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Contributions of processing ability and knowledge to verbal memory tasks across the adult life-span

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This study investigated the relationships of processing capacity and knowledge to memory measures that varied in retrieval difficulty and reliance on verbal knowledge in an adult life-span sample ($N = 341$). It was hypothesized that processing ability (speed and working memory) would have the strongest relationship to tasks requiring active retrieval and that knowledge (vocabulary ability) would be related to verbal fluency and cued recall, as participants relied upon verbal knowledge to retrieve category items (fluency) or develop associations (cued recall). Measurement and structural equation models were developed for the entire sample and separately for younger (aged 20–54 years, $n = 168$) and older (aged 55–92 years, $n = 173$) subgroups. In accordance with the hypotheses, processing ability was found to be most highly related to free recall, with additional significant relationships to cued recall, verbal fluency, and recognition. Knowledge was found to be significantly related only to verbal fluency and to cued recall. Moreover, knowledge was more important for older than for younger adults in mediating variance in cued recall, suggesting that older adults may use age-related increases in knowledge to partially compensate for processing declines when environmental support is available in memory tasks.

In the study of cognitive ageing, perhaps the most well known finding is that processing ability declines with advancing age even in the absence of pathology (Park, Lautenschlager, Hedden, Davidson, Smith, & Smith, 2002; Rabbitt & Lowe, 2000; Salthouse, 1996). Processing

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ability refers to one's capacity for efficiently executing mechanisms of controlled attention that are invoked to perform tasks requiring rapid selection of information, switching among multiple task goals, and actively maintaining multiple representations (e.g., Kane, Bleckley, Conway, & Engle, 2001, Meyer & Kieras, 1997). Common measures of processing ability, such as speed of processing and working memory capacity measures, predict age-related changes and individual differences in fluid intelligence and in long-term memory (Engle, Kane, & Tuholski, 1999a; Engle, Tuholski, Laughlin, & Conway, 1999b; Park et al., 2002; Park et al., 1996; Verhaeghen & Salthouse, 1997). In contrast to the declines in processing abilities, knowledge, as measured by vocabulary ability or semantic knowledge, tends to remain stable across the adult life span or show age-related increases until very late in life (Lindenberger & Baltes, 1997; Park et al., 2002; Salthouse, 1993a; Schaie, 1994, 1996).

Although there are abundant demonstrations of how decreases in measures of processing capacity such as speed and working memory predict performance on a range of higher order tasks that include long-term memory and reasoning, less is known about the relationship of knowledge to such tasks. There is evidence that knowledge may be a more important component of performance in late adulthood compared to earlier adulthood when processing capacity is at its peak. For example, findings indicate that knowledge and expertise in particular domains gained with age aid performance in solving crossword puzzles (Hambrick, Salthouse, & Meinz, 1999), in memory for music (Meinz & Salthouse, 1998), and in playing bridge and chess (Charness & Bosman, 1990). Indeed, older adults are often able to maintain a high level of functioning in familiar tasks of everyday living even while displaying declines in processing ability in laboratory tests (Allaire & Marsiske, 2002; Charness, 2000; Park, 1992; Park & Gutchess, 2000). Nevertheless, increased knowledge and expertise do not always protect against age-related processing declines within a domain of expertise (Meinz & Salthouse, 1998), nor do they slow the rate of decline in general processing abilities (Hambrick et al., 1999). To date, the findings suggest a complex relationship among knowledge, processing capacity, and performance, with knowledge potentially playing an increased role in aiding task performance with advancing age. The interplay between processing ability and knowledge across the lifespan should be most apparent on tasks where both processing capacity and knowledge can be relied upon to support performance.

The environmental support hypothesis proposed by Craik (1983) posited that as self-initiated processing ability declines with age, environmental support from external cues and internal habits plays an increasingly important role in supporting cognitive behaviours. Environmental support is here conceptualized as the prompting of internal processes by external cues. The presence of extensive cues does not itself provide environmental support, but must be accompanied by the successful prompting of task-relevant cognitive processes. We hypothesize that existing verbal knowledge (such as an extensive vocabulary), when prompted by cues contained in a task context, may provide environmental support for older adults and may partially compensate for processing declines on some memory tasks. For older adults, who have impoverished processing ability but a wealth of knowledge, the environmental support available in a memory task may be a particularly important factor in determining success or failure (Craik & Anderson, 1999; Hess, Flannagan, & Tate, 1993; Naveh-Benjamin, Craik, & Ben-Shaul, 2002).

In the present study, we examined the contributions of verbal knowledge and processing abilities (speed and working memory) to a range of commonly used measures of verbal memory: free recall, cued recall, and recognition. These measures, according to Craik and Byrd (1982), vary in the amount of self-initiated processing required to perform them. Verbal free recall tasks, in which a list of individual words is to be recalled, provide few retrieval cues for environmental support, and hence age differences are particularly large on these tasks (Anderson, Craik, & Naveh-Benjamin, 1998b; Craik & Byrd, 1982; Craik, Byrd, & Swanson, 1987; Park, Smith, Dudley, & Lafronza, 1989). Although one might expect that knowledge would assist in developing associations even among unrelated words during the encoding phase of free recall, Craik and Anderson (1999) implicated retrieval, rather than encoding, processes as the primary source of deficits experienced by older adults in remembering contextual associations. The absence of retrieval cues in a free recall task may therefore be particularly detrimental for older adults, who cannot effectively apply their knowledge without external cues and must rely instead on their diminishing processing ability. Suggesting the importance of processing ability to free recall, Park et al. (1996, 2002) reported strong associations between measures of speed and working memory to free recall.

Cued recall tasks, in which associations between paired cues and target words are memorized, also show large age differences (Anderson et al., 1998b; Craik et al., 1987; Park et al., 1989), but provide more of an opportunity for the application of verbal knowledge, particularly when the cues and targets are meaningfully associated with one another (Nelson & McEvoy, 2002). We hypothesized that individuals with large vocabularies may be able to use their superior knowledge to generate more or better associations to connect targets and cues. Thus, we would expect that both processing abilities and verbal knowledge would mediate variance on a cued recall task.

According to Craik and colleagues (Craik & Byrd, 1982; Craik et al., 1987), verbal recognition tasks provide the most environmental support through retrieval cues, as the studied word is provided at retrieval, and a participant need only accept or reject the word as a studied item. In support of this hypothesis, age differences in memory are reduced in cued recall tasks compared to free recall tasks (Anderson et al., 1998b; Craik et al., 1987), and recognition tasks display comparatively small age differences (Anderson et al., 1998b; Kausler, 1994, pp. 249–253; Spencer & Raz, 1995). Despite the small age differences in recognition memory, it seems unlikely that verbal knowledge is the mechanism mitigating age-related declines, as recognition tasks provide little opportunity for the application of verbal knowledge. Typically, all the words presented as targets and lures in a recognition task are known to the participant through extraexperimental knowledge, so that the only distinction among targets and lures is that targets have recently been presented on the study list. Rather than relying on processing ability or verbal knowledge, recognition relies heavily on familiarity processes, in which judgements are based on perceptual fluency or relative activation of items in memory (Anderson, Bothell, Lebiere, & Matessa, 1998a; Johnston, Dark, & Jacoby, 1985; Kausler, 1994, p. 253). These familiarity processes have been found to occur prior to the influences of recollection in recognition tasks (McElree, Dolan, & Jacoby, 1999; Yonelinas & Jacoby, 1994). Furthermore, indices of familiarity in recognition appear to be age invariant, suggesting that familiarity processes may support recognition performance even in the absence of controlled recollection (Jacoby, 1999; Jennings & Jacoby, 1997). In keeping with the work of Jacoby and colleagues and the emphasis on familiarity and fluency (Anderson et al., 1998a; Jennings & Jacoby, 1997; Johnston et al., 1985), we hypothesized that recognition performance would not be strongly related to either processing ability or verbal knowledge.

Besides studying free recall, cued recall, and recognition in the present study, we also examined the relationship of processing ability and verbal knowledge to verbal fluency. In verbal fluency tasks, participants are presented with a letter or a category and are required to retrieve as many words as they can that begin with the letter or that belong to the category. Fluency tasks are commonly used neuropsychological indicators of frontal lobe dysfunction (Bryan & Luszcz, 2000; Lezak, 1995). Fluency measures typically load on the same factors as other executive function tasks and are particularly sensitive to age-related changes in frontal functioning (Glisky, Polster, & Routhieaux, 1995; Glisky, Rubin, & Davidson, 2001). Of interest, individual differences in frontal function, measured in part by fluency, predict which older adults will suffer declines in memory tasks (Davidson & Glisky, 2002; Glisky et al., 2001; Henkel, Johnson, & De Leonardis, 1998; Parkin, Walter, & Hunkin, 1995). Although verbal fluency is not generally considered a memory task, fluency tasks are a type of self-initiated semantic memory task. Performance on a verbal fluency task requires self-initiated retrieval as in free recall, but from semantic rather than episodic memory (Rosen & Engle, 1997). Moreover, fluency tasks share some qualities with cued recall tasks in that the initial cue provided by the experimenter (letter or category name) may provide environmental support. Also, like cued recall, it seems likely that high verbal knowledge would be an important predictor of performance. Although large age differences are typically observed on fluency tasks, one might expect these differences to be limited to processing limitations with ageing, with younger and older adults similarly applying knowledge to aid task performance. Indeed, Salthouse (1993a) found that vocabulary knowledge contributed to production in fluency tasks for both younger and older adults.

In the present study, we used structural equation modelling to investigate the simultaneous relationships of processing ability and verbal knowledge to verbal memory outcome measures that differed in the environmental support provided to participants through retrieval cues. Processing ability was indexed primarily by working memory tasks, but also by measures of speed of processing. Vocabulary was used as a proxy for verbal knowledge. The verbal memory outcomes included free recall, cued recall, fluency, and recognition. We developed models for a lifespan sample and then investigated whether this general model fitted data similarly for older and younger adults.

The initial study design and the reported models were developed to measure specific hypothesis-driven constructs and to investigate theoretically plausible relationships among those constructs. Rather than developing many alternative models for comparison, we instead investigated specific theoretically relevant path strengths within individual models of interest. In developing the models, we relied upon past findings to guide construct development and path specification. Prior reports have found that short-term memory (maintenance of representations) directly contributes to working memory (simultaneous maintenance and manipulation of representations), but does not have direct paths to memory outcomes (Engle et al., 1999b; Park et al., 2002). Although our individual measures of working memory include tasks that use either visuospatial or verbal content, past structural modelling reports have indicated that visuospatial and verbal working memory measures either load on a unitary construct (Engle et al., 1999b) or are so highly related that they should perhaps not be considered as distinct constructs (Park et al., 2002). We therefore include only a single construct of working memory that is perhaps best described as an executive function component of processing ability (Baddeley, 1986, 1996; Engle et al., 1999b).

EXPERIMENT

In testing individual paths from working memory (processing ability) and vocabulary (knowledge), we hypothesized that: (a) greater retrieval demands and less contextual cues, as in free recall, would require greater contributions from working memory and little from vocabulary; (b) as environmental support provided by retrieval cues increases in availability, as in cued recall and verbal fluency, vocabulary will increase in importance; (c) furthermore, vocabulary should be more important to older adults than to younger adults, as the older adults rely on knowledge when they are faced with declines in processing ability; (d) recognition performance would not be well predicted by working memory or by vocabulary, relying instead on familiarity processes.

Method

Participants

Participants were 345 community-dwelling individuals in the Ann Arbor, Michigan area, aged 20 to 92 years. Participants had vision sufficient to be able to read comfortably from a computer screen, had at least a ninth-grade education level, and were able to provide their own transportation to the study site. Other details of the sample are described in Park et al. (2002). Four participants were dropped from the reported analyses due to incomplete data.

Procedure

Participants were tested on three separate days for a total of 7 hours in groups of four or fewer. Tasks were presented either with paper and pencil or using the PsyScope 1.0.2 software package (Cohen, MacWhinney, Flatt, & Provost, 1993) on Apple Power Macintosh 7500 computers with 17-inch Apple colour monitors (Apple Computer, Cupertino, CA). Each participant completed a series of tasks that measured cognition, sensory function, and verbal ability. Task order was invariant across participants. Those tasks relevant to the current report are described below. Details of other tasks and order of task presentation are described in Park et al. (2002). Structural equation analyses were conducted using the LISREL 8.30 software (Jöreskog & Sörbom, 2001).

Description of tasks associated with latent variables

Speed of processing. There were three measures of speed of processing: the digit symbol adapted from the WAIS-III (Wechsler, 1997) and two measures developed by Salthouse and Babcock (1991)—letter comparison and pattern comparison. All were paper-and-pencil tasks.

Digit symbol. Participants were shown nine geometric figures, with each assigned a digit from 1 to 9. The digits were presented in a random order, and participants drew, as quickly as possible, the corresponding geometric figure for each. The dependent measure was the number of items completed in 90 seconds.

Letter comparison. Participants were presented with pairs of letter strings consisting of three, six, or nine letters each. Participants determined whether the two strings were the same or different and responded by writing an S or D on an answer sheet. They were given 30 seconds to complete as many items as possible at each level (three, six, or nine letters). The dependent measure was the sum of the number correct from the three levels.

Pattern comparison. This task was identical to the letter comparison task, except that participants compared pairs of line drawings consisting of three, six, or nine line segments. Again, the dependent measure was the total number of correct responses in the three trials.

Working memory. There were four working memory tasks. Each task had a processing component, involving a simple decision (e.g., whether three shapes were identical), and a storage component, involving memory for a series of items (e.g., the last word in each sentence in a series). For all tasks, the dependent measure was the total number of trials on which the processing component and the storage component were both correct.

Reading span. Adapted from the Salthouse and Babcock (1991) version of the task originated by Daneman and Carpenter (1980), participants heard simple sentences read aloud one at a time (e.g., "After dinner, the chef prepared dessert for her guests."). For the processing component, participants answered a question presented on the computer screen after each sentence (e.g., "What did the chef prepare?—A. fish; B. dessert; C. salad") by pressing the appropriate key. For the storage component, participants had to simultaneously remember the last word in each of the sentences. At the end of a sequence of sentences, participants wrote these words on an answer sheet (e.g., "guests"). The number of sentences in a sequence varied from 1 to 6, with three trials given at each of these six levels. The task was discontinued when a participant made an error on the storage component of at least two out of three trials on a level.

Computation span. Adapted from Salthouse and Babcock (1991), the structure of this task was similar to that of the reading span task. For the processing component, participants heard simple maths problems read aloud, one at a time (e.g., "$5 - 3 =$"). After each problem, three possible solutions were given on the computer screen (e.g., "A. 2, B. 1, C. 9"), and participants pressed the appropriate key to indicate their response. For the storage component, they had to simultaneously remember the last number in each problem (e.g., "3"). At the end of a sequence of problems, participants wrote these numbers on an answer sheet. The number of problems in a sequence ranged from 1 to 6. The number of trials and discontinuation of the task were the same as those in the reading span task.

Line span. In this task, adapted from Morrell and Park (1993), two types of visuospatial information were displayed simultaneously on a computer screen: (a) three irregular shapes in random locations, and (b) a single line segment (presented horizontally, vertically, or diagonally) in one of 42 possible positions. For the processing component, participants decided whether the three irregular shapes were identical and responded by pressing one of two keys. For the storage component, they had to simultaneously remember the position of the line segment in the display. After a series of these displays, the participants reproduced all of the line segments by drawing them on a grid, in the exact position and orientation in which they had been presented. The number of displays in a sequence varied from one to six, with three trials given at each of these six levels. The task was discontinued when a participant made an error on the storage component of at least two out of three trials on a level.

Letter rotation. In a task adapted from Shah and Miyake's (1996) spatial span task, participants were shown a series of letters, one at a time on a computer screen. Some letters were presented as mirror images, while others were presented in their normal form. Each letter was also tilted at an angle (45, 90, 135, 180, 225, 270, or 315 degrees from the normal vertical orientation). For the processing component, participants decided whether the letter was normal or mirror-imaged, indicating their decision by pressing one of two keys. For the storage component, they had to simultaneously remember the angle at which the letter was tilted. After a series of these letters, the participants recalled the angles of the letters by marking an answer grid. The number of letters in a series varied from two to five, with five trials given at each of the four levels. The task was discontinued when a participant made an error on the storage component of at least three out of five trials on a level.

Vocabulary. The three vocabulary tasks were the vocabulary section of the Shipley Institute of Living Scale (Shipley, 1986) and computerized versions of the synonym vocabulary and antonym vocabulary tests developed by Salthouse (1993a). In all tasks, the dependent measure was the total number of correct items.

Vocabulary section of the Shipley Institute of Living Scale. Forty target words from the Shipley scale (Shipley, 1986) were presented on a computer, one at a time, with four response alternatives.

Participants chose which of the four alternatives had nearly the same meaning as the target word by pressing one of four keys. They were given 10 minutes to complete all 40 items.

Synonym vocabulary. Participants were presented with 10 words on a computer, one at a time, and indicated which of 5 alternative words had nearly the same meaning as the target word by pressing one of five keys. Participants were given 5 minutes to complete this task.

Antonym vocabulary. This task was similar to the synonym vocabulary task, except that participants had to decide which of the five alternative words had most nearly the opposite meaning to each target word.

Verbal long-term memory. For each verbal long-term memory construct, multiple versions of the same task were presented. In the free recall, cued recall, and recognition tasks, participants were instructed to "study each word and try to remember it" during initial presentation of the words to be remembered.

Free recall. Two versions each consisted of 16 words presented on a computer one at a time for 5 seconds each. After viewing all of the words in a list, participants wrote on an answer sheet as many words as they could recall in any order. Three minutes were given for recall. For the 32 words used in both versions, the Thorndike and Lorge (1944) frequency counts ranged from 120 to 3,133 with mean frequencies for each version of 901 and 904. The dependent measures were the total number of words recalled on each version.

Cued recall. Two versions each consisted of 16 word pairs presented on a computer. Each word pair consisted of a cue word in lower-case letters and a target word in capital letters, presented one at a time for 5 seconds each. Each cue was a weak associate of its paired target (e.g., dark–CANDLE). After all 16 word pairs in a list had been presented, the cues were presented again, one at a time. Participants wrote on an answer sheet the target originally paired with each cue. Mean frequencies of the targets in the two lists were 908 and 914. The number of words correctly produced was the dependent measure for each version.

Verbal fluency. Participants completed three forms of this task (Spreen & Benton, 1977). In each form, participants were presented with a letter (F, A, or S) and asked to write as many words beginning with that letter as possible in 90 seconds. Proper nouns, numbers, and repeated words with a different suffix were not counted as correct. Dependent measures were the number of correct words produced on each form.

Recognition. Two versions each consisted of 48 study words presented on a computer one at a time for 5 seconds each. After all 48 words in a list had been presented, participants were presented with a recognition list consisting of 24 target words and 24 lure words, one word at a time. Participants responded via a key press to indicate whether each word was a target (e.g., on the study list) or a lure. Mean frequencies of the target words were 928 and 902, while mean frequencies of the lure words were 903 and 916. The signal detection measure of d', calculated from the hit rate for targets and the false alarm rate for lures, was the dependent measure for each version.

Results

The analyses were designed to investigate the contributions of processing ability (working memory and speed of processing) and knowledge (vocabulary) to verbal long-term memory tasks (free recall, cued recall, recognition, and verbal fluency) in the entire sample, and then separately in younger adults and older adults. The entire sample was examined first to provide an overall view of developmental changes across the adult life span, and subgroups were compared to assess age differences in early versus late adulthood (Table 1). The analytic procedures included the following steps. First, a measurement, or correlated factors (CF),

TABLE 1
Means and *SD*s for all participants and for subgroups

	All participants		*Younger*		*Older*		*Effect size*
Task	*M*	*SD*	*M*	*SD*	*M*	*SD*	*Cohen's d*
Letter comparison	35.29	10.61	41.55	9.61	29.21	7.59	1.43
Pattern comparison	49.54	13.11	58.07	10.70	41.27	9.42	1.67
Digit symbol	54.08	16.00	63.89	12.51	44.54	12.98	1.52
Reading span	7.89	3.47	9.61	3.18	6.23	2.88	1.11
Computation span	7.47	4.00	9.35	3.92	5.64	3.15	1.04
Line span	5.46	2.99	6.66	3.04	4.30	2.45	0.85
Letter rotation	8.60	6.27	11.60	5.95	5.68	5.10	1.06
Shipley vocabulary	34.56	3.92	33.83	4.34	35.26	3.32	0.37
Synonym vocabulary	7.51	2.53	7.07	2.68	7.94	2.29	0.35
Antonym vocabulary	6.39	2.59	6.27	2.68	6.51	2.51	0.09
Free recall 1	8.85	2.85	10.13	2.73	7.61	2.38	0.98
Free recall 2	9.28	3.20	10.68	3.28	7.93	2.46	0.95
Cued recall 1	9.95	4.21	11.69	3.43	8.26	4.21	0.89
Cued recall 2	11.09	4.06	12.87	3.29	9.36	4.00	0.96
Verbal fluency F	15.22	4.49	16.86	4.61	13.64	3.75	0.77
Verbal fluency A	15.25	4.86	16.87	4.96	13.68	4.21	0.69
Verbal fluency S	19.38	5.78	21.86	5.69	16.97	4.80	0.93
Recognition 1	2.29	1.06	2.50	1.06	2.09	1.01	0.40
Recognition 2	2.37	1.14	2.71	1.19	2.03	0.98	0.62
Age	55.25	19.79	37.78	10.11	72.21	9.35	3.54

model was constructed to assess the relationships between individual tasks and their associated latent constructs in the entire sample ($N = 341$) (Table 2). Second, separate CF models were developed for younger (aged 20–54 years, $n = 168$) and older (aged 55–92 years, $n = 173$) subgroups to address the possibility that the two age groups differed at the level of observed relationships between tasks and constructs. Third, a confirmatory structural equation (SE) model using the latent constructs developed in the CF models was estimated. This SE model provided an estimate of the contributions of process and knowledge to each verbal memory construct. Finally, separate SE models were estimated for the younger and older subgroups and used to directly compare the contributions of process and knowledge to verbal memory in each age group.

Correlated factor models

The first step, the development of a CF model, measured whether the indicators hypothesized to form conceptual latent constructs (e.g., letter comparison, pattern comparison, and digit symbol are hypothesized to be indicators of the latent construct of speed of processing) actually shared sufficient variance to form latent constructs. The CF model used in this study included seven latent constructs: speed of processing, working memory, vocabulary, free recall, cued recall, verbal fluency, and recognition. A total of 19 dependent measures were used as indicators of these constructs. Although age had only a single indicator and could be viewed as an exogenous variable, it was included in the CF model to allow a direct comparison with

TABLE 2

Correlations among tasks for all participants

Task	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
1. Letter comparison	1.0																			
2. Pattern comparison	.83	1.0																		
3. Digit symbol	.75	.76	1.0																	
4. Reading span	.59	.55	.58	1.0																
5. Computation span	.56	.54	.51	.62	1.0															
6. Line span	.54	.56	.50	.55	.52	1.0														
7. Letter rotation	.53	.54	.54	.62	.55	.64	1.0													
8. Shipley vocabulary	.09	−.01	.03	.19	.21	.15	.18	1.0												
9. Synonym vocabulary	.09	−.05	.01	.17	.15	.10	.12	.75	1.0											
10. Antonym vocabulary	.20	.12	.14	.29	.32	.21	.23	.66	.71	1.0										
11. Free recall 1	.52	.50	.55	.55	.47	.44	.48	.11	.12	.20	1.0									
12. Free recall 2	.55	.54	.58	.52	.42	.47	.53	.15	.16	.25	.69	1.0								
13. Cued recall 1	.54	.48	.53	.49	.46	.48	.49	.25	.26	.36	.56	.57	1.0							
14. Cued recall 2	.53	.50	.56	.50	.46	.46	.51	.21	.32	.31	.58	.61	.76	1.0						
15. Verbal fluency F	.53	.47	.46	.48	.47	.38	.39	.28	.32	.34	.43	.47	.46	.44	1.0					
16. Verbal fluency A	.50	.45	.44	.48	.49	.37	.39	.38	.39	.47	.45	.48	.50	.44	.75	1.0				
17. Verbal fluency S	.58	.55	.55	.54	.51	.41	.46	.22	.24	.36	.51	.54	.51	.50	.75	.76	1.0			
18. Recognition 1	.21	.25	.27	.23	.23	.23	.28	.11	.11	.17	.44	.40	.46	.40	.26	.28	.32	1.0		
19. Recognition 2	.31	.35	.39	.29	.30	.32	.34	.07	.10	.17	.50	.51	.53	.54	.34	.31	.41	.61	1.0	
20. Age	−.66	−.75	−.70	−.56	−.55	−.50	−.57	.22	.23	.07	−.49	−.49	−.45	−.49	−.36	−.32	−.44	−.22	−.34	1.0

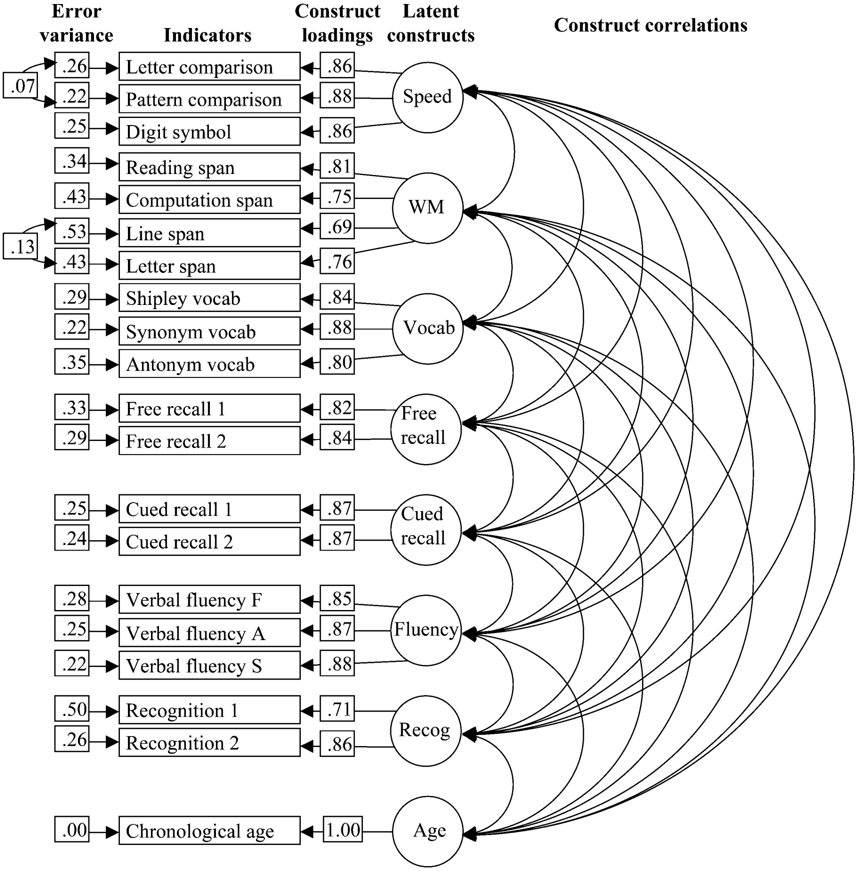

Figure 1. Measurement model for all participants. All values are from the completely standardized solution. Correlations among constructs are given in Table 3. Speed = speed of processing; WM = working memory; Vocab = vocabulary; Fluency = verbal fluency; Recog = recognition memory.

the later structural models. The CF model specifying the relationships among indicators and latent constructs for all participants is depicted in Figure 1. Note that this model yields information about the correlations among the latent constructs (see Table 3), but does not specify the directionality or hierarchy of relationships among the constructs (as do the structural equation models described later). The overall goodness of fit of the model was acceptable, suggesting that the hypothesized relationships between indicators and constructs were statistically confirmed. Although no single criterion for assessing goodness of fit has been established, a model considered to have acceptable fit would have several characteristics:

1. Perhaps the most likely statistic to become a standard measure of model fit is the root mean square error of approximation (RMSEA), an estimate of the amount of error in the

TABLE 3
Correlations between latent constructs in measurement models

Participants	*Construct*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
All	1. Speed	–						
	2. Working memory	.82	–					
	3. Vocabulary	.07	.29	–				
	4. Free recall	.75	.77	.22	–			
	5. Cued recall	.69	.73	.35	.80	–		
	6. Recognition	.45	.46	.16	.71	.71	–	
	7. Verbal fluency	.66	.70	.44	.67	.63	.47	–
	8. Age	−.81	−.72	.22	−.59	−.54	−.37	−.43
Young[a]	1. Speed	–						
	2. Working memory	.65	–					
	3. Vocabulary	.32	.56	–				
	4. Free recall	.64	.63	.44	–			
	5. Cued recall	.69	.63	.51	.80	–		
	6. Recognition	.33	.29	.16	.66	.66	–	
	7. Verbal fluency	.60	.66	.62	.57	.59	.32	–
	8. Age	−.44	−.39	.23	−.24	−.27	−.15	−.05
Old[b]	1. Speed	–						
	2. Working memory	.79	–					
	3. Vocabulary	.25	.43	–				
	4. Free recall	.63	.73	.28	–			
	5. Cued recall	.48	.65	.53	.70	–		
	6. Recognition	.32	.44	.32	.66	.67	–	
	7. Verbal fluency	.55	.52	.52	.58	.51	.48	–
	8. Age	−.69	−.62	.04	−.40	−.28	−.21	−.22

[a] Aged 20–54 years. [b] Aged 55–89 years.

model. RMSEA should be less than .08 for acceptable fit and less than .05 to be considered an excellent fit (see Browne & Cudeck, 1993, p. 144; Loehlin, 1998, pp. 76–78).

2. The non-normed index (NNFI) and comparative fit index (CFI) should be greater than .90 for acceptable fit and greater than .95 for close fit (Bentler & Bonett, 1980).
3. Some researchers have suggested that an indication of good fit occurs when the χ^2 value is no greater than twice the degrees of freedom (Bollen, 1989, p. 278). Although ideally a model will have a nonsignificant χ^2 value, this metric tends to have excessive power at larger sample sizes, and even a model with excellent fit will possess a significant χ^2 value (Tanaka, 1993).

The CF model provides an upper limit on the best possible fit for its corresponding SE models. Goodness of fit index (GFI) statistics are reported in Table 4. Although the x2 value was significant, the model meets all three of the above criteria and was accepted as a model of good fit for the entire sample.

For the second step in the analyses, we were interested in determining whether the CF model presented in Figure 1 for the entire sample differed in fit for younger adults

TABLE 4
Fit statistics of measurement and structural models

Model	*Participants*	*N*	χ^2	*df*	*p*	*GFI*	*NNFI*	*CFI*	*RMSEA*	χ^2/df
Correlated factors	All	341	210.29	141	<.001	.94	.98	.99	.038	1.49
	Younger[a]	168	152.10	141	.25	.92	.99	.99	.015	1.08
	Older[b]	173	189.52	141	<.005	.90	.96	.97	.044	1.34
Structural models	All	341	386.73	157	<.001	.89	.94	.95	.070	2.46
	Younger[a]	168	275.05	157	<.001	.85	.92	.94	.073	1.75
	Older[b]	173	260.67	157	<.001	.87	.93	.94	.063	1.66

Note: GFI = goodness of fit index; NNFI = non-normed fit index; CFI = comparative fit index; RMSEA = root mean square error of approximation.

[a] Aged 20–54 years. [b] Aged 55–89 years.

compared to older adults. Prior studies have reported group differences in relationships between indicators and the constructs they measure for young adults compared to older adults and in relationships among constructs, although the pattern of loadings and constructs has generally been found to be age invariant (Babcock, Laguna, & Roesch, 1997; Hertzog, 1987; Nyberg et al., 2003). In order to address this issue, we directly compared the CF models for a younger and an older subgroup of participants. The sample was split at age 55 years, so that there were 168 participants aged 20–54 years, and 173 aged 55–89 years. Both age groups displayed acceptable fit with goodness of fit indices for the individual subgroup models shown in Table 4. To assess whether there were differences in fit between the age groups, we performed a series of successively restrictive tests. This sequence (adapted from Jöreskog, 1971) begins by examining the relationship of constructs to their indicators, followed by an examination of the amount of variance not accounted for by the constructs and an examination of the relationships among constructs. The first three comparisons provide an increasingly restrictive estimation of how similarly the constructs account for task variance in each group, while the fourth comparison estimates the similarity of construct correlations. We first compared the CF models for qualitative (or configural) equivalence, constraining only the number of latent constructs and the pattern of loadings from indicators to constructs to be equal between the groups. This comparative model (H1 in Table 5) provides acceptable fit statistics, indicating that the general pattern of constructs and their indicators was similar among younger and older adults. The second comparison constrained the loadings of indicators to constructs to be invariant between the groups, testing quantitative (or metric) fit (H2 in Table 5). This comparison, although providing acceptable fit, had a significantly poorer fit than the prior comparison (based on $\Delta\chi^2$). To determine the source of this difference, each loading from an indicator to its construct was independently constrained to be equal between the groups. Only one loading, that from the second recognition task to the recognition construct, showed a significant group difference, $\Delta\chi^2$ $(1, N = 341) = 7.65$, $p = .006$, at the Bonferroni-corrected level when accounting for the mean correlation among tasks ($r = .41$, $\alpha = .01$). This loading was larger in the younger than in the older subgroup. A third comparison added the constraint that residuals for the indicators (error variance not accounted for by the constructs) were invariant between the

TABLE 5
Equality of measurement models for younger and older subgroups

Hypothesis	χ^2	*df*	$\Delta\chi^2$	Δdf	*p*	*GFI*	*NNFI*	*CFI*	*RMSEA*	χ^2/df
H1: Equal factor patterns	341.62	282	–	–	–	.90	.98	.98	.033	1.21
H2: Invariant factor loadings	363.20	294	21.58	12	.04	.90	.97	.98	.033	1.24
H3: Invariant residuals	428.18	315	64.98	21	<.001	.88	.96	.97	.042	1.36
H4: Equal factor covariation	518.01	351	89.83	36	<.001	.86	.95	.95	.048	1.48

Note: Each subsequent test adds a constraint to the immediately prior model, and the $\Delta\chi^2$ is tested against that prior model.

groups (H3 in Table 5). This comparison produced a significant change in χ^2 when compared to the prior model (H2). As above, each residual was independently constrained to be equal between the groups. Three residuals—those for the letter comparison task, the pattern comparison task, and the line span task—showed a significant group difference, smallest $\Delta\chi^2$ (1, $N = 341$) = 7.37, $p = .007$, at the Bonferroni-corrected level ($r = .41$, $\alpha = .01$). In all three cases, the residual variance was larger in the younger subgroup than in the older subgroup. A fourth comparison added to the prior model the constraint that the variance–covariance matrix among constructs be equivalent between the age groups (H4 in Table 5). This comparison also had a significantly poorer fit than the prior model (H3). Again, each variance and covariance was independently constrained to be equal between the groups. The variance of the vocabulary construct showed a significant group difference with greater variance in the younger group, $\Delta\chi^2$ (1, $N = 341$) = 8.13, $p = .004$, at the Bonferroni-corrected level ($r = .55$, $\alpha = .01$), as did covariances involving the vocabulary and fluency constructs.[1] Hence, the two age groups appear to have models of similar configural form, while differences in metric properties were relatively limited. When metric differences did occur, they were due to larger variance or covariance values in the younger than in the older subgroup.

Structural equation models

For the third step in the analyses, we used the CF models developed in the first two steps as the basis for structural equation models that allowed us to specify relationships among constructs in the entire sample and in the two subgroups. Because we observed some differences in covariation among constructs for the young adult compared to the older adult CF models, we expected differences in structural equation model fit between the two subgroups.

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[1] Significantly different covariances were between fluency and working memory, $\Delta\chi^2$ (1, $N = 341$) = 7.29, $p = .007$, and between vocabulary and fluency, $\Delta\chi^2$ (1, $N = 341$) = 6.97, $p = .008$. In both cases, the covariance was greater for the younger than for the older adults.

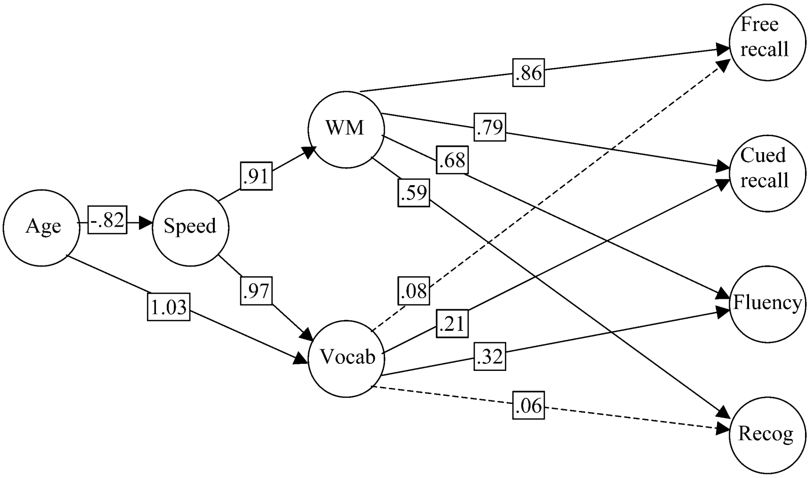

Figure 2. Structural model for all participants. Path values are standardized coefficients. Nonsignificant paths ($p > .05$) are indicated by dashed lines. Age = chronological age; Speed = speed of processing; WM = working memory; Vocab = vocabulary; Fluency = verbal fluency; Recog = recognition memory.

Structural models were developed in which speed of processing, working memory, and vocabulary were used as mediators of age-related variance in the verbal memory constructs. Our primary interest was in the relative strength of paths from processing ability (as indexed by working memory) and knowledge (indexed by vocabulary) to each of the verbal memory constructs. We expected that for free recall, the most process-intensive of the memory constructs, knowledge would have a relatively small contribution, while processing ability would play a large role. For cued recall and fluency, we expected that both processing and knowledge would have a significant contribution, as these memory measures provide support for or even necessitate the use of knowledge in task performance. For recognition, we expected that the roles of processing and knowledge would be relatively small, as recognition largely relies upon familiarity processes (Jennings & Jacoby, 1997; Kausler, 1994, p. 253).

The structural equation model for the entire sample is depicted in Figure 2, and overall fit statistics are reported in Table 4. As expected, age had a direct negative relationship to speed of processing, but a direct positive relationship to vocabulary.[2]

The model generally indicates that age-related variance was mediated by speed of processing, which in turn was mediated by working memory. Of primary interest, all four

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[2] The positive relationship of age to vocabulary was in part due to the presence of a path from speed to vocabulary, which has a strongly positive value. Removing the path from speed to vocabulary greatly reduces the fit of the model, $\Delta\chi^2$ (1, $N = 341$) = 74.02, $p < .001$, but does not significantly alter any of the path values from vocabulary to the memory measures. This path suggests a strong relationship between speed and vocabulary, which may be expected due to the substantial relationships reported between speed and intelligence measures (e.g., Salthouse, 1992). However, including this path also uncovers a substantial relationship between age and vocabulary, and it suggests that ageing is associated with two counteracting processes that affect vocabulary ability—lowered speed of processing tends to reduce access to vocabulary, while increased experience tends to increase vocabulary knowledge.

paths from working memory to the verbal memory constructs were significant. However, these path values did differ from one another, as constraining them to be equal resulted in a significant decrease in model fit, $\Delta\chi^2$ (3, $N = 341$) = 351.83, $p > .001$. As expected, working memory had the largest relationship to free recall and the smallest relationship to recognition, supporting the hypothesis that as environmental support provided by retrieval cues in a task increases, reliance upon processing ability decreases. Of the paths from vocabulary to the verbal memory constructs, only the paths to cued recall and to fluency were significant. These two path values did differ significantly from one another, $\Delta\chi^2$ (1, $N = 341$) = 4.51, $p = .03$, with the path from vocabulary to fluency being larger than that to cued recall. Fluency tasks appear to necessitate the use of knowledge, while cued recall provides an opportunity for its use. In general, these results support the hypothesis that knowledge contributes to task performance through the environmental support invoked by the presence of retrieval cues.

We should note that direct paths from age to working memory and to the verbal memory constructs were not indicated by an analysis of the modification indices and expected path changes (largest expected change of .02). Prior studies have also found age-related variance in memory outcomes to be directly mediated only by speed of processing (Park et al., 1996; Park et al., 2002; Salthouse, 1993b). The influence of speed on the verbal memory measures was entirely mediated by working memory and vocabulary, as adding direct paths from speed to the four verbal memory constructs resulted in negative path values that did not significantly differ from 0 (largest $t = -0.66$, $p = .50$). This result confirms prior findings that the relationship of speed to memory operates through working memory (Park et al., 1996; Park et al., 2002).

We next developed identical structural models for the younger and older subgroups, displayed in Figures 3a and 3b, respectively. Goodness of fit indicators for the two separate models are reported in Table 4, with each model having acceptable fit. Each group shows a similar overall pattern to that seen in analyses of the entire sample, with the exception that the younger adults displayed a nonsignificant path value from vocabulary to cued recall ($t = 1.91$, $p = .06$), whereas the path was significant in the model for older adults ($t = 4.42$, $p < .001$). In addition, the path from vocabulary to recognition was significant only in the model for older adults ($t = 2.04$, $p = .04$). When we directly compared the two structural models to one another with all specified parameters free to vary in each group, this comparison had acceptable fit, $\chi^2(314, N = 341) = 535.71$, $p < .001$, GFI = .87, NNFI = .92, CFI = .94, RMSEA = .068, $\chi^2/\text{df} = 1.71$, indicating that the two groups had similar overall patterns of relationships among constructs. Using this model as a reference, we next made direct metric comparisons between the age groups among individual path values of interest. Based upon the hypothesis that age would affect the relationship between knowledge and verbal memory but not between process and memory, we assessed the equality between the groups of each path from working memory to the verbal memory constructs and of each path from vocabulary to the verbal memory constructs, for a total of eight individual tests. The only path to significantly differ between the younger and older subgroup was the path from vocabulary to cued recall, $\Delta\chi^2$ (1, $N = 341$) = 8.66, $p = .003$. This difference was significant at the Bonferroni-corrected level, both when the mean correlation among the verbal memory constructs was considered ($r = .60$, $\alpha = .02$) and when the correlation was not considered ($\alpha = .006$). All other path values were equivalent among the groups, as constraining

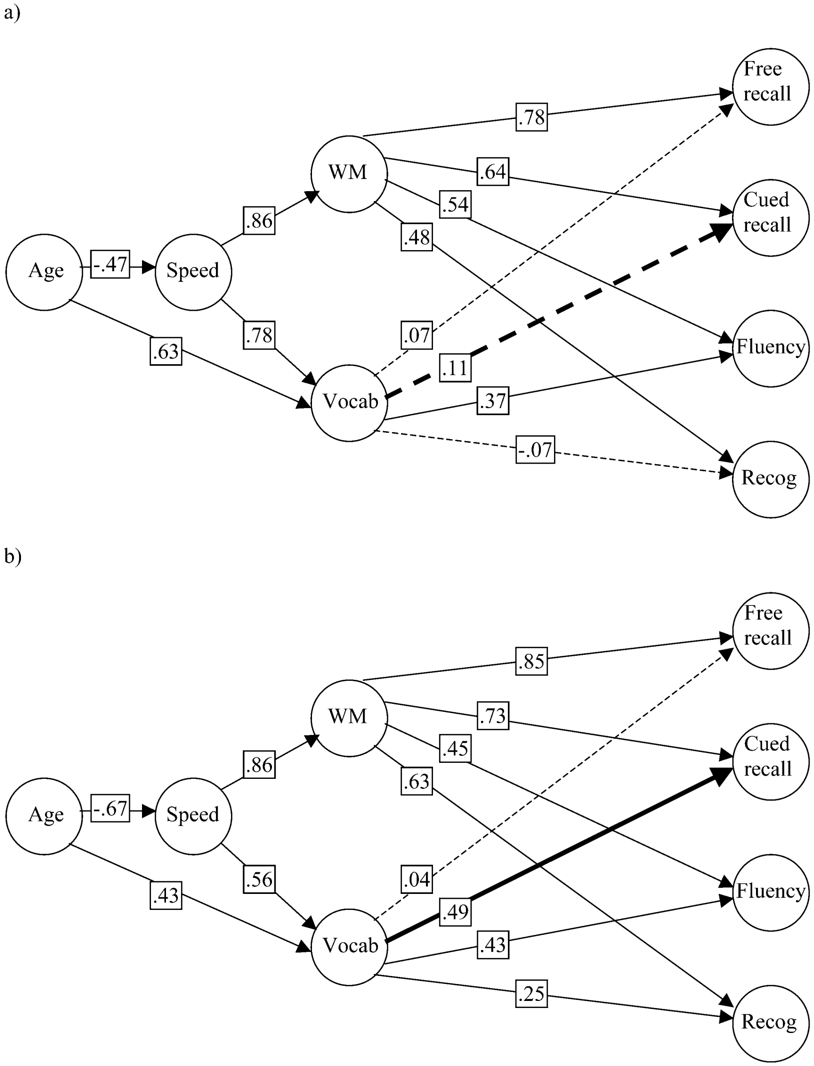

Figure 3. (a) Structural model for younger (age 20–54 years) participants. (b) Structural model for older (age 55–89 years) participants. Path values are common metric standardized coefficients. Nonsignificant paths ($p > .05$) are indicated by dashed lines. Note that only the path value from vocabulary to cued recall (bold line) significantly differed among the age groups. Age = chronological age; Speed = speed of processing; WM = working memory; Vocab = vocabulary; Fluency = verbal fluency; Recog = recognition memory.

all paths except vocabulary to cued recall did not result in a significant change in model fit, $\Delta\chi^2$ (11, $N = 341$) = 15.72, $p = .15$. Although the path from vocabulary to recognition had a significant value in the older subgroup but not in the younger subgroup, constraining this path to be equal between the groups did not result in a significant change at the Bonferroni-corrected level, $\Delta\chi^2$ (1, $N = 341$) = 4.76, $p = .03$.

Discussion

This study assessed how processing ability and verbal knowledge contributed to a range of verbal memory tasks, and how those contributions differ across the adult life span. Structural equation models demonstrated that processing ability, as measured by speed and working memory, contributed most to verbal memory when environmental support prompted by retrieval cues was least available (as in free recall) and contributed least when such support was most available (as in recognition). These results confirm predictions of the environmental support hypothesis (Anderson et al., 1998b; Craik, 1983) in that greater processing ability is required for free recall than for recognition (see also Park et al., 1996). Despite age-related decreases in processing ability, working memory contributed similarly to memory performance for younger and older adults, suggesting that environmental support is an important variable in predicting memory performance across the adult life span. When processing ability is most invoked, and environmental support from cues is least available, as in free recall, observed age differences in memory tend to be largest (see effect sizes in Table 1). In recognition, where processing ability is less invoked and environmental support from cues is most available, age differences in memory are smallest (see Table 1). In contrast, knowledge, as measured by vocabulary ability, contributed only to the verbal memory tasks of cued recall and verbal fluency. Of particular interest was the finding that age-related differences in these relationships were observed. Younger adults relied solely upon processing ability in cued recall tasks whereas older adults invoked both knowledge and processing ability in cued recall. These results indicate that verbal knowledge operates jointly with processing ability to support performance on some memory tasks where knowledge can play a role, and that older adults are more likely than younger adults to take advantage of the application of knowledge in such tasks.

The findings emphasize the importance of processing ability for long-term memory function across the lifespan, as reported by Park et al. (1996, 2002). Although age operated directly through speed, speed had no direct paths to the memory measures. The influence of processing ability on memory was therefore indexed by working memory, which had significant direct paths to all measures of verbal memory in analyses of the entire sample and in analyses of the two age subgroups. In all groups, working memory had the strongest path to free recall, suggesting that processing ability is most important to performance when environmental support provided by retrieval cues is absent. In contrast, vocabulary was observed to have a significant direct path only to fluency in all groups, suggesting that verbal knowledge is used to support memory when appropriate semantic retrieval cues are provided as a form of environmental support. Verbal fluency is a semantic rather than episodic memory task, as the processing requirements are not tied to an encoded event. Rather, participants must use a combination of processing ability and extraexperimental knowledge to retrieve semantically or orthographically related items from memory. Hence, both younger and older adults exhibited a relationship between knowledge and memory in fluency tasks (see Salthouse, 1993a, for a similar finding).

Vocabulary was positively related to speed of processing, indicating that age-related declines in speed and increases in experience have counteracting influences on vocabulary ability. This may, in part, explain the curvilinear trajectory of vocabulary ability across the adult life span, with gains throughout most of life followed by late-life declines

(Park et al., 2002; Schaie, 1996). Such a curvilinear trajectory later in life accounts for the lack of a correlation between age and vocabulary in the older subgroup (see Table 3), although there is still a substantial path from age to vocabulary when the influence of speed is taken into account (see Figure 3b). This pattern also helps explain why speed is positively correlated with vocabulary in both age subgroups, but has a small correlation to vocabulary in the combined sample. When the subgroups are combined, the influence of age on vocabulary becomes greater than that of speed (see Table 3), although the path from speed to vocabulary remains substantial when accounting for age (see Figure 2).

Within the two age subgroups, the paths from age to vocabulary were positive and equivalent. However, vocabulary was related to cued recall performance only in the older subgroup. Vocabulary was also significantly related to recognition in the older subgroup only, although this relationship did not differ from the nonsignificant path exhibited in the younger subgroup and should therefore be interpreted cautiously. These results suggest that as individuals age there is a shift in cognitive emphasis from reliance upon processing ability to the use of increasing knowledge in performing memory tasks where environmental support is available to facilitate its application. This pattern of findings suggests that not only do older adults exhibit poorer levels of absolute memory performance than do young adults, but that the qualitative nature of their memory processes may differ from younger adults. These results are in agreement with prior research indicating that older adults invoke accumulated knowledge in support of task performance. Older adults perform well on measures of wisdom (Baltes & Staudinger, 2000; Baltes, Staudinger, Maercker, & Smith, 1995), but also rely upon knowledge of stereotypes in making memory judgements (Mather, Johnson, & De Leonardis, 1999). Social knowledge can be used by older adults to aid in making impression judgments (Hess & Auman, 2001) and to assist in making source memory judgments (Rahhal, May, & Hasher, 2002).

The present results are relevant to recent debates in the literature on the cognitive neuroscience of ageing regarding neural compensation and strategic shifts with advancing age (e.g., Meyer, Glass, Mueller, Seymour, & Kieras, 2001; Reuter-Lorenz, 2002). Age-related increases in knowledge, such as vocabulary ability, may allow older adults to institute strategies not readily available to younger adults with a less established knowledge base. Such strategic shifts could, in principle, account for compensation in behavioural performance (Charness & Bosman, 1990; Rogers, Hertzog, & Fisk, 2000) and for neural activation patterns unique to older adults (Cabeza, 2002; Reuter-Lorenz, 2002). Alternatively, such knowledge may be automatically activated by older adults in situations when a task cues representations of relevant knowledge (Craik & Anderson, 1999; Park & Gutchess, 2000). It may be possible to resolve the strategic differences with age versus automatic activation argument by studying contrasts between situations where automatically activated knowledge would detract from or facilitate performance. A complementary approach would be to train older adults in the use of strategies that invoke task-relevant knowledge.

Recognition memory was relatively poorly explained by the constructs in the models. Indeed, only 36% of the variance in recognition was accounted for among all participants, in contrast to 62% for fluency, 70% for cued recall, and 75% for free recall. Recognition had the weakest relationship to working memory and no significant relationship to vocabulary. Even in the older subgroup, where recognition was significantly related to vocabulary, this relationship was quite weak. The latter results were observed despite the fact that recognition provides extensive retrieval cues (Craik, 1983); indeed, it could be said to supply maximal cueing, as the item to be retrieved is itself provided as a cue. However, it may be difficult to effectively apply knowledge in recognition tasks because all items are known. Hence, knowledge may not help to discriminate items that were seen earlier in the experimental setting from items not seen. In this sense, recognition is a source or context memory task that can be solved on the basis of familiarity due to recent presentation (Anderson et al., 1998a; Kausler, 1994, p. 253).

Also noteworthy is the finding that the older subgroup did not display a pattern of larger correlations among constructs than did the younger subgroup (see Table 3). Indeed, only three correlations among the seven latent constructs differed significantly between the younger and older adults. These were the correlation between speed and working memory ($z = -2.71$, $p = .007$), which was larger in the older adults, and the correlations between speed and cued recall ($z = 2.97$, $p = .003$) and between working memory and verbal fluency ($z = 1.98$, $p = .048$), which were both larger in the younger adults. This pattern of findings fails to support the hypothesis of dedifferentiation, which holds that cognitive abilities become more related with advancing age, possibly due to common neurobiological processes affecting multiple cognitive systems (Anstey, Hofer, & Luszcz, 2003; Balinsky, 1941). Other recent studies have also found no evidence of dedifferentiation with advancing age (Anstey et al., 2003; Park et al., 2002). The current findings are consistent with an interpretation in which cognitive processes remain distinct into advanced age, yet are used differentially by younger and older adults as task conditions change.

In conclusion, adult age-related differences were observed in the contributions between processing ability and knowledge to performance on verbal memory tasks. Although both younger and older adults displayed similar relationships between processing ability and memory, the influence of knowledge increased with adult ageing. Processing ability was most highly related to memory when environmental support was limited, as in free recall performance, and was least related to memory in recognition performance, providing evidence for the environmental support hypothesis (Craik, 1983). Knowledge, in turn, contributed to memory when cues facilitated its use, as in cued recall and verbal fluency. Furthermore, older adults displayed a greater relationship between knowledge and cued recall performance than did younger adults, whereas both age groups applied knowledge to verbal fluency performance. This suggests that when a memory task allows for, but does not necessitate, the use of knowledge, older adults can successfully support memory performance through the increased verbal abilities that often accompany ageing.

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