Psychology and Aging
2002, Vol. 17, No. 2, 299–320
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0882-7974/02/$5.00 DOI: 10.1037//0882-7974.17.2.299

Models of Visuospatial and Verbal Memory Across the Adult Life Span

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The authors investigated the distinctiveness and interrelationships among visuospatial and verbal memory processes in short-term, working, and long-term memories in 345 adults. Beginning in the 20s, a continuous, regular decline occurs for processing-intensive tasks (e.g., speed of processing, working memory, and long-term memory), whereas verbal knowledge increases across the life span. There is little differentiation in the cognitive architecture of memory across the life span. Visuospatial and verbal working memory are distinct but highly interrelated systems with domain-specific short-term memory subsystems. In contrast to recent neuroimaging data, there is little evidence for dedifferentiation of function at the behavioral level in old compared with young adults. The authors conclude that efforts to connect behavioral and brain data yield a more complete understanding of the aging mind.

The present study is a life span approach to understanding visuospatial and verbal working memory and its relationship to long-term memory. It is well-documented that measures of overall cognitive resource such as speed of processing and working memory capacity mediate virtually all age-related variance on higher order cognitive tasks, including long-term memory tasks (Hultsch, Hertzog, & Dixon, 1990; Kliegl, Mayr, & Krampe, 1994; Park et al., 1996; Salthouse, 1996). Thus far, the primary debate among researchers on aging has focused on understanding the interrelationships among basic indicators of cognitive resources (e.g., sensory function, speed of processing, working memory capacity) in explaining age-related decline on more complex cognitive tasks (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994; Park et al., 1996; Salthouse, 1996). The present study builds on this long history of work on aging and cognitive resources by addressing the possibility that working memory resources are specialized by content (visuospatial and verbal) and that this specialization may change with age. Moreover, we examined the relationship of content-based working memory tasks to long-term memory for visuospatial and verbal information, with a particular focus on the role of working memory. We used findings from the neuroimaging and behavioral literature to develop neurobiologically plausible structural equation models to understand the relationship of domain-specific working memory to domain-specific long-term memory. We adopt a traditional view of working memory, conceptualizing it as a pool of mental energy or cognitive resources that can be used to encode, access, store, and manipulate information with verbal and visuospatial storage subsystems (Baddeley, 1986, 1996; Baddeley & Hitch, 1974).

Cognitive-aging models have not addressed the issue of organization of cognitive resource by content (e.g., Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994; Park, 2000; Park et al., 1996; Salthouse, 1996), even though both behavioral and neuroimaging data collected from young adults provide evidence for some differentiation. We use the term *dedifferentiation* to refer to the process where distinct pools of processing resources in young adulthood develop into a single, more general resource. Before discussing the possibility of dedifferentiation with age, we briefly consider models of working memory followed by evidence for the existence of independent visuospatial and verbal pools of resource in younger adults.

The traditional model of working memory (Baddeley & Hitch, 1974) is characterized by a processing-rich, domain-general central executive fed by relatively passive, domain-specific slave systems—the visuospatial sketch pad and the phonological loop. Empirical measures of the visuospatial sketch pad and the phonological loop are span measures that require maintenance and rehearsal, but no manipulation, whereas central executive processes require processing and manipulation of information. In a recent study using structural equation modeling, Engle, Tuholski, Laugh-

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This research was supported by National Institute on Aging Grant R01-AG06265. We gratefully acknowledge assistance in this research effort from Shana Hunter and Markus Joos. The conceptual framework and the results from this study were initially presented at the Cognitive Aging Conference in Atlanta, Georgia, in April 1998 and at the "Old Memories" Conference in Cold Spring Harbor, New York, in November 1999.

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lin, and Conway (1999) distinguished short-term memory from working memory in the verbal domain. Short-term memory was measured by forward and backward digit span, and working memory was measured by tasks that involved processing and storage of verbal and numerical material. Their models provide clear evidence that short-term memory and working memory are separable constructs. Despite the separability of the constructs, they also found that the two systems were highly related and that there was a strong relationship of the working memory but not the short-term memory component to a higher order general intelligence factor.

Engle, Kane, and Tuholski (1999) and Cowan (1995) have suggested that working memory, but not short-term memory, has a strong controlled attention component. This view was strongly supported by Kane, Bleckley, Conway, and Engle (2001), who reported that individuals with high working memory span had better attentional control than those with lower spans, as elegantly measured by errors on an antisaccade task. This finding of distinguishable short-term and working memory components in the verbal domain contrasts with recent work by Miyake, Friedman, Rettinger, Shah, and Hegarty (2001), who reported little distinction between short-term and working memory in the visuospatial domain, using structural equation modeling. None of these studies directly compared the structure of visuospatial and verbal working memory, so the differences in findings are not entirely resolved, because the two teams of investigators used somewhat different approaches. In the study we report here, we collected verbal and visuospatial measures of both short-term memory and working memory, which allowed us to examine differentiation of the two modalities directly and to determine how the differentiation might change across the life span. We also collected measures of visuospatial and verbal long-term memory to understand the interrelationships among memory systems. Although Engle, Tuholski, et al. (1999) did not make predictions about long-term memory, other models of working memory have postulated such relationships (see Kintsch, Healy, Hegarty, Pennington, & Salthouse, 1999, for a review).

Some information about domain specificity of resource and organization of working memory comes from the use of neuroimaging techniques. Extensive imaging research on humans has led to the following view. Ventral regions in the frontal lobes act as more passive storage–rehearsal units, whereas dorsal frontal regions serve as sites for the manipulation and monitoring of information (D'Esposito, Postle, Ballard, & Lease, 1999; Owen, 1997; Owen, Stern, Look, Tracey, Rosen, & Petrides, 1998). The ventral–dorsal distinction is reminiscent of the short-term memory–working memory distinction proposed by Engle, Tuholski, et al. (1999) as well as the passive subsystems of an active central executive that Baddeley and Hitch (1974) suggested. In an important meta-analysis of all relevant functional imaging studies to date, D'Esposito et al. (1998) found evidence for hemispheric organization of storage functions (e.g., spatial in the right hemisphere and nonspatial in the left hemisphere). This finding is consistent with a meta-analysis reported by E. E. Smith and Jonides (1999). Specifically, E. E. Smith and Jonides (1997, 1999) have argued that verbal storage is left ventral and visuospatial is right ventral. Generally, the prevailing view in the neuroimaging literature is that stimuli that require intensive processing in working memory are processed bilaterally in the dorsolateral prefrontal cortex (D'Esposito et al., 1998; Owen, 1997; E. E. Smith, Marshuetz, & Geva, 2002; E. E. Smith & Jonides, 1999) and that maintenance functions are performed in the ventral prefrontal cortex, with some evidence for specialization of content at this level.

The differentiation of short-term memory from working memory across modalities has remained largely unexplored across the life span. Single-mechanism views of aging have predominated. Salthouse (1996) has demonstrated convincingly in numerous studies that nearly all age-related variance on a broad range of cognitive tasks is mediated by a single construct: speed of processing (the rate at which mental operations are performed). Park et al. (1996) also demonstrated that perceptual speed mediated all significant age-related variance on a range of memory tasks, with a verbal working memory construct playing an intermediate role between speed and long-term memory. Because Park et al. (1996) used only verbal measures of both working memory and long-term memory and did not include short-term measures, their work did not examine the differentiation of short-term memory from working memory, nor did it address the visuospatial–verbal distinction, as our study does.

Lindenberger and Baltes (1994) and Baltes and Lindenberger (1997) have also argued, like Salthouse (1996), for a single mechanism model of age-related cognitive decline. They advance the "common cause" hypothesis of aging, reporting that all age-related variance on 15 different cognitive tasks was mediated by simple measures of visual and auditory function. The connection was stronger in very old adults aged 69 to 105 compared to younger adults aged 25 to 69. Sensory function appeared to be even more fundamental in explaining age-related variance on cognitive tasks than speed of processing (Lindenberger & Baltes, 1994). Baltes and Lindenberger argued that these simple measures of sensory function are indicators of overall neurological integrity. However, these studies do not address the organization of working memory and long-term memory across the verbal and visuospatial domains. It is entirely plausible that visuospatial and verbal differentiation of working and long-term memory exist across the life span but decline equivalently, so that a common-cause factor could account for all of the age-related variance, with neurobiological differentiation of the memory systems nevertheless maintained across the life span. One caveat about this statement is that a common cause interpretation can be difficult to distinguish from an interpretation involving both unique and mediated age-related variance when relying on cross-sectional data (Lindenberger & Potter, 1998).

The neuroimaging data suggest that some dedifferentiation of cognitive resource does occur with age. (See Park, Polk, Mikels, Taylor, & Marshuetz, 2001, for a detailed review of this topic.) Cabeza, McIntosh, Tulving, Nyberg, and Grady (1997) have suggested that global reorganization of brain function occurs in older adults such that more interaction occurs between left and right prefrontal regions. Reuter-Lorenz and colleagues (2000) reported a positron emission tomography (PET) study demonstrating recruitment in elderly of both left and right hemispheres to perform a verbal working memory task that is primarily left-lateralized in young adults. Rypma and D'Esposito (2000) found evidence for bilateral recruitment, but only under high load conditions. With respect to long-term memory, old adults show less left hemisphere activation than young at encoding (Cabeza, Grady, et al., 1997), but more bilateral recruitment than young at retrieval (Cabeza, Grady, et al., 1997; Madden et al., 1999). Overall, these data suggest that domain-specific distinctions in short-term, working memory, and long-term memory structures might deteriorate across the life span.

Visuospatial and verbal processing of information in older adults has been directly examined in a few studies. Morrell and Park (1993) had young and old adults assemble a complex figure from blocks according to pictorial or verbal instructions. In this study, visuospatial working memory mediated more age-related variance in performance than verbal working memory when instructions were presented pictorially and verbal working memory mediated more age-related variance when the instructions were presented verbally. This finding would support evidence for intact visuospatial–verbal organization rather than dedifferentiation. Myerson, Hale, Rhee, and Jenkins (1999) studied selective interference for digit and location span in young and old adults. They reported evidence for equivalent amounts of selective interference for old and young, but disproportionately lower location spans relative to digit span in old. The differential span declines provide evidence for domain specificity in older adults, with more decline occurring in the nonverbal modality. In line with this finding, Jenkins, Myerson, Joerding, and Hale (2000) also reported disproportionately greater difficulty in learning visuospatial compared to verbal material for old adults compared to young. In contrast to these findings, Salthouse (1995) demonstrated equivalent age-related effects on verbal–symbolic and visuospatial short-term span tasks and mediation of age differences by a single perceptual speed factor.

In the study we report here, we addressed a series of important issues with respect to differentiation of visuospatial and verbal resource and the mediational role of differentiated resources for long-term memory. First, the study permits direct comparisons of the structure of short-term and working memory in the visuospatial and verbal domains, resolving some of the differences in the work of Engle, Tuholski, et al. (1999) who used verbal stimuli and Miyake et al. (2001) who used spatial stimuli. This approach of distinguishing short-term from working memory is consistent with models of working memory organization from the neuroimaging literature (D'Esposito et al., 1998; Owen, 1997).

Second, we examined the structure of memory systems (short-term, working, and long-term memory) across the life span. Approximately 50 adults in each decade from age 20 to 92 were included, for a total sample of 345 adults. The sample is large enough that we were able to develop separate models for younger and older adults and determine what type of model provides a better fit for each age group.

Third, we examined how verbal and visuospatial working memory and short-term memory mediate long-term memory. One would expect that if working memory is differentiated as a function of domain, that structural models would show that visuospatial working memory would mediate variance on memory for abstract patterns but not free recall of words. Verbal working memory should evidence an opposite pattern. In contrast, if a domain-general model of working memory is accurate, the general working memory construct should mediate variance for both types of long-term memory. The design of the present study permitted us to assess these possibilities.

Finally, little is known about long-term memory for visuospatial and verbal information in older adults. There is evidence that visuospatial processes decline more precipitously than verbal processes with age (Jenkins et al., 2000; Myerson et al., 1999). However, there is also evidence for equivalent declines in the two domains. (See A. D. Smith & Park, 1990, and Reuter-Lorenz, 2000, for an overview of these issues.) The Salthouse (1995) data suggest equivalent decline, but he assessed only short-term span measures. The present study permitted us to directly examine decline functions across age for both working memory and long-term memory in the visuospatial and verbal domains.

METHOD

Participants

A total of 345 people, ranging in age from 20 to 92, participated in the study. There were 48 to 57 participants in each age decade, from the 20s through 80s. Two participants who were aged 90–92 were included with the 80- to 89-year-olds. All of the participants were community dwellers and were recruited through advertisements placed in the newspaper in Ann Arbor, Michigan, and through existing subject pools of older adults at the University of Michigan. Participants could see well enough 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.

As can be seen in Table 1, the number of male and female participants was roughly equivalent across the seven age decades (47% men and 53% women overall). The minority representation in this pool was 10%, which is comparable to the representation in the Ann Arbor area. The male and female participants did not differ significantly in years of education, verbal ability (as measured by the Shipley Institute of Living Scale; Shipley, 1986), or perceived health. Additionally, there were no age effects associated with years of education. There was, however, a significant effect of age group on number of medications being taken, $F(6, 338) = 15.47$, $p < .001$, with the mean number of medications increasing from .65 in 20-29-year-olds to 3.08 in 80- 92-year-olds. Each participant received $60.

Table 1
Participant Characteristics by Age Group

Age group (years)	*n*	% female	Age (years) *M*	Age (years) *SD*	Education[a]	Health[b]	Medications	Shipley Institute of Living Scale
20–29	48	50	25.22	2.90	3.96	3.56	0.65	33.19
30–39	48	56	35.42	2.88	4.33	3.42	0.88	33.46
40–49	48	52	45.04	3.05	4.27	3.50	1.35	34.06
50–59	47	51	54.95	3.05	4.68	3.57	2.02	34.72
60–69	57	53	65.60	2.40	4.46	3.89	2.25	35.33
70–79	49	59	74.59	2.75	4.49	3.94	3.31	36.02
80–89	48	54	83.94	3.23	3.63	3.96	3.08	35.15

[a] Participants rated their educational level on the following scale: 1 = *less than a high school degree*, 2 = *high school graduate*, 3 = *some college*, 4 = *Bachelor's degree*, 5 = *some graduate work*, 6 = *Master's degree*, 7 = *MD, JD, PhD, or other advanced degree*. [b] Participants rated their health on a scale from 1 (*much worse than average*) to 5 (*much better than average*).

Procedure

The participants were tested on 3 separate days. Sessions on the first 2 days were held 48 hr apart, either on Monday and Wednesday or on Tuesday and Thursday. On these days, the participants were tested in groups of four or fewer in which each person sat at a computer in a separate cubicle. Most of the tasks on these 2 days were presented using the PsyScope 1.0.2 software package (Cohen, MacWhinney, Flatt, & Provost, 1993) on Apple Power Macintosh 7500 computers with 17-in. (43.18 cm) Apple color monitors (Apple Computer, Inc., Cupertino, CA). Participants responded either by pressing labeled keys on the keyboard or by writing their answers on paper. The third day involved individual testing and vision and auditory tests. Typically, participants completed all 3 days of testing within the week. The first 2 days of testing took 2 to 3 hr to complete, whereas the 3rd day required an hour. The order of tasks and testing sessions was invariant across participants. Dropout rate was negligible after the first session, with only 3 participants not completing the tasks. An additional 3 participants were dropped because of health problems that impaired their ability to participate fully in all of the tasks.

Each participant completed a series of tasks that measured visuospatial and verbal short-term, working, and long-term memory, as well as speed of processing, sensory function, and verbal ability. All of these tasks are described in detail in the sections that follow. Other tasks that are not relevant to the theoretical questions associated with this study were presented; they are not described here. These other tasks were verbal in nature and included measures of lexical access, verbal fluency, and verbal recognition memory. Verbal recognition memory, a long-term episodic memory task, was not included in analyses because there was no visuospatial analogue for this measure. This measure was included in the battery to address issues associated with verbal episodic tasks that vary in environmental support, a matter to be considered elsewhere.

The constructs for which we were interested in developing latent variables were sensory function, speed of processing, visuospatial and verbal working memory, short-term memory, and long-term memory. Because we were interested in obtaining reliable and valid construct representations, we decided to use structural modeling procedures and collected multiple measures of each construct. Little, Lindenberger, and Nesselroade (1999) have demonstrated the superiority of structural equation modeling over exploratory factor analysis. We should note here that the sensory function measures used in the structural modeling are described last because they were not used in the initial development of measurement and structural models. They were used later in the modeling process. We also collected measures of verbal ability to assess crystallized knowledge, which were useful in describing the sample; these measures are presented below as well, followed by a description of task order in the three experimental sessions.

Description of Tasks Associated With Latent Variables

Speed of Processing

There were three measures of speed of processing: the Digit Symbol from the Wechsler Adult Intelligence Scale (3rd ed.; WAIS-III; Wechsler, 1997a) 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 (e.g., a line, circle, L shape) that were each assigned a digit from 1 to 9. They were then presented with the digits in a random order and asked to draw, as quickly as possible, the corresponding geometric figure for each. The dependent measure was the number of items completed in 90 s.

Letter comparison. Participants were presented with letter strings consisting of three, six, or nine letters each. The letter strings were presented in pairs. The participant's task was to compare the two strings and quickly decide whether the strings were the same or different by writing *S* or *D* on the answer sheet. They were given 30 s to complete as many items as possible at each level (three, six, or nine letters). The dependent measure was the sum of backward 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 that consisted of three, six, or nine line segments indicating whether they were the same or different. There were three 30-s trials, one at each level. Again, the dependent measure was the total number of correct decisions made in the three trials.

Short-Term Memory

We collected two visuospatial and two verbal measures of short-term memory. In all cases, the number of trials correctly completed was the dependent measure used for analysis.

Visuospatial short-term memory. There were two measures of visuospatial short-term memory: Forward and Backward Corsi Blocks from the Wechsler Memory Scale (3rd ed.; Weschler, 1997b), called the *Spatial Span task.*

1. Forward Corsi Blocks. The experimenter pointed to a series of raised blocks on a board. In this version of the task, the participant repeated the same pattern of pointing as the experimenter, pointing to the same blocks in the same order. The presentation rate was one block per second. There were two trials per block, with the number of blocks the experimenter pointed to in each trial ranging from 2 to 8. The task was discontinued when the participant missed both trials of a particular level.

2. Backward Corsi Blocks. This version of the task was the same as the forward Corsi blocks except that the participant had to repeat the pattern of pointing backward. The task was discontinued when he or she missed both trials of a particular block.

Verbal short-term memory. We used two measures of verbal short-term memory: Forward and Backward Digit Span from the WAIS–III (Weschler, 1997a).

1. Forward Digit Span. The experimenter read a series of digits aloud to the participant, who responded by repeating back the same series of digits in the same order (i.e., 9–1–7 for 9–1–7). The presentation rate was one digit per second. There were two trials per block, with the number of digits the experimenter read per trial ranging from 2 to 10. The task was discontinued when the participant missed both trials of a particular block.

2. Backward Digit Span. This task was similar to the Forward Digit Span except that the subject repeated the series of digits in reverse order (i.e., 9–1–7 for 7–1–9). There were also two trials per block, with the number of digits per trial ranging from 2 to 8. The task was discontinued when the participant missed both trials of a particular block.

Working Memory

There were four working memory tasks: two visuospatial and two verbal. Each task had a processing and a storage component. The processing component in each task involved making a simple decision (e.g., whether three shapes were identical). For the storage component, participants had to remember a series of items (e.g., the last word in a sentence).

Visuospatial working memory. There were two tasks used to measure visuospatial working memory: line span and letter rotation.

1. Line span. This task was adapted from Morrell and Park (1993). Two types of visuospatial information were displayed simultaneously on a computer screen: three irregular shapes in random locations and 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, indicating their choice by pressing one of two keys. At the same time, for the storage component, they had to 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 they had been originally. The number of displays in a sequence varied from one to six. There were 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 2 out of 3 trials at a particular level. The dependent measure was the total number of trials (ranging from 0 to 18) on which the processing component (making the same–different judgment about the shapes) and the storage component (remembering the positions of the lines) were both correct.

2. Letter rotation. This was adapted from Shah and Miyake's (1996) spatial span task. On a computer screen, participants were shown a series of letters, one at a time. Some of the letters were presented as mirror images, and others were presented in their normal form. All of the letters were also tilted at an angle from vertical (45°, 90°, 135°, 180°, 225°, 270°, or 315° 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. At the same time, for the storage component, they had to 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 sheet grid. The number of letters in a series varied from two to five. There were five trials given at each of the four levels (2–5). The task was discontinued when a participant made an error on the storage component of at least 3 out of 5 trials at a particular level. The dependent measure was the total number of trials (ranging from 0 to 20) on which the processing component (making the mirror-imaged or normal judgment about the form of the letter) and the storage component (remembering the angle that the letter was tilted from vertical) were both correct.

Verbal working memory. Two tasks were used to measure verbal working memory: reading span and computation span. The computation span task relies on simple equations that are highly familiar and part of the lexicon, so that it was viewed as primarily a verbal–symbolic task. Previous studies have found that verbal and numerical span tasks similar to those used in the present study (involving simple sentences and equations) correlate equally well with verbal ability scores (Engle, Cantor, & Carullo, 1992; Turner & Engle, 1989). So for modeling purposes, computation span was used as an indicator of verbal working memory in this study.

1. Reading span. This was adapted from Salthouse and Babcock (1991). Participants heard simple sentences read aloud, one at a time (e.g., "After dinner, the chef prepared dessert for her guests."). After each sentence, they answered a question presented on the computer screen (e.g., "What did the chef prepare? A. fish; B. dessert; C. salad") by pressing the appropriate key. In addition to answering the questions, participants had to remember the last word in each of the sentences they heard. 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. There were 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 2 out of 3 trials at a particular level. The dependent measure was the total number of trials (ranging from 0 to 18) on which the processing component (answering the question about the sentence) and the storage component (remembering the last word in the sentence) were both correct.

2. Computational span. This was also adapted from Salthouse and Babcock (1991). The structure of this task was similar to that of the reading span task. Participants heard simple math problems read aloud, one at a time (e.g., "5 − 3 ="). After each problem, they saw three possible solutions on the computer screen (e.g., "A. 2, B. 1, C. 9") and indicated their choice by pressing the appropriate key. They also had to remember the last number in each problem (e.g., in this problem "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 the calculation of the dependent measure were the same as in the reading span task.

Visuospatial Long-Term Memory

There were two measures of visuospatial long-term memory: the Rey Visual Design Learning Test (Spreen & Strauss, 1991) and the Benton Visual Retention Test (Sivan, 1992).

Rey Visual Design Learning Test. This test consisted of two sets of 15 simple line drawings (e.g., a triangle with a horizontal line under it) and was designed to be similar to the free recall task. The 15 drawings were presented on a computer screen, one at a time, at a 5-s rate. After seeing all the drawings, participants drew as many of the original drawings as they could recall, in any order. They were given 3 min to recall the drawings. Standard scoring methods as described by Spreen and Strauss (1991) were used. The dependent measure was the total number of designs reproduced correctly.

Benton Visual Retention Test. This task consisted of two sets of 10 line drawings that increased in complexity. In one set, the first drawing was a simple parallelogram whereas the last drawing had three separate figures in the same display. The drawings were presented on a computer screen one at a time, for 5 s each (Administration A; Sivan, 1992). After a drawing was removed from the screen, participants immediately drew the entire drawing from memory and then pressed a key to see the next drawing. They were given no time limit for recalling each of the drawings. The Number Correct Score (Sivan, 1992) was used as the dependent measure, with participants receiving one point for each design reproduced correctly (all of the figures in the same size, position, and orientation).

Verbal Long-Term Memory

Participants completed two lists of free recall and two lists of cued recall that served as measures of verbal long-term memory.

Free recall. This consisted of 2 lists of 16 words each presented on a computer. The words were shown one at a time for 5 s each. The participants were instructed to "study each word and try to remember it." After viewing all of the words in a single list, participants wrote on an answer sheet as many words as they could recall, in any order. They were given 3 min for the recall portion of the task. For the 32 words on both lists, the Thorndike and Lorge (1944) frequency counts ranged from 120 to 3,133 with mean frequencies for List 1 and List 2 of 901 and 904, respectively. The dependent measure was the total number of words recalled for each list.

Cued recall. In this task, 2 lists of 16 word pairs each were presented to participants on a computer. Each word pair consisted of a cue word in lowercase letters and a target word in capital letters. Each cue word was a weak associate of its paired target word. The word pairs were shown on the screen one at a time for 5 s each. Then after all 16 word pairs in a list had been presented, the cue words were presented again, one at a time. Participants wrote on their answer sheet the target word that was originally paired with each cue word. The mean frequencies of the target words in the two lists were 907.5 and 913.7.

Sensory Functioning

To assess the participant's sensory functioning, we did extensive vision and audition tests.

Vision tests. The vision tests were performed with Stereo Optical's OPTEC 2000 Vision Tester (Veatch Ophthalmic Instruments, Tempe, AZ). Near visual acuity (14 inches [35.6 cm]) and far visual acuity (20 feet [6.1 m]) were measured in Snellen decimal units both monocularly and binocularly. Measures of contrast sensitivity, stereo depth perception, and peripheral vision were also collected but were not used in the models, so they are not described here. All measurements were taken with corrected vision.

Audition tests. Auditory acuity was assessed with a Beltone Audio Scout Portable Screening Audiometer (Beltone Electronics Corporation, Chicago), using pure tones. Each participant's auditory thresholds were tested separately for the right and left ears at eight different levels (0.25, 0.50, 1.00, 2.00, 3.00, 4.00, 6.00, and 8.00 kHz, respectively). A standard staircase method was used, following the methods used by Lindenberger and Baltes (1994). For technical reasons, measurements were taken without hearing aids.

Verbal Ability

Three measures of verbal ability were used primarily to describe the sample: the Vocabulary section of the Shipley Institute of Living Scale (Shipley, 1986) and computerized versions of synonym and antonym vocabulary tests developed by Salthouse (1993).

Vocabulary section of the Shipley Institute of Living Scale. The 40 target words from the Shipley scale (Shipley, 1986) were presented on a computer, one at a time, with their four alternatives. Participants chose which of the four alternative words had nearly the same meaning as the target word by pressing one of four keys. They were given 10 min to complete all 40 items. The dependent measure was the total number of correct items.

Synonym vocabulary. This task was taken from Salthouse (1993). Participants were presented with 10 words on a computer, one at a time, and they were asked to indicate which of five alternative words had nearly the same meaning as the target word by pressing one of five keys. Participants were given 5 min to complete this task. The dependent measure was the total number of correct items.

Antonym vocabulary. This task was taken from Salthouse (1993). It was presented and scored like the synonym vocabulary task, except that participants had to decide which of the five alternative words had most nearly the opposite meaning to the target word.

Order of Task Presentation

On Day 1, participants completed the tasks in the following order (tasks discussed in this article are italicized): (a) *Rey List A,* (b) verbal fluency List 1, (c) word recognition List 1, (d) *computation span,* (e) synonym matching, (f) *cued recall List 1,* (g) *line span,* (h) *Shipley vocabulary,* (i) *letter comparison,* (j) *free recall,* (k) lexical decision, (l) verbal fluency List 2, and (m) *Benton List C.*

The order of tasks on Day 2 was as follows: (a) *Rey List B,* (b) verbal fluency List 3, (c) word recognition List 2, (d) *reading span,* (e) *Digit Symbol,* (f) *cued recall List 2,* (g) *letter rotation,* (h) *synonym vocabulary,* (i) *pattern comparison,* (j) *free recall List 2,* (k) semantic matching, (l) *antonym vocabulary,* (m) *Benton List D,* and (n) activity questionnaire.

On Day 3, the order of tasks was as follows: (a) *vision tests,* (b) *Forward Corsi Blocks,* (c) *Backward Corsi Blocks,* (d) *Forward Digit Span,* (e) *Backward Digit Span,* and (f) *audition tests.*

RESULTS

Overview

We designed the analyses to address the following questions. First, what is the nature of age-related decline on a broad range of memory tasks? Are the declines linear, or does decline accelerate in the later ages? Of particular interest was whether evidence existed for more decline in visuospatial compared to verbal processes across the life span in working memory and long-term memory. We used regression analyses to evaluate these issues. Second, we developed measurement and structural models to evaluate the issue of whether differentiation of working memory by domain better fit the data than a model where working memory was a general, undifferentiated resource. Third, we evaluated these models separately for young and older adults to address the possibility that the two age groups were characterized by different models. Finally, we examined the role that sensory function played in improving overall model fit, based on theorizing related to the "common cause" hypothesis (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994).

Memory Performance Across the Life Span

Participants' performance on the tasks was transformed into *z* scores, using the entire sample. Figure 1 presents performance in six panels on the measures of speed, visuospatial and verbal measures of working memory, short-term memory, long-term memory, and vocabulary. Panel F of Figure 1 depicts a summary of Panels A through E, using composite scores for the measures represented in the five panels. Figure 1 provides striking evidence for five general points about aging and memory (with supporting analyses reported next). First, age-related decline in memory processes is continuous across the adult life span, with no acceleration of decline in late adulthood. Second, there is little difference in age-related decline across processing intensive measures of function (speed, working memory, and long-term memory). Third, there is little difference across content domain (visuospatial or verbal), but there is a significant difference between the slopes of digit span compared to visuospatial measures of long-term memory. Fourth, short-term span measures show age-related decline but not as much as the processing-intense variables, and finally, measures of knowledge show small increases across the life span.

As can be seen in Figure 1A, there was a strong linear relationship of each measure of speed of processing with age, as expected, with performance declining in the older participants. Regression analyses, summarized in Table 2, confirm this. Of particular interest was a comparison of the slopes of the three measures of speed shown in Figure 1A. (We should note here that we report a number of comparisons of slopes in this section, in addition to the three speed slopes. Given the large sample size and multiple comparisons made of slopes, we used a Bonferroni adjustment for these comparisons, setting family alpha at .05.) We compared the confidence intervals for the slopes and intercepts of the three speed tasks and found such substantial overlap that the three different measures of performance could be accurately represented by a single line.

Figure 1B presents performance on the visuospatial and verbal measures of working memory. Again, regression analyses confirmed a significant linear relationship of performance to age, with older participants performing more poorly than younger participants. As in the analysis of perceptual speed, the comparison of confidence intervals suggested that the four measures of performance were statistically equivalent across the entire life span. We performed similar analyses for the long-term memory measures in Figure 1C, and the results were the same as those described for speed and working memory. We combined the 11 tasks shown in Figures 1A, B, and C for further analyses; again, we found no evidence for differentiation in performance across the 11 tasks. It is as though a single line could accurately represent the performance on these tasks.

Figure 1D presents performance on the visuospatial and verbal short-term span measures. Regression analyses confirmed a linear relationship of performance to age (reported in Table 2). The slopes of the four measures did not differ among themselves. When compared to the slopes in Figures 1A and 1B, there was some evidence, however, that the Backward and Forward Digit Span slopes were less steep than some of the long-term memory measures, because the confidence interval for these digit span measures did not overlap with those of the Rey or Benton long-term memory measures (as shown in Table 2).

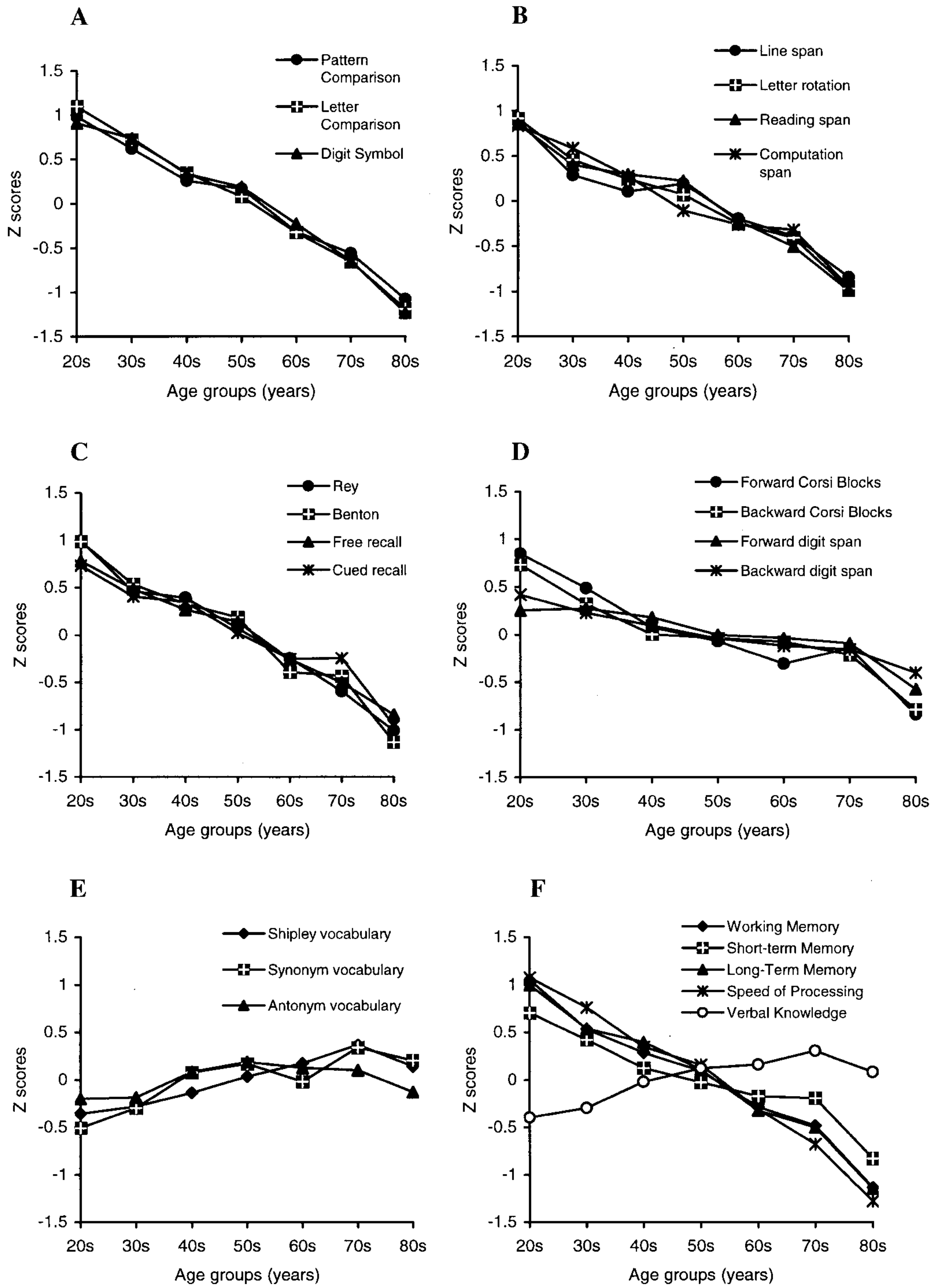

Figure 1. Life span performance measures. A: Speed of processing measures. B: Working memory measures (visuospatial and verbal). C: Long-term memory measures (visuospatial and verbal). D: Short-term memory measures (visuospatial and verbal). E: Knowledge-based verbal ability measures. F: A composite view of the aforementioned measures. Composite scores for each construct represent the *z* score of the average of all measures for that construct.

To summarize, we found little evidence for differential decline in visuospatial and verbal performance across the life span in processing-intensive measures, although short-term span measures did provide limited evidence for more decline in the visuospatial than verbal mode.

Figure 1E presents performance on the knowledge-based verbal ability measures of performance as a function of age. Unlike the process-based measures presented in Figure 1A–D, regression analyses indicated that the significant age-related variance in performance on the Shipley and synonym measures of verbal knowl-

Table 2
Comparing Regressions of Standardized Task Performance With Age

Dependent variable	Slope	Slope *SE*	Intercept	Intercept *SE*	R^2	Bonferonni CI for slope LL	Bonferonni CI for slope UL
Speed of processing							
Digit Symbol	−.035	.002	1.958	.115	.49	−.042	−.028
Letter comparison	−.033	.002	1.842	.121	.43	−.040	−.026
Pattern comparison	−.038	.002	2.080	.108	.55	−.045	−.031
Working memory							
Line span	−.025	.002	1.376	.140	.24	−.032	−.018
Letter rotation	−.028	.002	1.576	.133	.32	−.035	−.021
Reading span	−.028	.002	1.566	.133	.31	−.035	−.021
Computation span	−.028	.002	1.531	.135	.30	−.035	−.021
Short-term memory							
Forward Corsi Blocks	−.025	.002	1.357	.141	.24	−.032	−.018
Backward Corsi Blocks	−.021	.002	1.147	.147	.17	−.028	−.014
Forward Digit Span	−.013	.003	0.696	.156	.06	−.023	−.006
Backward Digit Span	−.012	.003	0.661	.156	.06	−.022	−.002
Long-term memory							
Rey	−.032	.002	1.774	.124	.40	−.039	−.025
Benton	−.033	.002	1.810	.123	.42	−.040	−.026
Free recall	−.027	.002	1.493	.136	.28	−.034	−.020
Cued recall	−.025	.002	1.397	.139	.25	−.032	−.018
Knowledge based							
Shipley	.011	.003	−0.629	.157	.05	.001	.021
Synonym	.012	.003	−0.667	.156	.06	.002	.022
Antonym	.004	.003	−0.192	.160	.00	−.006	.014

Note. $N = 345$. $p < .001$ for all R^2 except antonym, where $p = .20$. Bonferroni confidence intervals (CIs) are based on $\alpha = .05$ for the family of comparisons. LL = lower confidence limit; UL = upper confidence limit.

edge was due to older participants performing better than younger ones. This is a typical finding in the cognitive aging literature (see Park, 2000). Although we observed small amounts of significant age-related variance, examination of confidence intervals for the slope and intercept again confirmed that regression equations for the three measures were comparable. There was no significant age-related variance in performance on the antonym measure.

Two additional considerations require attention in this preliminary set of descriptive analyses. The first was whether there was evidence for the existence of quadratic effects of age, providing evidence for steeper declines in performance occurring in later adulthood. We examined this by regressing each study variable on both age and the squared value of age (age^2). Out of the 19 regressions conducted, only the Digit Symbol task was significantly correlated with age^2. Furthermore, this accounted for only 1% additional variance, whereas the linear effect of age accounted for 49% of the variance in this task. These results are consistent with previous work by Park et al. (1996) and suggest continuous, linear decline with age in memory function. Because of the negligible evidence for quadraticity in the data, we did not test for quadratic effects of age in the subsequent models we tested.

Next, we addressed the possibility that by using the entire sample as the basis for the *z* score transformation, we might artifactually produce comparable regression slopes. To assess this issue, we used the mean and standard deviation of 20- to 29-year-olds as the basis for standardization. When this standardization was applied, the results obtained were essentially equivalent to the results presented in Table 2. Exceptions were that (a) the slope for free recall was significantly flatter than that of the Benton measure and (b) the Forward Digit Span task had greater slope than either of the two Corsi tasks. All other confidence intervals overlapped within construct domains for this alternative standardization.

Development of Structural Models

We used structural equation models to understand the interrelationships among the processing measures: speed, short-term memory, working memory, and long-term memory. We used the structural models to evaluate (a) the organization of working memory and short-term memory, with particular interest in the relationship of short-term stores to working memory, as well as the evidence (if any) for differentiated visuospatial and verbal constructs; (b) whether the structural models that best fit the life span data also characterized data independently for younger and older adults; and (c) the interrelationships of the constructs of speed, short-term, and working memory to long-term visuospatial and verbal memory.

Unlike regression, structural equation modeling permits the specification of both direct and indirect relationships among variables, providing more information about potential causal relationships than does regression analysis. Structural equation modeling differs from path analysis (which also permits specification of relationships) in that in structural models, latent variable or hypothetical constructs are measured by collecting two or more indicators of important constructs (e.g., computational span and reading span are indicators of the construct of verbal working memory). Shared variance among these multiple measures forms the basis for the latent construct, providing increased power and reliability for explaining variance in the model. Three important steps in developing structural equation models are discussed in turn below. First, the indicators of the latent constructs must be reliable statistically, as discussed in the next section. Second, using only reliable measures, measurement models are developed to determine whether indicators of the hypothesized latent constructs share sufficient variance to form a latent construct (e.g., do reading span and computational span share sufficient variance to form a latent construct labeled *Verbal Working Memory*?). The measurement models specify what latent constructs (and indicators associated with them) are appropriate for use in structural equation modeling, but a measurement model does not specify relationships among the constructs. Finally, based on the latent constructs identified by the measurement model, a structural equation model that specifies theoretically derived relationships among the latent constructs is developed and tested.

Both measurement models and structural equation models have a series of fit statistics associated with them. There is no single criterion, nor are there reference tables to assess goodness of fit of structural equation models. Rather, multiple indicators of fit are considered jointly in assessing overall fit. Generally, a model that has excellent fit would have the following characteristics: (a) the chi-square index of fit is no greater than twice the degrees of freedom associated with it, indicating that the observed and estimated models are similar; (b) the nonnormed fit index and comparative fit index are greater than .90 (because a value of 1.0 for the latter index indicates perfect fit); and (c) the standardized root mean square residual is about .05 or less, because this is the estimate of error. In addition, it is useful to compare the fit of a given structural model to its respective measurement model to determine the comparative fit, because the measurement model provides the best fit possible of any given structural model with which it is consistent. It is also useful to examine the relative fit of competing or alternative structural models and to consider model parsimony when comparing alternate models, with the least complex model preferred when fit is equivalent.

Measurement Reliability

Table 3 summarizes the estimates of measurement reliability for all of the measures considered in the models. The reliabilities for the Digit Symbol and Digit Span were obtained from Wechsler (1997a), and reliabilities for Corsi Blocks were from Wechsler (1997b). We calculated reliabilities for the other tasks from the data using the procedures described in Table 3.

Descriptive Statistics and Missing Data

Of the 345 participants, 97% ($n = 336$) provided complete data for all measures used in the confirmatory analyses. Missing data resulted from nonresponse to instructions or noncompletion of a task. Of the total data points collected, less than 1% of the data points were missing. Because there was no discernible pattern of missing data on these measures, we estimated missing data with a regression approach using available data from measures within each affected construct (Lindenberger, Mayr, & Kliegl, 1993, p. 211). Table 4 presents the correlations, means, and standard deviations of variables used in the measurement and structural models after missing data were estimated.

Measurement Models

The initial measurement models included four constructs: speed of processing, short-term memory, working memory, and long-term memory. Because we were interested in examining two types of structural models, a domain-differentiated working memory model and a domain-general working memory model, we developed measurement models for both of these alternatives. The two measurement models differed from one another in their treatment of the working memory construct but not the speed, short-term memory, or long-term memory constructs. For the domain-differentiated model, line span and letter rotation were treated as indicators of visuospatial working memory, whereas reading span and computation span were treated as indicators of verbal working memory. For the domain-general model, these four measures were used as indicators of a single working memory construct. Preliminary models indicated that the short-term verbal and visual spans could not be combined with the working memory measures to form a single construct, so they were consistently treated as separable in all models. This finding is entirely congruent with behavioral work in young adults (Engle, Tuholski, et al., 1999) and neuroimaging work (D'Esposito et al., 1998). Similarly, preliminary measures indicated that the long-term memory measures did not form a single construct, so the Benton and Rey visual memory tests were used as indicators of long-term visuospatial recall, and the free and cued recall data were used as indicators of long-term verbal recall.

The measurement models for the domain-differentiated working memory model and the domain-general working memory model are shown in Figures 2 and 3 respectively. Table 5 presents the construct correlations (values of curved paths between constructs) in each of the two measurement models. In the domain-differentiated measurement model, there are separate latent constructs of visuospatial and verbal processes for working memory, short-term memory, and long-term memory. This contrasts with

(*text continues on page 311*)

Table 3
Task Reliability Estimates

Construct–task	Method	Reliability estimate
Speed		
Digit Symbol	Test–retest	.84
Letter comparison	Test–retest[a]	.89
Pattern comparison	Test–retest[a]	.91
Visuospatial working memory		
Line span	Split half	.86
Letter rotation	Split half	.92
Verbal working memory		
Reading span	Split half	.88
Computation span	Split half	.91
Short-term memory		
Corsi Blocks (fwd & bkwd)	Split half	.79
Digit Span (fwd & bkwd)	Split half	.90
Visuospatial recall		
Rey	Split half	.79
Benton	Split half	.82
Verbal recall		
Free recall	Split half	.82
Cued recall	Split half	.86

Note. Reliabilities for Digit Symbol and Digit Span were estimated by Wechsler (1997a), and Corsi Blocks was estimated by Wechsler (1997b). All other reliabilities were estimated by using the data from the present study. Fwd = forward; bkwd = backward.
[a] Average test–retest taken over three parallel forms.

Table 4
Correlation Matrix Used in Measurement and Structural Models

Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Age	—																			
2. Digit Symbol	−.70	—																		
3. Letter comparison	−.66	.74	—																	
4. Pattern comparison	−.74	.75	.83	—																
5. Line span	−.49	.49	.54	.56	—															
6. Letter rotation	−.56	.54	.52	.54	.64	—														
7. Forward Corsi Blocks	−.48	.52	.53	.52	.41	.52	—													
8. Backward Corsi Blocks	−.41	.44	.47	.47	.49	.55	.54	—												
9. Reading span	−.56	.58	.59	.56	.54	.62	.50	.44	—											
10. Computation span	−.55	.51	.56	.54	.51	.55	.53	.47	.62	—										
11. Forward Digit Span	−.25	.28	.39	.34	.34	.38	.48	.36	.48	.48	—									
12. Backward Digit Span	−.24	.30	.37	.31	.37	.43	.41	.36	.50	.46	.58	—								
13. Rey A	−.55	.57	.52	.54	.50	.60	.48	.41	.52	.54	.36	.34	—							
14. Rey B	−.61	.54	.48	.55	.52	.54	.42	.40	.52	.54	.27	.32	.70	—						
15. Benton C	−.55	.56	.55	.57	.54	.53	.44	.44	.53	.50	.24	.28	.53	.58	—					
16. Benton D	−.62	.58	.57	.64	.64	.65	.55	.56	.55	.59	.38	.40	.60	.62	.66	—				
17. Free recall 1	−.49	.55	.51	.49	.44	.48	.41	.34	.54	.47	.28	.31	.49	.50	.42	.47	—			
18. Free recall 2	−.49	.57	.54	.53	.46	.53	.43	.39	.51	.42	.29	.35	.54	.54	.40	.53	.69	—		
19. Cued recall 1	−.45	.52	.53	.47	.47	.49	.38	.34	.48	.46	.27	.31	.55	.55	.45	.46	.56	.57	—	
20. Cued recall 2	−.49	.55	.52	.50	.46	.51	.40	.40	.49	.46	.31	.32	.50	.52	.47	.49	.57	.60	.76	—
M	55.30	54.07	35.42	49.69	5.48	8.61	7.96	7.33	7.93	7.47	10.58	7.50	6.37	7.34	5.84	5.25	8.83	9.26	9.94	11.10
SD	19.73	15.99	10.66	13.12	2.98	6.27	2.14	2.03	3.49	4.02	2.52	2.44	2.57	2.94	1.79	2.48	2.84	3.20	4.20	4.05

Note. For 9 participants, we estimated missing data on some variables. Rey A = Rey List A; Rey B = Rey List B; Benton C = Benton List C; Benton D = Benton List D; Free recall 1 = free recall List 1; Free recall 2 = free recall List 2; Cued recall 1 = cued recall List 1; Cued recall 2 = cued recall List 2.

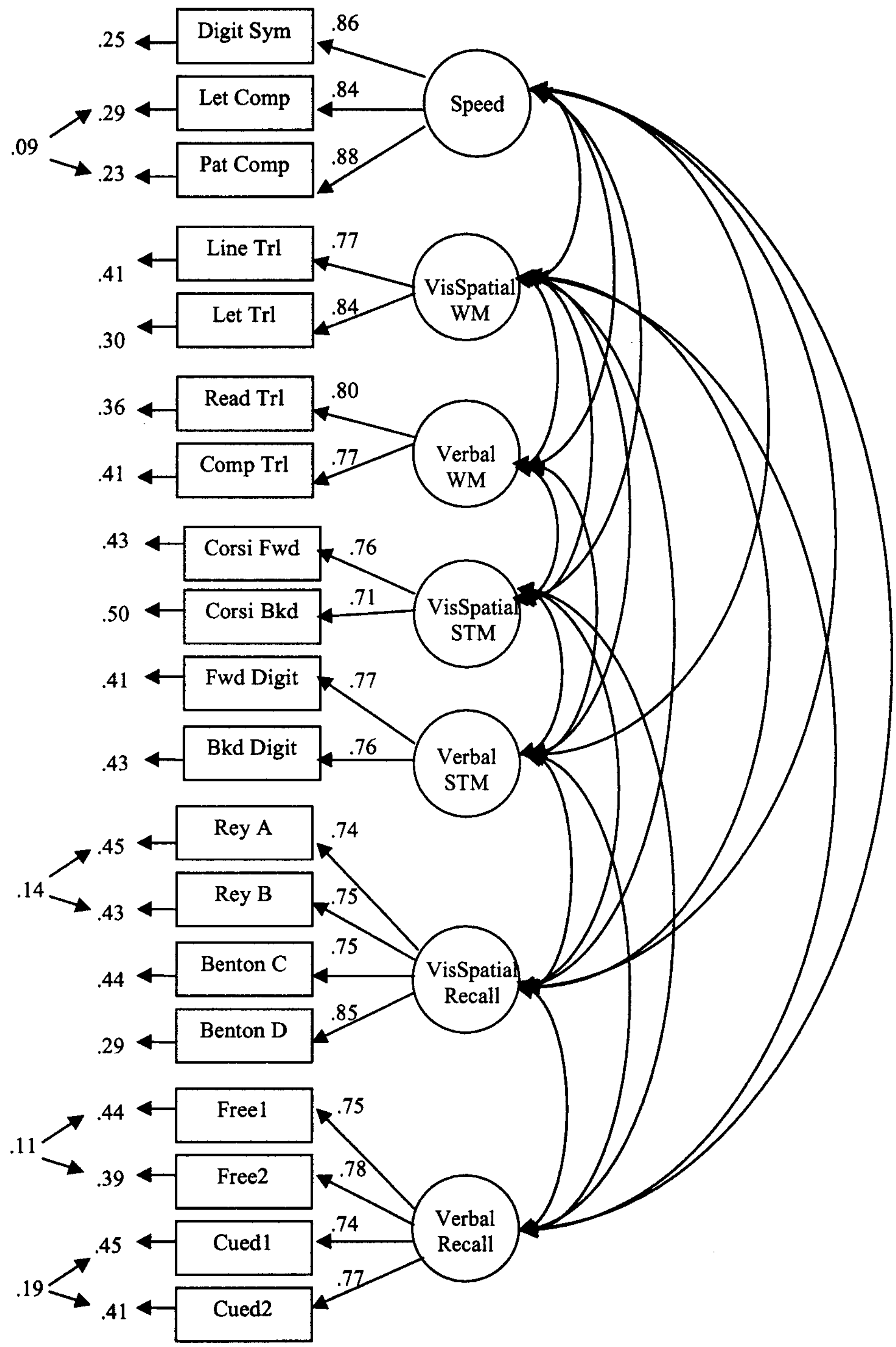

Figure 2. Domain-differentiated measurement model. Correlations among latent constructs are given in Table 5. Digit Sym = Digit Symbol; Let Comp = letter comparison; Pat Comp = pattern comparison; Line Trl = line span; Let Trl = letter rotation; Read Trl = reading span; Comp Trl = computation span; Corsi Fwd = Forward Corsi Blocks; Corsi Bkd = Backward Corsi Blocks; Fwd Digit = Forward Digit Span; Bkd Digit = Backward Digit Span; Rey A = Rey List A; Rey B = Rey List B; Benton C = Benton List C; Benton D = Benton List D; Free1 = free recall List 1; Free2 = free recall List 2; Cued1 = cued recall List 1; Cued2 = cued recall List 2; Speed = speed of processing; VisSpatial WM = visuospatial working memory; Verbal WM = verbal working memory; VisSpatial STM = visuospatial short-term memory; Verbal STM = verbal short-term memory; VisSpatial Recall = visuospatial recall.

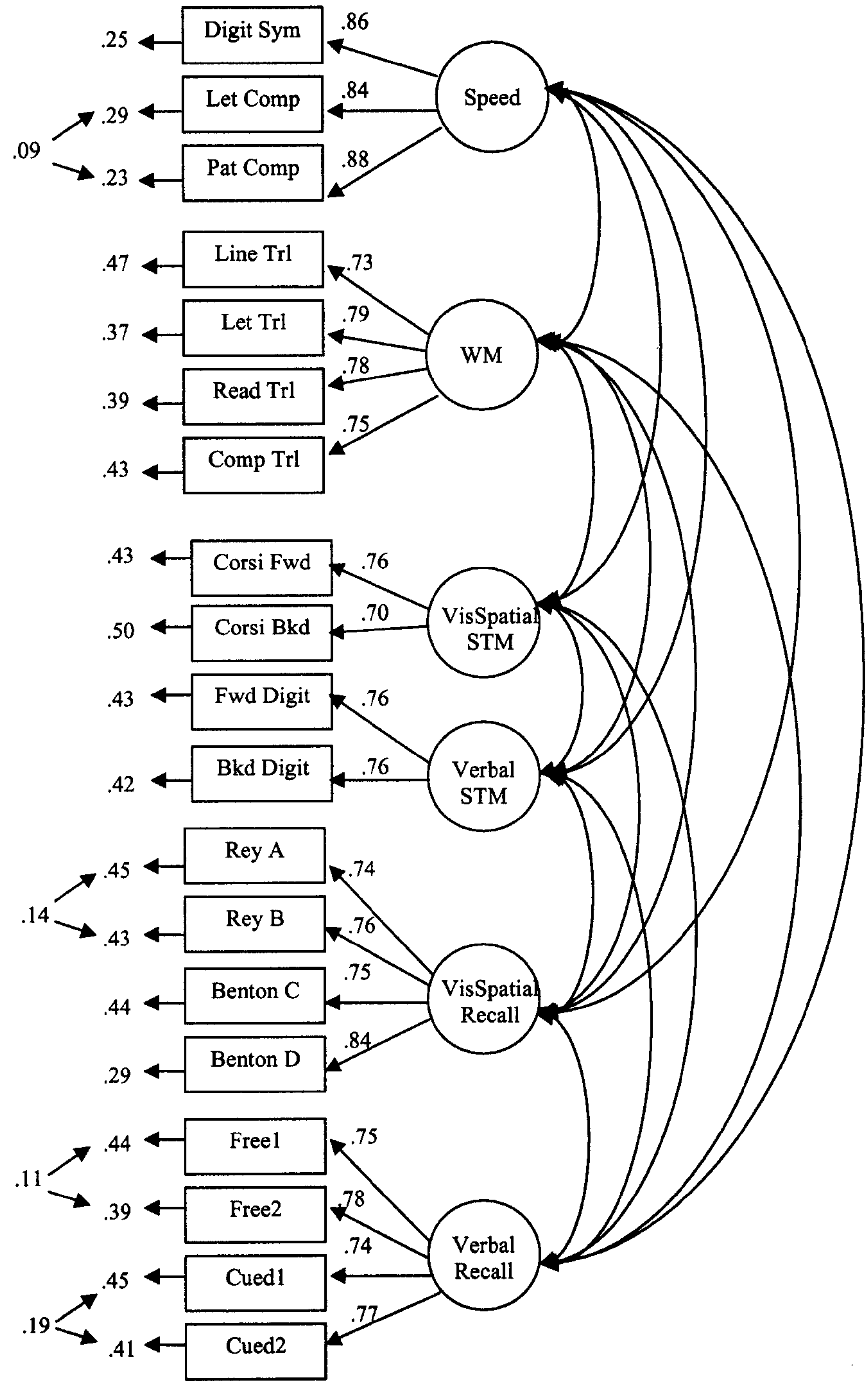

Figure 3. Domain-general measurement model. Correlations among latent constructs are given in Table 5. Digit Sym = Digit Symbol; Let Comp = letter comparison; Pat Comp = pattern comparison; Line Trl = line span; Let Trl = letter rotation; Read Trl = reading span; Comp Trl = computation span; Corsi Fwd = Forward Corsi Blocks; Corsi Bkd = Backward Corsi Blocks; Fwd Digit = Forward Digit Span; Bkd Digit = Backward Digit Span; Rey A = Rey List A; Rey B = Rey List B; Benton C = Benton List C; Benton D = Benton List D; Free1 = free recall List 1; Free2 = free recall List 2; Cued1 = cued recall List 1; Cued2 = cued recall List 2; Speed = speed of processing; VisSpatial WM = visuaospatial working memory; Verbal WM = verbal working memory; VisSpatial STM = visuospatial short-term memory; Verbal STM = verbal short-term memory; VisSpatial Recall = visuospatial recall.

Table 5
Correlations Between Latent Constructs in Measurement Models

Construct	1	2	3	4	5	6	7	8
Domain-differentiated model								
1. Speed	—							
2. Visuospatial working memory	.76	—						
3. Verbal working memory	.82	.89	—					
4. Visuospatial short-term memory	.78	.84	.84	—				
5. Verbal short-term memory	.49	.62	.80	.73	—			
6. Visuospatial recall	.84	.92	.88	.84	.56	—		
7. Verbal recall	.80	.79	.80	.70	.53	.82	—	
8. Age	−.82	−.66	−.70	−.61	−.32	−.75	−.63	—
Domain-general model								
1. Speed	—							
2. Working memory	.82	—						
3. Visuospatial short-term memory	.78	.87	—					
4. Verbal short-term memory	.49	.74	.73	—				
5. Visuospatial recall	.84	.93	.83	.56	—			
6. Verbal recall	.80	.83	.70	.53	.82	—		
7. Age	−.82	−.71	−.70	−.32	−.75	−.63	—	

the domain-general model where the visuospatial and verbal measures of working memory are combined to be indicators of a single working memory construct, although short-term and long-term memory remain domain specific. As Table 6 indicates, both models have acceptable fit (indicated by the correlated factors model). However, as Table 6 also shows, the domain-differentiated measurement model consistently fits better for all measures except PNFI (which one would expect because of the additional construct in the domain-specific model). It is significant that the domain-differentiated model's fit is statistically better than the domain-general model, $\Delta\chi^2(7, N = 345) = 37.37, p < .001$. For this reason, the domain-differentiated structural model was accepted as the basis for all structural modeling. Note that the measurement models do not specify the relationships among constructs but only indicate which constructs are appropriate to use to develop structural models.

Structural Equation Models

The structural equation model we initially developed was based on several considerations and is represented by the solid lines in Figure 4. The reasoning behind the development of this model is as follows. First, we were interested in explaining age-related variance, so age is the exogenous variable in the model. Second, the literature is very clear that speed of processing is fundamental in mediating age-related variance on nearly all cognitive tasks, so a path from age to speed was developed. As noted previously, speed of processing has been demonstrated to have a relationship to both working and long-term memory, so paths from speed to the visuospatial and verbal working memory constructs and long-term memory constructs were included. As can be seen in Figure 4, all of these paths were significant. With respect to working memory and short-term memory, we initially modeled the visuospatial and

Table 6
Fit Statistics of Measurement and Structural Models

Model	*df*	χ^2	χ^2/df	*p*	GFI	NNFI	CFI	RMSEA	PNFI
Domain-differentiated models									
Corr. factors	139	247.87	1.78	<.001	.93	.97	.98	.047	.69
Structural models									
1A: Domain specific	156	367.87	2.36	<.001	.91	.94	.95	.062	.76
1B: Domain distinct with WM corr. resid.	155	341.46	2.20	<.001	.91	.95	.96	.058	.76
1C: Domain distinct with WM & STM corr. resid.	154	277.54	1.80	<.001	.93	.97	.97	.047	.76
Domain-general models									
Corr. factors	146	285.24	1.95	<.001	.92	.96	.97	.053	.72
Structural models									
2A: Basic domain general	157	367.23	2.34	<.001	.90	.95	.96	.063	.76
2B: Domain general with STM corr. resid.	156	317.12	2.03	<.001	.91	.96	.97	.056	.77
Compare corr. factors	7	37.37		<.001					
Compare 1C to 2B	2	39.58		<.001					

Note. $N = 345$ for all models. GFI = goodness-of-fit index; NNFI = nonnormed goodness-of-fit index; CFI = comparative fit index; RMSEA = root-mean-square error of approximation; PNFI = parsimony normed fit index; corr. = correlated; WM = working memory; resid. = residuals; STM = short-term memory.

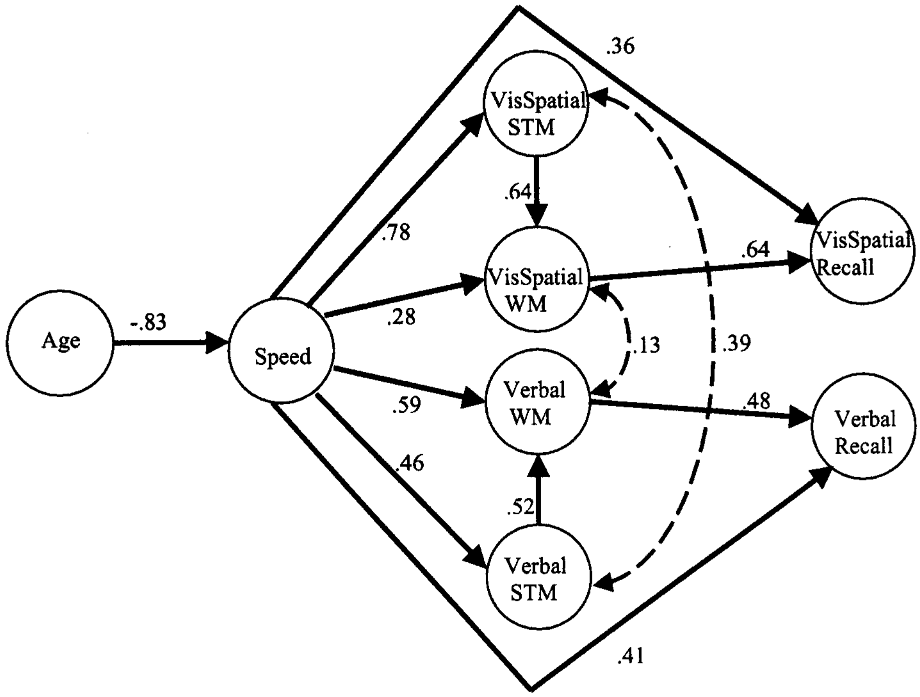

Figure 4. Domain-distinct structural model. For each path in the model, the completely standardized path coefficient is presented. Dashed curved lines represent correlations among residuals. Speed = speed of processing; VisSpatial WM = visuospatial working memory; Verbal WM = verbal working memory; VisSpatial STM = visuospatial short-term memory; Verbal STM = verbal short-term memory; VisSpatial Recall = visuospatial recall.

verbal resource pools to be independent of one another (a domain-specific model as suggested by Shah & Miyake, 1996). Moreover, we assumed, as in both the Baddeley (1986, 1996) and the Engle, Tuholski, et al. (1999) model, that the short-term stores were highly related subsystems of working memory and that only working memory would have direct paths to long-term memory. All of these paths were significant. When we fit this domain-specific model where the two types of working memory were truly independent of one another, the model fit relatively well, as shown in Table 6, Item 1A. The fit statistics indicated, however, that we would achieve better fit if, rather than setting the residuals to zero as in Item 1A, we correlated the residuals of both working memory and short-term memory. We termed these models where the two working memory domains were separable but related through correlated residuals to be *domain-distinct models*. These models indicated that although the two working memory measures were distinct constructs, they nevertheless shared considerable variance with one another. We examined the increased fit by correlating residuals in incremental steps. We initially correlated the residuals of the two working memory constructs (dashed line in Figure 4) and found a substantial improvement in fit of the model, $\Delta\chi^2(1, N = 345) = 26.41$, $p < .001$, as shown in Table 6, Item 1B. The fit of the model was also improved substantially when we additionally correlated the residuals of the short-term memory constructs, $\Delta\chi^2(1, N = 345) = 63.92$, $p < .001$, as reported in Table 6, Item 1C. This final model was the model of best fit and suggests that the independence of the visuospatial and verbal measures of working memory and short-term memory are real but limited, given the high interrelationships among the measures. This domain-distinct model confirms the findings of Engle, Tuholski, et al. (1999), who reported that short-term memory was distinguishable from, but highly related to, working memory. It extends the findings to show that these relationships exist for both verbal and visuospatial memory, which are highly related to one another. This model mediates 51% of the variance in visual recall and 44% of the variance in verbal recall.

Although the domain-distinct model portrayed in Figure 4 may seem very similar to a domain-general model, given the strong interrelationships among the visuospatial and verbal working memory and short-term memory measures, this model does differ significantly from a domain-general model. We include in Table 6 the fit statistics for a structural model identical to the domain-distinct model except that the four measures of working memory (two visuospatial and two verbal) are used to form a single working memory construct with all other relationships. The final domain-general model (Table 6, Item 2B) is statistically inferior to the domain-distinct model (Item 1C in Table 6), suggesting that, although the constructs are highly related, visuospatial and verbal working memory have unique properties.

We were interested in determining how well the domain-distinct model fit the data of older adults and younger adults separately. Thus we modeled the data of the 20- to 49-year-olds ($n = 144$) separately from the 60- to 92-year-olds ($n = 154$) for the differentiated models represented by Figure 4. The 50- to 59-year-olds were excluded from the analysis so that both age groups were represented by three decades. Table 7 presents the fit statistics for both the measurement (correlated factors) and structural model for both domain-specific and domain-distinct models. The domain-

Table 7
Fit Statistics of Domain-Differentiated Models for Young and Old Participants Separately

Model	*df*	χ^2	χ^2/df	*p*	GFI	NNFI	CFI	RMSEA	PNFI
Young participants ($n = 144$)									
Corr. factors	139	201.11	1.45	<.001	.88	.94	.96	.051	.64
Structural models									
Domain specific	156	257.54	1.65	<.001	.85	.91	.93	.063	.69
Domain distinct with WM corr. resid.	155	249.89	1.61	<.001	.86	.92	.93	.061	.69
Domain distinct with WM & STM corr. resid.	154	229.56	1.49	<.001	.87	.93	.95	.053	.69
Old participants ($n = 154$)									
Corr. factors	139	182.28	1.31	<.001	.90	.95	.97	.042	.64
Structural models									
Domain specific	156	215.72	1.38	<.001	.88	.94	.95	.047	.70
Domain distinct with WM corr. resid.	155	208.40	1.34	<.01	.88	.95	.96	.046	.70
Domain distinct with WM & STM corr. resid.	154	193.52	1.26	<.02	.89	.96	.97	.038	.70

Note. GFI = goodness-of-fit index; NNFI = nonnormed goodness-of-fit index; CFI = comparative fit index; RMSEA = root-mean-square error of approximation; PNFI = parsimony normed fit index; corr. = correlated; WM = working memory; resid. = residuals; STM = short-term memory.

distinct model with correlated residuals for working memory and short-term memory was the model of best fit for both age groups. When we compared fit of the domain-general model to the domain-distinct model for both young and old, in each case, the domain-distinct model showed significantly better fit; for the young, $\Delta\chi^2(7, N = 144) = 20.17$, $p < .01$, and for the old, $\Delta\chi^2(7, N = 154) = 19.15$, $p < .01$. Because the domain-distinct model fit both age groups well, we wanted to directly compare the two models to one another. A comparison of the covariance matrices for the young and old, however, indicated a significant difference, $\chi^2(210, N = 298) = 322.30$, $p < .001$. Moreover, a further test comparing the equivalence of factor patterns also indicated a significant difference between old and young models, $\chi^2(278, N = 298) = 383.39$, $p < .001$. These two results together indicate that no direct comparison of the young and old structural models is statistically feasible. The differences in the covariance matrices and factor patterns resulted from restriction on age. In general, there was greater variability on tasks for the young, although not uniformly so. This greater variability also contributed to differences in covariance between tasks, both within and across constructs. The domain-distinct structural models for old and young adults are shown in Figure 5. Nonsignificant paths are included and indicated by dotted lines on the figure. Dropping these nonsignificant paths does not change the fit (changes in χ^2 values of only 1%). We should note that the models for each individual age group resulted in data with a more limited range of scores and thus a decrease in the total variance explained by the models. The model for the old accounts for 26% and 22% of the variance in visuospatial and verbal long-term memory, and in the young, 11% and 13% of the variance for these two constructs respectively.

Although the young and old models could not be directly compared for the reasons described above, we did have the ability to compare differences in path strengths within each model. We reasoned that evidence for more differentiation in young would be found if there were significant differences between domain-specific paths in young but not old adults. There were two critical comparisons to test this argument. We compared in each age group whether the paths from visuospatial and verbal working memory to long-term memory were equal and whether there was equivalence between the path from visuospatial short-term to visuospatial working memory and the path from verbal short-term memory and verbal working memory. For both age groups, each of these path pairs could be constrained as equal without creating an increased lack of fit, suggesting equivalent differentiation between visuospatial and verbal constructs. In addition, we looked at differential relationships of speed to other constructs, comparisons that do not address the issue of domain differentiation. We compared for each age group whether the paths were equal from speed to visuospatial recall and verbal recall and whether the paths were equal from speed to visuospatial and verbal working memory and from speed to visuospatial and verbal short-term memory. We did find one difference for each age group with respect to speed. For young adults, the path from speed to verbal recall (.58) was significantly stronger, $\Delta\chi^2(1, N = 144) = 9.34$, $p < .005$, compared to the path to visuospatial recall (.18). For old, the path to verbal working memory (.66) was significantly stronger, $\Delta\chi^2(1, N = 154) = 8.03$, $p < .005$, than the path to visuospatial working memory (.20). Overall, there was little evidence for more differentiation of relationships in young adults compared to old adults.

By the same token, an examination of Figure 5 and Table 7 suggests that in general, there were stronger relationships of speed to verbal recall for the younger participants and of speed to visuospatial recall for older participants. When one considers that fluid abilities (better measured by visuospatial recall) decline more in the elderly than younger individuals, and that in our sample, the old had better verbal abilities than the young, it may be that speed becomes important for the recall task on which the age group is somewhat more disadvantaged. Although this is an appealing interpretation, it is perhaps more likely that the differences occurred because of the strong paths from speed to working memory

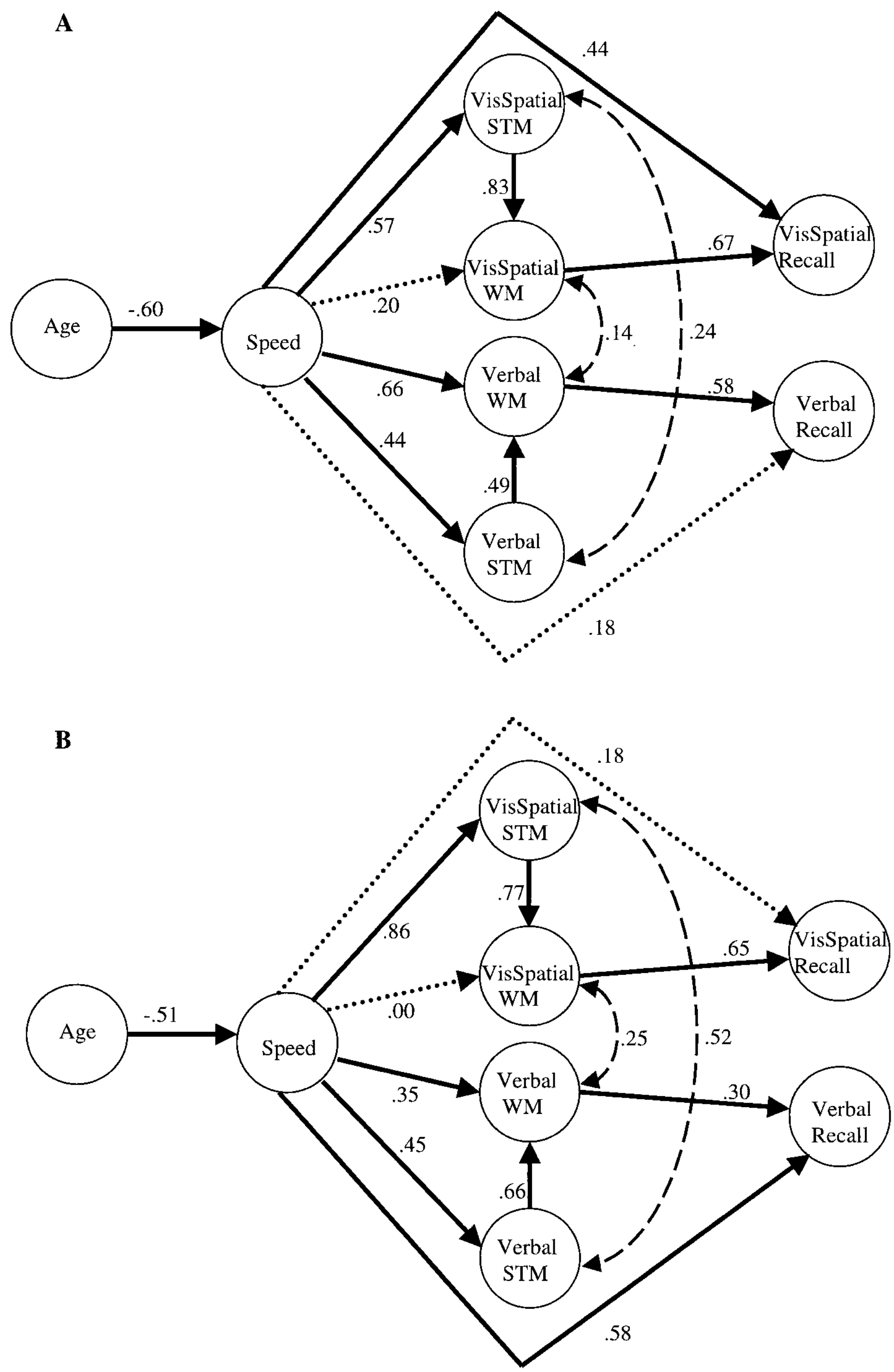

Figure 5. Domain-distinct structural model. A: Model for old adults (60–89). B: Model for young adults (20–49). For each path, the common metric completely standardized path coefficient is presented. Dashed curved lines represent correlations among residuals. Dotted lines represent nonsignificant paths. Speed = speed of processing; VisSpatial WM = visuospatial working memory; Verbal WM = verbal working memory; VisSpatial STM = visuospatial short-term memory; Verbal STM = verbal short-term memory; VisSpatial Recall = visuospatial recall.

and short-term memory, so that there was little remaining variance in speed for direct paths to occur to long-term memory.

A final issue that this study was designed to address was whether sensory function mediated significant variance and was more fundamental than even speed of processing in explaining age-related variance. Lindenberger and Baltes (1994) reported that in a sample of adults aged 70–103, measures of vision and hearing were more powerful predictors of age-related variance in cognitive function than speed. In a later study with individuals aged 25–103, Baltes and Lindenberger (1997) reported sensory function to be a cognitive primitive, mediating negative age-related gradients in cognitive function. We were interested in including sensory function in the existing structural models in Figure 4. Like Lindenberger and Baltes (1994), we could not combine vision and audition into a single construct of sensory function, but we were successful at developing individual constructs of vision and audition within a measurement model (partially depicted in Figure 6A, with fit statistics reported in Table 8). Lindenberger and Baltes

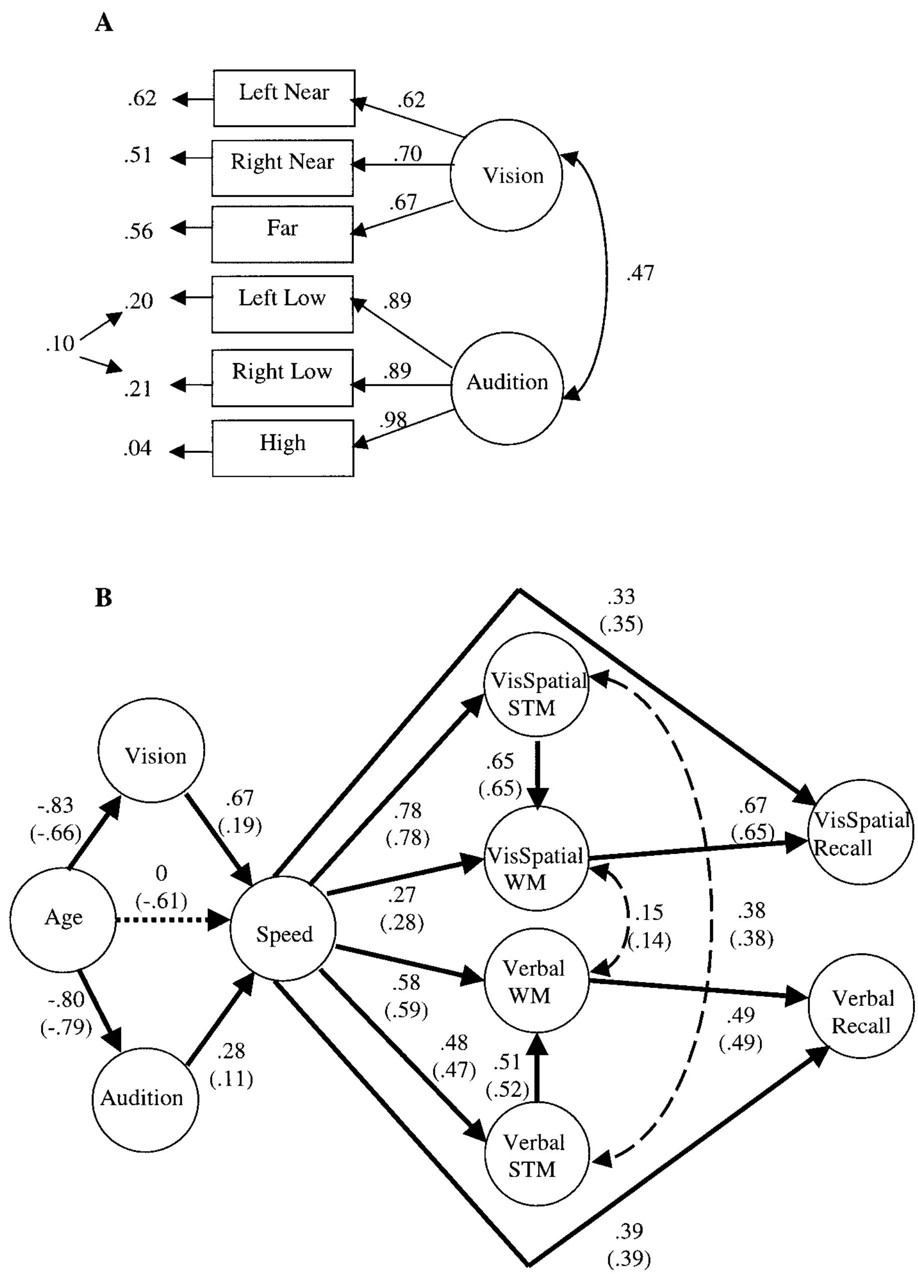

Figure 6. Models involving sensory constructs. A: Measurement model for sensory constructs. The factor loadings and paths to and among the other constructs are not depicted; they remained virtually unchanged by the addition of the two sensory constructs. Left Near = near visual acuity in left eye; Right Near = near visual acuity in right eye; Far = binocular far visual acuity; Left Low = auditory acuity for low tones in left ear; Right Low = auditory acuity for low tones in right ear; High = auditory acuity for high tones in both ears. B: Base sensory structural model. For each path, the completely standardized path coefficient is presented. Path values for sensory plus speed model are indicated in parentheses. Dashed curved lines represent correlations among residuals. The dotted path from age to speed was not included (i.e., set to zero) in the base sensory model. Speed = speed of processing; VisSpatial WM = visuospatial working memory; Verbal WM = verbal working memory; VisSpatial STM = visuospatial short-term memory; Verbal STM = verbal short-term memory; VisSpatial Recall = visuospatial recall.

Table 8
Fit Statistics of Measurement and Structural Models Involving Sensory Constructs

Model	*df*	χ^2	χ^2/df	*p*	GFI	NNFI	CFI	RMSEA	PNFI
Correlated factors	250	366.33	1.47	<.001	.93	.98	.98	.035	.73
Structural models									
1: Base sensory model	279	471.72	1.69	<.001	.91	.97	.97	.043	.80
2: Base sensory model with paths to STM & WM	271	460.03	1.70	<.001	.91	.96	.97	.044	.78
3: Sensory plus speed	278	421.97	1.52	<.001	.92	.97	.98	.036	.80
Compare 1 to 2	8	11.69		.166					
Compare 1 to 3	1	49.75		<.001					

Note. N = 345 for all models. GFI = goodness-of-fit index; NNFI = nonnormed goodness-of-fit index; CFI = comparative fit index; RMSEA = root-mean-square error of approximation; PNFI = parsimony normed fit index; STM = short-term memory; WM = working memory.

(1994) speculated that sensory function was more fundamental than speed of processing in accounting for age-related variance, so we developed a structural model where age had a direct relationship to vision and audition and these two constructs had a direct relationship to speed. This base sensory model is shown in Figure 6B and is represented by the solid lines and by the path strengths presented outside of parentheses. The fit of this base sensory model is excellent as reported in Table 8, but strong paths remain from speed to working memory and short-term memory. We attempted to improve the fit of the model by having direct paths from the two sensory constructs (vision and audition) to the four measures of short-term memory and working memory (adding a total of eight paths). As shown in Table 8, this second model did not show measurable improvement in fit, when correcting for the number of degrees of freedom lost. We then considered whether the fit of the model would improve by allowing age to operate simultaneously through the two sensory measures, as well as speed (see the addition of the dashed line in Figure 6B). The paths for this sensory plus speed model are shown in parentheses. A direct comparison indicated that the sensory plus speed model evidenced significantly better fit than the base sensory model (results of comparison in Table 8). The findings suggest that, in contrast to the findings of Lindenberger and Baltes (1994), sensory function does not mediate variance at a level more fundamental than perceptual speed of processing. It is important to note, in accounting for the present findings, that Lindenberger and Baltes modeled only data from very old individuals (aged 70–105) and that Baltes and Lindenberger (1997), whose life span sample was more comparable to the present study, did not use structural modeling techniques. There are also notable sampling differences between this study and that of Baltes and Lindenberger's life span study. These points are further addressed in the DISCUSSION section. In summary, it is accurate to say that sensory function was not as powerful a mediator of age-related variance as observed by Baltes and Lindenberger and that model fit was not markedly improved by the inclusion of either audition or vision as constructs.

DISCUSSION

This study addressed four major issues: (a) At the most global level, what is the cognitive architecture that best describes the interrelationship of speed, short-term memory, working memory, and long-term memory structure across the life span for the visuospatial and verbal domains? (b) in particular, what is the organization of short-term memory and working memory across the visuospatial and verbal modality? (c) does domain-specificity of working memory dedifferentiate into a domain-general resource with age? and (d) are there differences in decline trajectories for visuospatial and verbal memories (short-term memory, working memory, and long-term memory) across the life span? The first two issues are discussed together, followed by individual discussion of the latter two.

A Model of Memory Across the Life Span

Figure 4 presents a model depicting the interrelationships among speed, short-term memory, working memory, and long-term recall. As has typically been found in the literature, the most fundamental construct in mediating age-related variance on cognitive tasks is speed of processing. Speed had significant relationships to every other construct in the model, confirming the importance of this construct for understanding aging and cognition as proposed by Salthouse (1996). The general structure of the Figure 4 model also confirms the work of Park et al. (1996), who reported strong relationships of both speed and working memory to long-term memory. What is new about the present model is that it includes short-term stores for visuospatial and verbal modalities and also differentiates between visuospatial and verbal working memory and long-term memory. The model suggests the following. Working memory is differentiated into visuospatial and verbal stores, and each working memory construct has a domain-specific short-term store associated with it. Unlike short-term memory, working memory has direct domain-specific relationships to visuospatial and verbal long-term memory. However, the two measures of working memory are highly interrelated; the short-term memory stores are very closely related to working memory, and indeed, as Engle, Tuholski, et al. (1999) suggested, appear to be part of working memory. Moreover, the two short-term stores are highly related to one another.

Despite all of these strong interrelationships among constructs, these interrelationships do not suggest a domain-general working memory system. First, it was not possible at the basic level of the measurement model to form a working memory construct that included the short-term span measures as indicators. Thus the distinction between the short-term and working memory stores occurred at the basic level of the measurement model. Second, at the level of structural models, a domain-general model where all the working memory measures were combined into a single construct evidenced inferior fit compared to the model presented in Figure 4. Because of the strong interrelationships among the short-term and working memory measures, we hesitated to describe Figure 4 as a domain-specific model, because this implies more independence than the constructs actually have. Rather, we suggested the term *domain-distinct model*, indicating that the four constructs are distinguishable from one another while allowing for the strong interrelationships among the working memory and short-term stores.

There are important things to recognize about the domain-distinct model. First, it is generally neurobiologically plausible. There is strong evidence for short-term memory subsystems organized by visuospatial and verbal content in the appropriate hemisphere of the ventral lateral prefrontal cortex. Tasks that require demanding processing are processed bilaterally in the dorsolateral prefrontal cortex (D'Esposito et al., 1998; Owen, 1997, E. E. Smith & Jonides, 1999). The differentiation of working memory into visuospatial and verbal subsystems has less precedent in the imaging literature, but conceivably tasks that are domain-specific with relatively low working memory demands might show more hemispheric specialization in the dorsolateral prefrontal cortex compared to more demanding tasks. There is considerable confusion in the imaging literature about what constitutes short-term memory and working memory, with many tasks that are termed *working memory* tasks in the imaging literature better described as short-term memory tasks from the present theoretical perspective. More imaging research on these important issues is occurring and evolving rapidly.

Second, the domain-distinct model fits well with the work of Engle, Tuholski, et al. (1999), who reported evidence for short-term memory as a separable but highly related system to working memory. The present findings extend their model to the visuospatial domain, although we recognize a difference between their work and the present study is that we used long-term memory as an outcome variable rather than general intelligence. The work is less supportive of Shah and Miyake's (1996) suggestion that visuospatial and verbal working memory are entirely independent systems. We also did not find evidence for Miyake et al's (2001) later view that visuospatial short-term memory was less separable from visuospatial working memory than its verbal analog. Rather, our work suggests that the Engle and colleagues' model (Engle, Kane, & Tuholski, 1999; Engle, Tuholski, et al., 1999) better describes both systems.

Differentiation of Visuospatial and Verbal Resources Across the Life Span

Park et al. (2001) have proposed that dedifferentiation of resource may have multiple meanings. As suggested earlier, this term is used behaviorally to suggest that differentiated cognitive resources become more general and less domain specific. We find no evidence in the present study for this type of dedifferentiation in older adults. The same measurement and structural models fit both young adults and old adults well. Even though the models were not directly comparable to one another, critical comparisons of paths within each model that addressed the dedifferentiation hypothesis were not significant. That is, both old and young participants showed equivalent path strength from visual and verbal working memory to visual and verbal long-term memory and equivalent path strength from working memory to short-term memory across the visuospatial and verbal modes. Other noncritical comparisons with respect to dedifferentiation were significant between paths, so although we are accepting null results with respect to the dedifferentiation hypothesis, the findings indicated that the models were sensitive to some differences.

Even though we do not have evidence for dedifferentiation at the behavioral level in this study, it is important to recognize that that does not mean dedifferentiation is not occurring at the neurobiological level. It is entirely possible that the behavioral models look relatively similar between young and old because some form of compensatory neural recruitment indicative of dedifferentiation is occurring in the older adults. Park et al. (2001) have suggested that dedifferentiation of neural resources can occur in three ways: (a) through *contralateral recruitment* of a homologous brain area in old adults that is hemisphere-specific in young adults (e.g., reported by Reuter-Lorenz et al., 2000); (b) through *unique recruitment* where older adults recruit nonhomologous sites in addition to the sites used by young adults (reported by McIntosh et al., 1999); or (c) through s*ubstitution*, where older adults use a different part of the brain to perform a task compared to young adults (e.g., occipital cortex in lieu of frontal cortex as reported by Hazlett et al., 1998). It is crucially important to understand differences in neural activations when patterns of behavior across age are similar (Park et al., 2001). Comparisons of visuospatial and verbal processes in young and old would appear to be good candidates for such a neuroimaging analysis, based on the present behavioral findings.

Even though the organization and structure of working memory and its subsystems appear to be constant across the life span, the model also reiterates the importance of speed of processing in understanding age-related variance on cognitive tasks, a finding consistent with a single-mechanism, common cause view of aging (Lindenberger & Baltes, 1994; Salthouse, 1996). It is plausible that the organization and structure of the brain could remain intact, with general decline of neuronal integrity resulting in a single factor cause of age-related decline. There are numerous candidates for the neurobiological bases of age-related decline in speed (see Park et al., 2001). These include declines in the brain weight of specific memory structures (Raz, 2000), a decrease in dopamine receptors (Backman et al., 2000; Volkow, Gur, et al., 1998; Volkow, Logan, et al., 2000), a decrease in overall brain weight, or increased dendritic projections that result in circuitous neural processing (Salthouse, 2000). Again, this is an area where there is a critical need to connect brain data with behavioral data, given the powerful connection between speed of processing and age-related decline in cognitive function.

In addition to the importance of speed in the models, a second finding consistent with a single-factor view of age-related decline is that the trajectory of age-related decline on the 11 measures of speed, working memory, and long-term memory were identical (Figures 1A–C), even though the measures differed in terms of visuospatial–verbal content and whether they assessed speed, working memory, or long-term memory. Short-term memory age gradients were somewhat less steep than those for working memory and long-term memory, as shown in Figure 1D, a finding consistent with the differentiation of short-term memory from working memory and with the less active processing requirements of these tasks. Knowledge measures showed a positive age gradient (Figure 1E), because these reflect experience more than processing. These data are reminiscent of the findings of Baltes and Lindenberger (1997) who argued for a "common cause" of aging, where they demonstrated steep age-related trajectories across the life span for measures of speed, reasoning and memory, with negative, but less steep gradients for knowledge and verbal fluency.

We should note a difference of conceptual importance between our findings and those of Baltes and Lindenberger (1997). Baltes and Lindenberger reported that the crystallized verbal ability of their study participants declined with age, whereas we reported age invariance in verbal ability if not a small improvement across the life span. We believe that there are three reasons for this discrepancy. First, Baltes and Lindenberger included a large number of individuals from age 90 to 103, and much of the decline occurs at these older ages (ages that are not represented in our sample). Nevertheless, given that our sample is well represented up to age 92, this is not likely the primary source of the discrepancy. Baltes and Lindenberger also have a population-based representative sample in terms of education and socioeconomic status, whereas our sample is more select than theirs in terms of education and function; we tested individuals in the laboratory and the Baltes and Lindenberger sample was tested in the home. A third important difference is that the tasks used in the two studies as measures of knowledge differed considerably. Baltes and Lindenberger measured world knowledge with three indicators: practical problems (recognizing a solution to a bus scheduling or medication problem), recognizing a word from a field of four nonwords, and the WAIS Vocabulary, which requires active recall of information. The tasks measuring knowledge in the present study subsumed a more limited measurement space (all vocabulary) than those used by Baltes and Lindenberger, and our tasks were all more passive, recognition tasks. Thus, the Baltes and Lindenberger knowledge measures may have been more effortful than those in the present study and required some problem-solving abilities, unlike the tasks we used. Another major difference between our findings and that of Baltes and Lindenberger is that we did not find sensory function to be as fundamental as speed in explaining age-related variance on the cognitive tasks. This may be due to the sampling differences between the two studies, as described above.

Rates of Decline in Visuospatial and Verbal Processes

A striking finding apparent in Figure 1, besides the similarity of decline just discussed across the 11 different processing measures, is the regularity of the decline as a function of decade. Not only is there little differentiation in decline of speed of processing, visuospatial and verbal working memory, and long-term memory, the magnitude of decline is as great from 20 to 30 as it is from 70 to 80. This seeming equivalent decline decade by decade is deceptive, suggesting equivalent loss of function across the life span. As Park and Hedden (2001) noted, even though the amount of cognitive resource loss is the same decade by decade, the proportional loss is greater in the later decades. If one suffers the same absolute loss in the 60th decade as in the 20th (now having considerably less resource than one had in the 20th decade), the magnitude of the loss if much greater in the 60th decade compared to the 20th. There likely reaches a point where the absolute loss begins to be noticeable on demanding tasks (probably in the 40s and 50s), and ultimately begins to have implications for everyday functioning (probably in the 80s and 90s; Park & Hall-Gutchess, 2000).

With respect to the hypothesis that there is more decline in visuospatial than verbal processes, the present data are generally not suggestive of this. Relatively little is known about visuospatial and verbal long-term memory across the life span. There has been some speculation of less deterioration of left hemisphere function compared to right hemisphere function in older adults (Goldstein & Shelly, 1981; Reuter-Lorenz, 2000). Studies conducted to date are mixed. The present study suggests that long-term, episodic memory evidences equivalent age-related declines regardless of whether it is visuospatial or verbal, a finding congruent with the majority of studies in the literature. Similarly, we found equivalent declines in working memory regardless of domain (visuospatial or verbal). Although large age-related changes in interference in verbal working memory have been recently reported (Hedden & Park, 2001), we note that Myerson et al. (1999) found evidence for greater interference on a visuospatial compared to a verbal span task with age. In our study, the slope of the digit span task differed significantly only from the long-term visuospatial tasks, providing little convergence with the Myerson et al. finding. Thus, our results are similar to those of Salthouse (1995), who found no distinction between the visuospatial and verbal domains. Jenkins et al. (2000) also found evidence for greater age-related differences in visuospatial compared to verbal processes, using sensitive measures of reaction time, a dependent variable not used in the present study. More work on this important question is required, because it has been almost entirely unexplored until recently.

Summary

The present findings suggest the following: (a) Age-related changes decrease in a continuous fashion across the life span for processing intense tasks that include speed of processing, working memory, and long-term memory; (b) there is relatively little differentiation between declines in visuospatial and verbal memory processes across the life span; (c) despite the "lock-step" decline, visuospatial and verbal memory processes retain some distinctiveness but are highly interrelated; (d) working memory is characterized by domain-specific subsystems and related but distinct visuospatial and verbal pools of working memory that mediate considerable variance in long-term memory; (e) in contrast with the neuroimaging data, there is little evidence for dedifferentiation of function at the behavioral level in old adults compared to young adults; and (f) efforts to connect behavioral and brain data will yield a more complete understanding of the aging mind.

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Received October 30, 2000
Revision received September 11, 2001
Accepted September 13, 2001 ■

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