-associated memory change is discussed. Before discussing the findings, there is a need to discuss an important caution regarding the statistical procedures used and their interpretation.

Interpretations of the present findings rely to some extent on commonality analysis (i.e., decomposing the effect of independent variables into unique and shared components) to determine the relative importance of an independent variable. Despite its widespread use in cognitive aging research, this practice is highly questionable. Unless predictor variables are completely orthogonal, as is the case with experimental designs, the practice of partitioning the regression sum of squares (i.e., the proportion of variance accounted for) is an inherently ambiguous enterprise. Statisticians have strongly cautioned against using variance partitioning to determine the relative theoretical importance of variables included when the predictor variables are intercorrelated (Darlington, 1968). Although the present claims regarding the relative importance of speed as a mediator of age and dementia effects on memory depend to some extent on widely accepted analytic techniques, they must be viewed in light of the inherent limitations of variance partitioning in hierarchical regression analysis.

**Speed Mediation of Age Differences in Cued Recall**

Before discussing the evidence that speed attenuates age differences in cued recall, it is important to establish that there is an age difference before adjusting for processing speed. The analysis of both cued recall measures (Table 2) indicates significant and substantial age effects, but that the amount of age-related variance in the CCR and ICR measures was substantially decreased after statistical control on a composite speed measure. This finding is consistent with the study of Park et al. (1996), which reported large age differences in cued recall that were eliminated by statistical control of processing speed. These results are especially compelling, because both ICR and CCR used controlled learning procedures (Buschke, 1984, 1987) to ensure that both young and older participants encoded each item, and because participants were not restricted in the amount of time allowed to study each item. Moreover, CCR used the same category cue at learning and retrieval to maximize encoding specificity and optimize recall. Therefore, the present findings indicate that the largest age differences occur under conditions designed to promote optimal encoding and retrieval, and that these differences appear to be largely mediated by processing speed. However, it is still possible that there exist detectable age differences in specific memory processes that are not accounted for by speed. That there were significant residual age effects for the CCR measure is consistent with this possibility.

**Differential Age Effects After Control of Processing Speed**

Although the literature is very consistent with regard to the attenuation of age differences by controlling for speed, there is little consensus regarding the existence of residual age effects or what they mean. That is, there seems to be considerable evidence that speed plays an important role in accounting for adult age differences in memory, but little agreement on whether there are meaningful residual age effects for different types of memory. For example, Hultsch et al. (1990) report significant, although substantially attenuated, age effects for both text and word memory after control of speed measures, working memory, and gender, whereas the present study found that speed mediated the entire effect of age on memory for text. Results from structural modeling also disagree about the presence of residual age effects. Lindenberger et al. (1993) reported no direct influence of age on memory as measured by text memory, paired associated, and activity recall, whereas Salthouse et al. (1996b) reported direct effects of age on a memory factor indicated by paired associates and free recall learning tasks.

One possible explanation for the apparent discrepancy in findings across studies is that studies with larger samples tend to detect residual age effects because of increased power relative to smaller sample studies. Although differences in statistical power might explain why some studies detect residual age effects and others do not, the lack or presence of statistical power cannot explain how to interpret these findings. Because there is considerable evidence to support the importance of speed as a mediator of age difference in different types of memory, attention should now be turned to offering principled accounts of residual age effects. Age-related variance in memory measures that remains after controlling for processing speed (and other covariates) might indicate the presence of a specific age impairment in particular memory processes that is not mediated by the general deficit in processing speed. That is, the contrast of residual age effects across different types of memory procedures could prove to be a valuable means of identifying a genuine age-related memory impairment (Buschke & Grober, 1986) that is not secondary to an age-related decline in processing speed. The present study attempted to provide such principled contrasts by examining measures thought to reflect different types of memory. Although there was consistency across the measures in that processing speed substantially reduced age differences, there remained significant residual age differences on the CCR measure.

**A Specific (Nonmediated) Age Deficit in ES**

The rapidly growing literature addressing the role of speed and other ability factors as mediators of adult age differences in memory has improved understanding of the general (nonspecific) mechanisms that underlie many different age effects. General mechanisms are important be-
cause they can parsimoniously account for a wide range of age-related cognitive phenomena. Mechanisms related to processing speed are general because they are not specific to memory performance; processing speed can account for age differences in cognitive abilities other than memory (see Salthouse, 1996b, for a review of the literature). However, a complete description of cognitive aging requires the identification of specific as well as general mechanisms, and a sensible approach might be to invoke specific accounts only when hypothesized general mechanisms fail to explain an important age-related phenomenon.

One such phenomenon appears to be the failure of older adults to benefit to the same extent as younger adults from conditions of increased ES. This phenomenon has been demonstrated previously (Buschke et al., 1995; Rabinowitz, Craik, & Ackerman, 1982) and was shown to remain even after adjusting for measures of speed, verbal ability, and working memory. The results from Study 1 confirm this previous finding. The CCR and ICR components of the DMT are identical except that the latter uses category cues only during retrieval whereas the former uses the same cues during both learning and retrieval. Therefore, the residuals obtained from regressing CCR on ICR can be interpreted to reflect the benefit of receiving the same category cues at the time of learning and recall. Because older adults have lower residuals than younger adults, the argument has been advanced that there is an age-associated deficit in the ability to benefit from ES.

However, age differences in ES have not been invariably obtained. Rabinowitz et al. (1982) compared the performance of older and young adults on a task in which target words were paired either with a strong or weak associate during acquisition. These associates served as cues during retrieval. Their results indicated that both young and older adults benefited by the presentation of strong cues at encoding and retrieval, but that only the young adults benefited from weak cues presented at both encoding and retrieval. In contrast, other studies (Park, Puglisi, Smith, & Dudley, 1987; Puglisi, Park, Smith, & Dudley, 1988) have demonstrated that older adults benefit to the same extent as young adults from ES. Procedural differences among the present and previous studies might account for these discrepant findings. Although they concluded that age did not interact with ES, Puglisi et al. noted that older adults did not benefit from specific encoding for recall of words under a divided attention task. They argued that task difficulty and stimulus characteristics might determine the conditions under which age interacts with ES, and that only under high difficulty might older adults show a deficit in specific encoding. The DMT assesses ES by using "cue overload" (Watkins, 1979) such that multiple targets are associated with each category cue. Because increasing the number of targets per cue increases task difficulty (Earhard, 1967), Puglisi et al.'s account of the discrepant findings regarding age and encoding specificity might apply to the present results. This account predicts that age by encoding specificity interactions should be influenced by manipulations of task difficulty, such as the number of targets per cue. Additional research is needed to isolate the encoding mechanisms responsible for the differential effect of age on the CCR-ICR residual under cue-overload.

The next logical question is whether this age effect is general (mediated by speed) or specific (not mediated by speed). The results from Study 1 indicate that this deficit is specific, or at least that it is not mediated by processing speed. This finding is important because it represents an example of a specific age-related impairment in a construct known to be central to memory performance (Tulving, 1979), and because it provides a rare example of an age difference that is not accounted for by processing speed. Although it is tempting to interpret this result as demonstrating a specific effect of normal cognitive aging on memory, such a conclusion is premature for two reasons. First, although the present finding supports previous work (Buschke et al., 1995), it would be desirable to replicate these findings using procedures other than the DMT. Second, the possible effects of preclinical dementia must be ruled out before concluding that the observed age differences are attributable to normal aging and not to unidentified age-related pathology.

Mediators of Dementia-Related Memory Impairment and Preclinical Dementia

The primary purpose of Study 2 was to determine whether processing speed mediates dementia-related memory differences as it does age-related memory differences. The results indicate that although control of processing speed substantially attenuates the amount of age-related variance in memory measures, it does not attenuate dementia-related variance nearly as much. Because the total age and dementia effects are approximately equivalent in magnitude, this finding cannot be attributed to the presence of a larger total dementia effect.

The finding that large residual dementia effects remain after control of processing speed is important for two reasons. One significant implication of this finding is that the memory impairment in dementia is not simply a more severe form of the kind of memory decline observed in healthy aging: The two are qualitatively different. This finding supports the argument that memory impairment in dementia and memory decline in aging cannot be placed on a single severity continuum, since if it could, one might reasonably expect that the same factors should mediate cognitive impairment attributable to either aging or dementia.

Results from Study 2 provide evidence that the same factors are not responsible for both age-related and dementia-related memory change. Instead, the present findings suggest that although memory decline in healthy aging may be secondary to general declines in processing speed and efficiency, memory impairment in dementia is primary in the sense that it is not mediated by a more general functional deficit. It is important to note that the present study cannot rule out the possibility that some general factor other than processing speed could mediate dementia-related memory effects. However, the present results do support the contention that the same general factor, i.e., processing speed, that accounts for a substantial amount of age-related cognitive change cannot account for dementia-related impairment in memory.

This conclusion is interesting in light of recent histopathologic evidence suggesting that the pathology associated
with early Alzheimer's disease is not a part of the normal aging process (Morris et al., 1996). Admittedly, there are no direct links between the functional mediators of cognitive change (e.g., processing speed) and pathologic variables (e.g., senile plaques); however, converging evidence from experimental studies, longitudinal studies (Bondi, Monsch, Galasko, & Butters, 1994; Jacobs et al., 1995; LaRue & Jarvik, 1987; Masur, Sliwinski, Lipton, Blau, & Crystal, 1994; Sliwinski, Lipton, Buschke, & Stewart, 1996), and neuropathologic studies (Morris et al., 1996) supports an essential distinction between aging and dementia.

A second reason why the finding that processing speed mediates age-related but not dementia-related memory effects is important is that it suggests an alternative interpretation of the residual age effects from Study 1. The residual age effects might not result entirely from cognitive aging per se but from the presence of individuals with unrecognized preclinical dementia. Preclinical dementia refers to that stage of a dementing disease, such as Alzheimer's, in which cognitive decline is such that affected individuals still perform within normal limits on cognitive measures. Therefore, such individuals can usually be detected only in the context of longitudinal research by conducting retrospective analyses at a time at which their symptoms are severe enough to permit a diagnosis of dementia. Unrecognized preclinical dementia has been shown to contaminate estimates of aging effects in well-screened, presumably nondemented samples of healthy older adults (Sliwinski et al., 1996). Therefore, it is possible that the current sample is a mixture of two subsamples representing different populations of individuals, namely nondemented adults and adults with preclinical dementia. Consequently, the overall residual age effects from Study 1 might be driven, at least in part, by a mixture of two different effects, namely an aging effect that is mediated by processing speed and a dementia effect that is not.

If residual age effects are partly driven by the contamination of older adult samples by preclinical dementia, then one would expect them to be largest for those measures most sensitive to dementia-related memory impairment. A recent study (Buschke et al., 1997) compared the discriminative validity of the DMT (CCR, ICR), WMS Logical Memory, and the WMS Paired Associated memory tests for classifying individuals with early, mild dementia. The CCR proved to be the most sensitive test for discriminating individuals with mild dementia from age- and education-matched controls, and the specific memory deficit in early dementia was shown to be impairment of the ability to benefit from ES. The present experiment showed residual age effects only for the CCR test and that these effects may have resulted from a specific deficit of the aged to benefit from ES. Although the data are far from conclusive, converging evidence is consistent with the possibility that residual age effects on the CCR test (and the CCR-ICR residual) may be driven, at least in part, by contamination of the presumably nondemented older adult sample by individuals with preclinical dementia.

Conclusions
The present results differ from previous findings (Park et al., 1987; Puglisi et al., 1988) in that older adults, although showing a large ES effect, did not benefit as much as young adults from specific encoding. The present experiment did not include the necessary conditions to determine whether this was the result of an age deficit in processes required for ES or to the effect of cue overload on encoding processes. It is important to determine the mechanism underlying this age deficit because it is a rare example of an age effect that is not mediated by processing speed and may point to specific (as opposed to general) age effects on encoding processes.

Study 2 identified an important dissociation between normal aging and dementia, suggesting that the memory deficit in dementia is not simply an exaggeration of the memory decline in normal aging. This result supports an essential distinction between cognitive aging and dementia, and is not consistent with an aging–disease (dementia) continuum account of memory decline in older adults.

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