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Differential Age Effects in Semantic and Episodic Memory

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Results from 4 experimental tasks and 8 data sets (the 4 tasks involved either multiple sessions or different stimuli) as well as a vocabulary test conducted on the same 80 participants (40 younger and 40 older adults) are reported. The authors employed 2 semantic memory tasks (lexical decision and multiplication verification) using data from 2 sessions (for a total of 4 semantic data sets) and 2 episodic memory tasks (hybrid visual search and memory search with digits and with words as stimuli). Factor analyses using slope and intercept data from the 8 experimental data sets indicated the presence of 3 latent factors: a single intercept factor for both episodic and semantic tasks and separate slope factors for episodic and semantic tasks. A structural equation model with paths from age to 3 different 1st-order latent factors (episodic central processes, semantic central processes, and combined episodic and semantic peripheral processes) fit better than general factor models. These data are consistent with a theoretical framework in which there are age-related dissociations between peripheral and central processes across semantic and episodic memory.

OUR goal in the present study was to examine whether cognitive aging is generalized or process/stage-specific using a psychometric approach. To examine this issue, we replicated and extended Mitchell's (1989) study, which observed differential age effects in episodic and semantic memory. We were particularly interested in examining age differences in memory type across processing stage. The tasks in the present investigation used reaction time (RT) as the primary dependent variable so that we could use Sternberg's (1967) method of measuring peripheral and central processes. (Mitchell, 1989, did not use RT as a dependent variable in several of his tasks, and he did not separate slope and intercept data.) Sternberg's (1967; Roberts & Sternberg, 1993) method of indexing peripheral processing stages (encoding and response execution) by using RT intercepts and indexing central processing stages (storage, retrieval, response selection, and decisions) by using RT slopes (for aging applications, see Allen, Smith, Jerge, & Vires-Collins, 1997; Bashore & Smulders, 1995; Cerella, 1985, 1991) has been applied widely in experimental psychology. Sternberg (1967, 1969) proposed that slopes measure the comparison time per item (for matching tasks such as memory search, hybrid visual search, multiplication verification, and lexical decision), but that the intercepts measure the duration of all other processes not involved in the comparison process. RT slopes and intercepts were computed in the present study as a function of task difficulty. For example, in the present series of experiments, we used problem size (multiplication verification), word frequency (lexical decision), memory set size (memory search using digits or words), and visual search set size effects (hybrid visual search using digits or words) as measures of task difficulty.

In the present study, we tested 40 younger adults and 40 older adults on four RT tasks (two episodic and two semantic, although two different stimulus types were used for the episodic tasks and participants were tested twice on each semantic task so that there were four episodic and four semantic data sets on which to examine intercepts and slopes) and a standardized vocabulary test (which is a semantic task). The research question was whether age differences are generalized or process-stage-specific. If age differences are generalized, then age differences for semantic and episodic memory should be comparable across slope and intercept data. If age differences are process-specific, then differential age effects should be present across semantic and episodic slope and intercept data.

We used these particular tasks because all (except the vocabulary test) involved RT as the primary dependent variable, all are relatively simple tasks involving both peripheral- and central-process components, and all have difficulty manipulations that have been studied extensively (e.g., Allen, Madden, Weber, & Groth, 1993; Fisk & Rogers, 1991; Geary & Wiley, 1991). Hybrid visual search and memory search involve difficulty manipulations of probe set size and memory set size, respectively (Fisk & Rogers, 1991). Lexical decision and multiplication verification tasks involve difficulty manipulations of word frequency (Allen, Madden, & Crozier, 1991) and problem size (Geary & Wiley, 1991), respectively. We know of no other memory type manipulation of tasks, using RT as the dependent variable, for which the difficulty manipulations are more comparable. The present tasks also allow us to use words and digits as stimuli for both episodic and semantic tasks. Finally, all four tasks require that participants compare presented stimuli to information stored in memory—this suggests that all these tasks involve a similar memory comparison process. This comparison process is crucial because it is at the core of our central-process manipulation.

The Episodic Versus Semantic Memory Distinction

Mitchell (1989) reported evidence for the existence of three memory systems in an aging study. The first system is semantic, or context-independent, memory. Tulving (1985, p. 386) defined semantic memory as an "organism's knowledge of its world." The second system is episodic, or context-dependent, memory, which involves the conscious remembrance of "personally experienced events and their temporal relations" (Tulving, 1985, p. 387). The third system is procedural memory (knowledge and memory for how to do procedures; Tulving, 1985). In the present study we concentrated on episodic and semantic memory because frequently there are no age differences in procedural memory (e.g., Light & Singh, 1987).

There is disagreement about the semantic/episodic distinction. McKoon, Ratcliff, and Dell (1986) proposed that there is no theory that predicts the differential manner in which episodic and semantic information is encoded, stored, and retrieved. Also, Roediger (1984) claimed that many of Tulving's functional dissociations between episodic and semantic memory involved only a single measure of each memory type. To show true converging operations, investigators must use at least two measures of each memory type so that they can test whether both of the "episodic" measures index the episodic memory system but not the semantic system, and vice versa for the "semantic" tasks.

Mitchell (1989) used the multiple dissociation method suggested by Roediger (1984) and found that (a) older adults showed a performance decline in episodic memory tasks but not in semantic memory tasks, and (b) exploratory factor analysis revealed separate latent factors for episodic and semantic memory. Consequently, Mitchell provided empirical evidence of a functional dissociation between episodic and semantic memory using two or more measures of each memory type, and the exploratory factor analysis of Mitchell's data showed separate constructs for episodic and semantic memory. These separate constructs for episodic and semantic memory laid the foundation for a theory of the relation between age (younger adults vs older adults) and memory type (episodic vs semantic memory) that McKoon and colleagues (1986) found to be lacking in Tulving's (1972, 1985) concept of differential episodic and semantic memory systems.

Conceptual Underpinnings of the Present Task Manipulations

As noted earlier, Mitchell (1989) used Tulving's (1985) classification scheme for memory: episodic, semantic, and procedural memory. Two of these memory types—episodic and semantic—are pertinent to the present study. In the present study, we used both memory search (one, three, or five targets and one probe) and hybrid visual search (two targets and one, three, or five probes, i.e., a two-alternative, forced-choice task) separately employing words and digits as stimuli (see Table 1 for a description of the tasks used in this study). Memory search is used widely as an episodic memory task. Furthermore, we classified the hybrid visual search task as being an episodic task because of the autobiographic nature of the task. That is, participants were required to hold two target items in memory on each trial (and the targets changed across trials), and these two items held in memory were compared to a subsequent set of one, three, or five probe items. Participants were instructed to decide which of the two target items they had seen earlier as a probe item (see Fisk & Rogers, 1991).

Episodic tasks are linked in time to autobiographical contexts and, thus, are different than semantic tasks that do not require an autobiographical context (Mitchell, 1989). In the present study, we used lexical decision and multiplication verification tasks as semantic memory tasks. Word frequency effects obtained from a lexical decision task are assumed to index semantic memory (lexical) access (e.g., Allen, McNeal, & Kvak, 1992; Allen, Smith, Lien, Weber, & Madden, 1997; Forster, 1976; Monsell, Doyle, & Haggard, 1989; cf. Balota & Chumbley, 1984). In a lexical instance framework, it is assumed that each word is coded separately in the "mental dictionary" or lexicon (Carr & Pollatsek, 1985). It is also assumed that words can be processed more rapidly and/or more accurately as they become more familiar (i.e., as word frequency increases). Logogen-type models (e.g., Allen & Emerson, 1991; Allen, Wallace, & Weber, 1995; McClelland & Rumelhart, 1981; Morton, 1969) assume that the "firing threshold" of the logogen representing a higher frequency word is lower than the firing threshold of the logogen representing a lower frequency word.

Table 1. Tasks Used in the Present Study and Examples of Target and Probe Stimuli

Task Name	Target	Probe	Question Participant Is Answering in Responding to the Probe
Hybrid visual search for words	When, then	Then, what, have	Which one of the two target words appeared later as a probe word? (probe set size = 3)
Hybrid visual search for digits	3 5	3 7 6	Which one of the two target digits appeared later as a probe digit? (probe set size = 3)
Memory search for words	Then, what, have	Have	Does the probe word match any of the target words?
Memory search for digits	1 7 2 4 9	8	Does the probe digit match any of the target digits?
Lexical decision 1	Then	None	Does the target letter string form a real word, or not?
Lexical decision 2	Then	None	Does the target letter string form a real word, or not?
Multiplication verification 1	$6 \times 5 = 32$	None	Is the target answer the correct answer to the problem presented?
Multiplication verification 2	$6 \times 5 = 30$	None	Is the target answer the correct answer to the problem presented?

The present multiplication verification task (which used 0–9 as operands) is also assumed to be a semantic memory task. There is evidence that simple multiplication and addition tasks involve the retrieval of general knowledge information from long-term memory (Allen, Ashcraft, & Weber, 1992; Allen, Smith, Jerge, et al., 1997; Ashcraft, 1992; Geary & Wiley, 1991; but cf. Sliwinski, Buschke, Kuslansky, Senior, & Scarisbrick, 1994). For example, problem size effects (problems with products of 20 or less were classified as being of a small problem size, and problems with a product of greater than 20 were classified as being of a large problem size) in arithmetic verification tasks suggest that retrieval from long-term semantic memory occurs (see Ashcraft, 1992, 1995).

The network model (Ashcraft, 1992) hypothesizes the existence of associations between problem operands and problem answers that are stored in long-term semantic memory. The degree of learning is represented by the strength of the connections among operands and answers (Allen, Smith, Jerge, et al., 1997; Ashcraft, 1995). This network model predicts that fact retrieval speed from long-term memory is a function of the absolute value of operands, the number of competing associations between operands and potential answers, and the frequency of exposure (Allen, Smith, Jerge, et al., 1997; Ashcraft, 1995; Gallistel & Gelman, 1992). Consequently, the network model predicts the problem size effect: Retrieval duration increases as problem size increases for addition (Geary & Wiley, 1991), subtraction (Geary, Frensch, & Wiley, 1993), and multiplication (Allen, Ashcraft, et al., 1992; Allen, Smith, Jerge, et al., 1997). Thus, for the small operands (0–9) used in the present multiplication verification task, there is evidence that individuals retrieve answers from semantic memory.

Age Differences in Episodic Memory: Meta-Analyses and Processing Stage

Most research on episodic memory and aging has indicated that older adults show a decrement relative to younger adults (e.g., Allen, 1990, 1991; Allen, Kaufman, Smith, & Propper, 1998a, 1998b; Coyne, Allen, & Wickens, 1986; Craik, 1977; Craik & Jennings, 1992; Kausler, 1994; Light, 1991, 1992). Light (1991) noted that there presently is no single acceptable explanation of age differences in memory. However, meta-analyses examining age differences in timed tasks have provided insight into how increased adult age affects stages of information processing. In particular, a meta-analysis conducted by Cerella (1985) has been quite influential. Cerella used meta-analysis techniques to analyze the data (189 data points) from 35 tasks that required a speeded response (nonsemantic memory tasks that included primarily episodic memory tasks). Cerella, using Brinley plots, found large age differences in slopes and much smaller age differences in intercepts. Cerella hypothesized that the Brinley plot slopes indexed central processes but that the Brinley plot intercepts indexed peripheral processes. A Brinley plot examines the RTs of older adults (plotted on the y-axis) relative to younger adults (plotted on the x-axis) across processing complexity within a task(s) (Bashore & Smulders, 1995; Brinley, 1965). The key result in Cerella's Brinley plot study was that age differences in nonsemantic memory were primarily the result of a central-process decrement on the part of older adults.

Age Differences in Semantic Memory?

After concluding that there are age differences in episodic memory (e.g., Craik, 1977; Craik & Jennings, 1992; Light, 1991) and that these age differences show a pronounced central-process locus (Cerella, 1985), we now turn to the influence of increased adult age on semantic memory. Mitchell (1989) did not find significant age differences in semantic memory performance on four tasks. Other reviews of the lexical/semantic memory aging literature have come to the same conclusion (e.g., Allen, Madden, & Slane, 1995; Amrhein, 1995; Laver & Burke, 1993; Light, 1992). Namely, although older adults do show evidence of peripheral-process decrements in their intercept data (Allen, Smith, Jerge, et al., 1997), they show no appreciable evidence of central-process age differences in their slope data for semantic priming (Laver & Burke, 1993), lexical decision/naming (Allen, Madden, et al., 1995, 12 data sets, 184 data points), picture-word production (Amrhein, 1995; Amrhein & Theios, 1993), and multiplication verification (Allen, Smith, Jerge, et al., 1997). The only evidence of a slope difference for semantic memory tasks was found for verbal-pictorial comparison tasks (Amrhein, 1995), and this was probably the result of age differences in recoding (from words to pictures or vice versa) rather than the result of age differences in semantic retrieval. Indeed, there is no evidence of an age decrement in semantic retrieval for lexical decisions (Allen et al., 1991, 1993), lexical naming (Allen, Cerella, Madden, Smith, & Lien, 1999; Balota & Ferraro, 1993), or basic multiplication or addition processing (Allen, Ashcraft, et al., 1992; Geary & Wiley, 1991; Verhaeghen, Kliegl, & Mayr, 1997). Consequently, the literature on aging and semantic memory indicates that there are peripheral-process age differences, but no appreciable age differences in central processes. These results are the opposite of those found by Cerella (1985) for nonsemantic memory tasks.

Differential Age-Related Effects in Episodic and Semantic Memory

Lima, Hale, and Myerson (1991) suggested that differential age-related effects exist across "processing domains." Lima and colleagues (1991) reported three Brinley plot meta-analyses. Analysis 1 involved 10 lexical decision studies, Analysis 2 involved nine lexical tasks that were not lexical decision tasks (e.g., naming), and Analysis 3 involved seven nonlexical tasks (e.g., visual search and memory search). The two "lexical domain" analyses (semantic memory tasks) revealed slopes of approximately 1.5, but the nonlexical domain analysis (primarily episodic memory tasks) revealed a slope of approximately 2.0. Given that slopes are assumed to measure central processing speed (Cerella, 1985; Allen, Smith, Jerge, et al., 1997), Lima and colleagues suggested that older adults showed smaller central-process decrements for lexical domain tasks than for nonlexical domain tasks.

It may appear that the Brinley slope of 1.5 found by Lima and colleagues (1991) for lexical domain tasks is inconsistent with our earlier claim that most meta-analyses of semantic memory tasks showed no age differences in slopes (a Brinley plot slope of approximately 1.0; e.g., Allen, Madden, et al., 1995; Amrhein, 1995; Laver & Burke, 1993). These results indicate that older adults' central-process performances were slowing at the same rate as were younger adults' central-process performances. However, as Amrhein noted, Lima and colleagues mixed production and nonproduction lexical domain tasks. When production (e.g., naming) and nonproduction (e.g., categorization) tasks are separated, they show different slowing functions. The slope for the production tasks was .93, but the slope for the nonproduction tasks was 1.47 (Amrhein, 1995). Thus, the categorization-type lexical memory tasks show evidence of age differences in central processing speed only. Amrhein's finding of differential Brinley slopes across different lexical domain tasks suggests that process-specific age differences continue to persist even within the lexical domain.

Allen and colleagues (1991, 1993) and Balota and Ferraro (1993, 1996) also found evidence of process-specific age differences in the lexical domain. They found evidence of peripheral-process age differences but no evidence of central-process age differences for both lexical decision and naming tasks. These data indicate that differential age-related effects across processing stage for lexical/semantic memory indicate the presence of process-specific slowing within the same processing domain.

Structural Equation Modeling

We used structural equation modeling in the present study to test three theories of aging. Structural equation modeling was used because it provides a formal quantitative method of testing theoretical models. The three model types are illustrated in Figures 1–3 as Type A, Type B, and Type C. Type A models have been referred to as *independent factors models* (Salthouse & Czaja, 2000). This type of model contains exclusively nonshared (process-stage-specific) age effects. That is, age is assumed to have independent effects on different latent first-order factors. By first-order factors, we refer to process-specific or domain-specific latent factors (e.g., central semantic memory factors). Type B models have been referred to as *hierarchical, common factor models* (Salthouse & Czaja, 2000). This type of model contains exclusively shared (generalized) age effects. That is, age is assumed to have a common cause on component first-order latent factors such as episodic and semantic memory, and there are no nonshared, or independent, age effects on first-order latent factors. Thus, in Type B models, all age effects are carried through a single common factor. Finally, Type C models are referred to as *hierarchical, common factor, mixed models* (Allen et al., 2001). Type C models contain both shared and nonshared age effects. We modeled this by including both indirect paths (shared age effects) and direct paths (nonshared age effects) in the structural equation model.

Predictions

For factor analysis using the eight task-difficulty-based slopes (central processes) and eight task-difficulty-based intercepts (peripheral processes) as indicators, we predicted that there would be two separate latent factors for central processes across memory type (semantic and episodic memory) but that just a single latent factor for peripheral processes would be observed.

For structural equation modeling, we predicted that age would have significant direct paths to both the central, episodic memory factor and to the episodic/semantic peripheral factor, but not to the central, semantic factor (because there are no appreciable age differences in semantic central processes, Allen et al., 1991, 1993). A particular prediction of the present factor-specific model was that a Type A model would fit better than a Type B model (see Figures 1–3). This is because we predicted that there would be nonshared age effects for the two of the three predicted first-order latent factors—peripheral semantic/episodic and central episodic—but not for central semantic (because this factor was predicted to show no age effects). Our factor-specific theoretical model was also consistent with a Type C model.

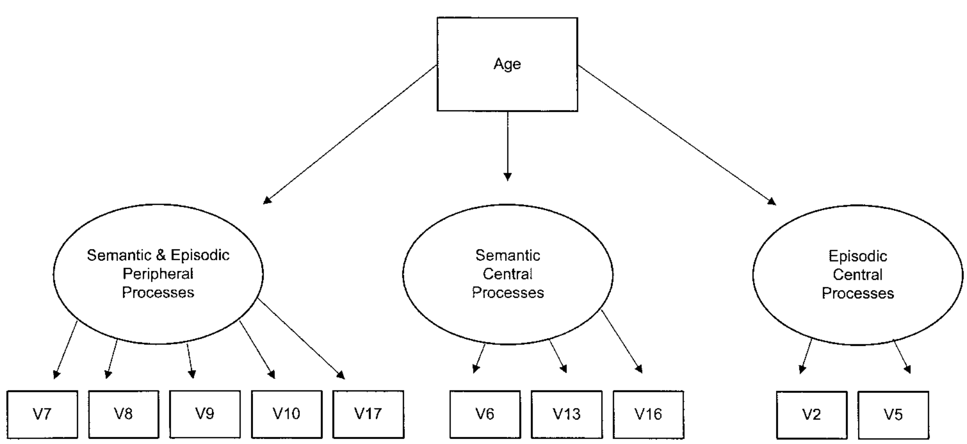

Figure 1. Type A, an independent factors model of cognitive aging in which all age effects on first-order latent factors are nonshared. Indicator variables: V2 = hybrid visual search for digits; V5 = hybrid visual search for words; V6 = lexical decision 1; V13 = WAIS-R Vocabulary scores; V16 = lexical decision 2; V7 = memory search for digits; V8 = hybrid visual search for digits; V9 = multiplication verification 1; V10 = memory search for words; V17 = lexical decision 2.

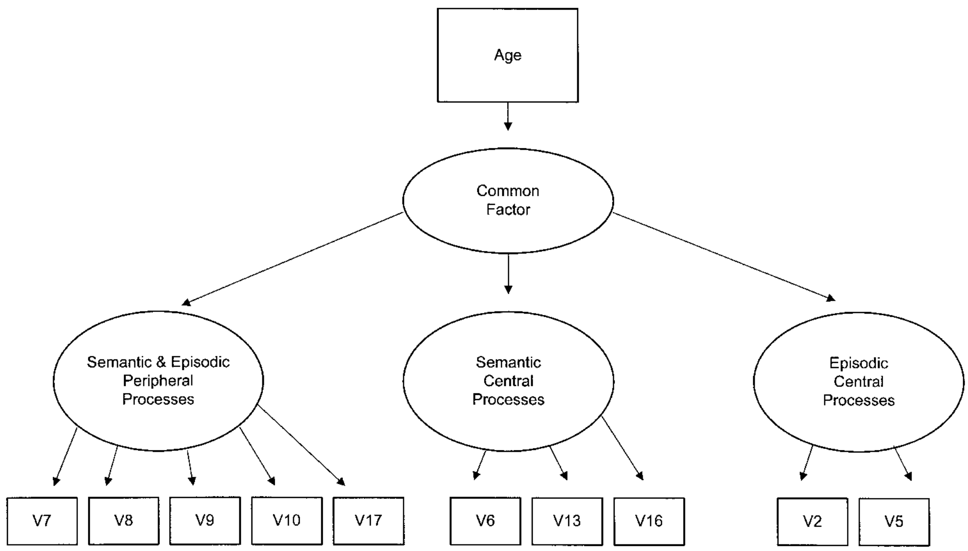

Figure 2. Type B, a hierarchical, common factor model of cognitive aging in which all age effects on first-order latent factors are shared. Indicator variables: V2 = hybrid visual search for digits; V5 = hybrid visual search for words; V6 = lexical decision 1; V13 = WAIS-R Vocabulary scores; V16 = lexical decision 2; V7 = memory search for digits; V8 = hybrid visual search for digits; V9 = multiplication verification 1; V10 = memory search for words; V17 = lexical decision 2.

Method

Participants

We tested the same 40 younger adults (mean age = 23.4 years, range = 18–44 years) and the same 40 older adults (mean age = 71.7 years, range = 63–90 years) on all six tasks. Each individual participated in two 90–120-min sessions. Younger adults were Cleveland State University (CSU) undergraduates who participated for course credit. Older adults were participants in CSU's Project 60 or were independent-living individuals from the Cleveland, OH, community. Project 60 is an Ohio program in which residents aged older than 60 can audit college courses for free. The older adults were paid $20.00 each for participating. All participants were screened for visual acuity of at least 20/40. Participants completed the Vocabulary and Digit Symbol Substitution subscales of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981).

There were no age differences in mean years of education (younger = 14.5 years, older = 14.83 years; $p > .50$). How-

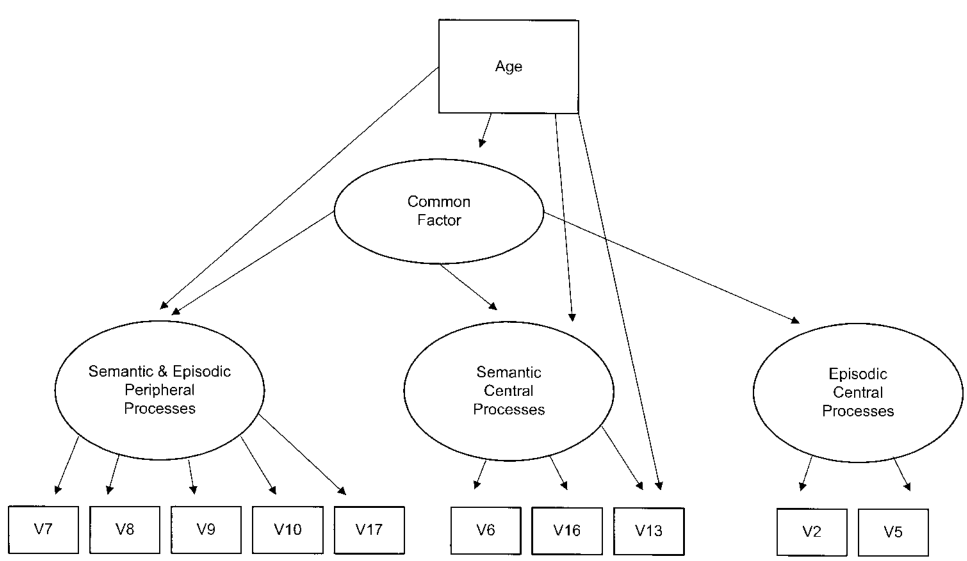

Figure 3. Type C, a hierarchical, common factor, mixed model of cognitive aging in which age effects on first-order latent factors are both shared and nonshared; that is, there are both direct and indirect paths from age to the first-order latent factors. Indicator variables: V2 = hybrid visual search for digits; V5 = hybrid visual search for words; V6 = lexical decision 1; V13 = WAIS-R Vocabulary scores; V16 = lexical decision 2; V7 = memory search for digits; V8 = hybrid visual search for digits; V9 = multiplication verification 1; V10 = memory search for words; V17 = lexical decision 2.

ever, older adults (59.95) scored higher than younger adults (51.8) on the Vocabulary subscale, $t(78) = -4.38$, $p < .001$, and younger adults (61.15) scored higher than older adults (45.53) on the Digit Symbol Substitution subscale, $t(38) = 4.98$, $p < .001$.

Apparatus

We tested all participants individually using a 286 microcomputer with a video graphics adaptor (VGA) card. We used Micro Experimental Laboratory (MEL) software (Schneider, 1988) to present the stimuli and collect RT and accuracy data. For all tasks, participants responded by using the index and middle fingers of the right hand to tap the left and right arrow keys located in the lower right corner of the computer keyboard. Participants pressed a *true* or *false* button for multiplication verification. For the lexical decision task, a *word* or *nonword* button was used. For hybrid visual search using digits or words as stimuli, a *left* or *right* button was used (i.e., a two-alternative, forced-choice task). For memory search using digits or words as stimuli, a *yes* or *no* button was used. For all six tasks, the two response buttons always corresponded to the left and right arrow keys located in the lower right corner of the keyboard. *Yes* or *no* was counterbalanced with the left or right buttons across participants. Each letter or digit in the display subtended a visual angle of approximately 0.28 degrees horizontally and 0.56 degrees vertically.

Materials and Procedure

For the semantic tasks, we used a lexical decision task on two sessions and a multiplication verification task on two sessions. For the episodic tasks, we used hybrid visual search and memory search tasks involving both digits (the stimuli used for the multiplication verification task) and words (the stimuli used for the lexical decision task). For the memory search and hybrid visual search tasks using words, if a word was used as a target on one trial it was not used as a distractor on any subsequent trials (on 48 hybrid visual search trials, a word was used as a distractor on two trials; all 48 of the trials occurred for set sizes of three and five words). The words were selected from the corpus presented in Allen, Wallace, and Weber (1995), based on Kucera and Francis (1967). A total of 432 words were used with equal numbers of four-, five-, and six-letter words as well as equal numbers of words from four different word frequency categories (108 words in each): very high frequency (range = 240–1,016 occurrences in the Kucera & Francis, 1967, corpus), medium high frequency (range = 151–235 occurrences), low frequency (range = 40–54 occurrences), and very low frequency (range = 1–5 occurrences). Target words and probe words were of the same length and word frequency category.

For half of the participants, memory search with word stimuli, lexical decisions, memory search with digits, and multiplication verification were presented on the first session, and for the other half of the participants, hybrid visual search with words, lexical decisions, hybrid visual search with digits, and multiplication verification were presented first. A counterbalancing design was used so that memory search and hybrid visual search were presented first equally often.

There were 6 practice trials and 40 experimental trials (20 *yes* or *left* trials and 20 *no* or *right* trials) for each set size (i.e., one, three, and five items) for all four episodic memory tasks: memory search and hybrid visual search with digits as stimuli as well as memory search and hybrid visual search with words as stimuli. For the multiplication verification task, there were 100 basic multiplication problems, although only the data from problems with multiplicands between 2 and 9 were analyzed (i.e., 64 problems) because participants use rules rather than retrieval from semantic long-term memory to process problems with multiplicands of 0 or 1 (Allen, Ashcraft, et al., 1992; Allen, Smith, Jerge, et al., 1997). Half of these 64 problems were *true* (e.g., $3 \times 3 = 9$), and half were *false* (e.g., $3 \times 3 = 11$). Also, problems with products of 20 or less were classified as being of a small problem size, and problems with a product of greater than 20 were classified as being of a large problem size (see Allen, Ashcraft, et al., 1992; Allen, Smith, Jerge, et al., 1997). This resulted in 25 small problems (13 *true* and 12 *false*) and 39 large problems (19 *true* and 20 *false*). Finally, for the lexical decision task, there were 432 trials (216 *word* and 216 *nonword*). These 432 stimuli (nonwords were formed by misspelling words from the same frequency category; see Allen, Wallace, et al., 1995) were split into four different word frequency categories. Because we wanted to examine slopes and intercepts, and we derived slopes and intercepts for the lexical decision tasks (Sessions 1 and 2) using the four word frequency categories to predict RT, we reported just the analyses for the 216 *word* trials.

All trials began with a 500-ms fixation presentation—a + in the center of the display screen. For hybrid visual search trials, the two target digits or words were presented until the participants pressed the space bar to continue the trial (self-paced presentation for up to a maximum of 32 s, i.e., participants were allowed to look at the targets for up to 32 s). Next, a 500-ms mask consisting of uppercase *X*s covered the display location previously used by the target stimuli. After the offset of the mask, the probe set of one, three, or five words or digits appeared in a circular display extending around the central fixation point location (the probe stimulus that matched the target stimulus could occur at any of five different positions around the imaginary circle).

For the memory search trials, the fixation presentation was followed by the presentation of the target (or memory) set consisting of one, three, or five words or digits. The target set presentation was for 200 ms per target-set item (i.e., either 200 ms, 600 ms, or 1,000 ms) in one, three, or five lines extending above and below the central fixation point. After the target set was offset from the computer screen, a 500-ms mask consisting of one, three, or five mask stimuli of six uppercase *X*s covered the display location previously used by the target set. After the offset of the mask stimuli, a single probe word or digit was presented in the center of the screen (i.e., in the location of the original fixation point). On half of the trials, this probe stimulus matched one of the target items (i.e., a *yes* trial), and on the remaining half of the trials this probe stimulus did not match any of the target items (i.e., a *no* trial).

Table 2. Intercept and Slope Reliabilities as a Function of Task

Reliability	Mult Ver	Lex Dec	VS-D	MS-D	VS-W	MS-W
Intercept	.90	.83	.92	.92	.94	.96
Slope	.62	.67	.77	.80	.86	.78

Note: Mult Ver = multiplication verification; Lex Dec = lexical decision; VS-D = hybrid visual search for digits; MS-D = memory search for digits; VS-W = hybrid visual search for words; MS-W = memory search for words.

For both the lexical decision and multiplication verification tasks, each trial began with a 500-ms fixation point presentation (again, a +) in the center of the screen. Next, a word or nonword (for the lexical decision task) or a *true* or *false* math problem (for the multiplication verification task) was presented in the center of the screen until the participant responded.

Results

Task Reliability

The intercept and slope reliabilities (using the Spearman-Brown method) for these eight data sets are presented in Table 2. Reliabilities ranged from .62 to .96. We derived reliability indices for intercepts and slopes for the eight experimental data sets using the Spearman-Brown method. Reliabilities for the multiplication verification and lexical decision tasks were computed across sessions. We computed split-half reliabilities for the other four tasks using odd versus even trials across set size.

Exploratory Factor Analysis

Following Mitchell (1989), who reported an exploratory factor analysis using data similar to the present slopes, we reported exploratory factor analyses using both non-age-partialled and age-partialled correlation matrices. However, we also extended Mitchell's work by developing and testing structural equation models using age as the manifest, causal variable. We developed these models using the correlation matrix including all eight slopes and eight intercepts as well as age (entered as a continuous variable) and WAIS-R Vocabulary score (see Table 3). We first conducted an exploratory factor analysis (using a promax rotation) in which the effect of age was not partialled from the remaining factors. The rotated factor pattern of this analysis (in standardized

Table 4. Results of Exploratory Factor (Promax Rotation) on Variables From Table 3, Age Not Partialled

Variable	Peripheral Processes	Episodic Central Processes	Semantic Central Processes
Slopes			
Memory search for digits	.090	.411	−.369
Hybrid visual search for digits	.257	.702[a]	.208
Memory search for words	−.217	.379	−.128
Hybrid visual search for words	−.044	.823[a]	.194
Lexical decision 1	.078	.205	.738[a]
Lexical decision 2	.145	.188	.624[a]
Multiplication verification 1	.036	.098	.243
Multiplication verification 2	.229	−.305	.060
WAIS-R Vocabulary scores	.229	.098	−.637[a]
Intercepts			
Memory search for digits	.749[a]	−.015	.168
Hybrid visual search for digits	.757[a]	.056	.139
Memory search for words	.885[a]	−.068	.037
Hybrid visual search for words	.876[a]	−.135	.105
Lexical decision 1	.866[a]	−.091	−.225
Lexical decision 2	.853[a]	−.080	.114
Multiplication verification 1	.837[a]	.168	−.034
Multiplication verification 2	.649[a]	.404	−.126

[a]Refers to retained indicators. Values are standardized regression coefficients.

Table 3. Correlation Matrix for All 16 Experimental Variables, Vocabulary, and Age Correlation Matrix

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18
V1	(48)																	
V2	.273	(72)																
V3	.219	.100	(4.6)															
V4	.439	.094	.445	(49)														
V5	.281	.653	.318	.240	(81)													
V6	−.111	.325	.068	−.109	.143	(28)												
V7	−.188	.385	.047	−.015	.168	.192	(248)											
V8	.055	.349	.119	−.076	.344	.189	.626	(320)										
V9	.281	.505	−.080	−.144	.236	.217	.621	.671	(369)									
V10	.072	.431	−.084	−.467	.150	.243	.654	.669	.798	(335)								
V11	.100	.461	−.056	−.217	.052	.253	.569	.677	.726	.717	(431)							
V12	.344	.328	.144	.063	.145	−.108	.586	.609	.713	.660	.610	(178)						
V13	.221	.094	−.078	.106	.086	−.430	.141	.113	.212	.175	.058	.249	(9.2)					
V14	.087	.008	.452	.095	−.075	−.009	.022	.008	−.036	.038	.149	.159	.008	(2.8)				
V15	.402	.566	.087	.128	.375	.104	.652	.572	.822	.626	.548	.683	.289	−.085	(307)			
V16	−.144	.260	.230	−.025	.257	.502	.303	.285	.252	.162	.209	.096	−.270	.028	.167	(22)		
V17	.238	.362	.115	−.011	.186	.274	.537	.656	.715	.663	.756	.708	.032	.147	.544	.216	(227)	
V18	.256	.479	.030	.061	.305	−.014	.418	.531	.624	.553	.568	.562	.501	.132	.566	.023	.525	(25)

Notes: $N = 80$; Slopes: V1 = memory search for digits; V2 = hybrid visual search for digits; V3 = multiplication verification 1; V4 = memory search for words; V5 = hybrid visual search for words; V6 = lexical decision 1; V14 = multiplication verification 2; V16 = lexical decision 2. Intercepts: V7 = memory search for digits; V8 = hybrid visual search for digits; V9 = multiplication verification 1; V10 = memory search for words; V11 = hybrid visual search for words; V12 = lexical decision 1; V15 = multiplication verification 2; V17 = lexical decision 2. Other variables: V13 = WAIS-R Vocabulary scores; V18 = age. Standard deviations are on the negative diagonal.

Table 5. Results of Exploratory Factor Analysis (Promax Rotation) on Variables From Table 4, Age Partialled

Variable	Peripheral Processes	Semantic Central Processes	Episodic Central Processes	Multiplication Verification Central Processes
Slopes				
Memory search for digits	.103	.384	.608[a]	.127
Hybrid visual search for digits	.076	.426	.641[a]	−.171
Memory search for words	−.187	.241	.575	.451
Hybrid visual search for words	−.137	−.144	.777[a]	−.034
Lexical decision 1	.087	.778[a]	.080	.043
Lexical decision 2	.163	.689[a]	.140	.213
Multiplication verification 1	.051	.241	.294	.806[a]
Multiplication verification 2	.112	.130	−.275	.816[a]
WAIS-R Vocabulary scores	.086	−.753[a]	.033	−.119
Intercepts				
Memory search for digits	.672[a]	.176	−.025	.021
Hybrid visual search for digits	.660[a]	.229	.012	.086
Memory search for words	.770[a]	−.112	−.184	−.209
Hybrid visual search for words	.732[a]	.226	−.233	.062
Lexical decision 1	.846[a]	−.289	.058	.223
Lexical decision 2	.854[a]	−.105	−.020	.228
Multiplication verification 1	.801[a]	.020	.154	−.212
Multiplication verification 2	.638[a]	−.116	.516	−.177

[a]Refers to retained indicators. Values are standardized regression coefficients.

regression coefficients) is reported in Table 4. We retained three separate factors. The scree plot also suggested the presence of three separate factors. This three-factor solution exhibited simple structure. The three factors were Peripheral Processes (episodic and semantic intercepts), Episodic Central Processes (episodic slopes), and Semantic Central Processes (semantic slopes).

We conducted a separate exploratory factor analysis using age-partialled variables in an attempt to confirm that our results were similar for both age groups. This analysis showed similar results to the first analysis except that the order of the second and third factors reversed relative to the non-age-partialled analysis, and a fourth latent factor emerged: a Multiplication Verification Central Processes (i.e., slope-based) factor (see Table 5). The age-partialled results did provide evidence, then, that both age groups showed similar patterns of latent factors.

Structural Equation Modeling

From the results shown in Table 4, the beginning measurement model included the 17 aforementioned variables. Using the working hypothesis developed in the introductory section, we developed a model in which all intercepts served as indicators for a single latent factor. Alternatively, for slopes we used separate latent factors for semantic and episodic tasks. Our Model 1 included 11 variables (10 indicator variables and the manifest variable of age, entered as a continuous variable). In this conceptualization, age was the cause of performance differences on three different latent factors. Model 1 used five indicator variables to measure the latent factor for Peripheral Processes (memory search with words and with digits, hybrid visual search with words, multiplication verification 1, and lexical decision 2), two indicator variables to measure the latent factor for Episodic Central Processes (visual search with words and with digits), and three indicator variables to measure the latent factor for Semantic Central Processes (the two sessions of the lexical decision task, and WAIS-R Vocabulary). Model 2 was identical to Model 1 except that we included a multiplication verification slope indicator for the Semantic Central Processes factor. We tested Model 2 even though it was not justified by exploratory factor analysis because our a priori theory predicted that both lexical decision and multiplication verification tasks were indices of semantic memory. Note that both Models 1 and 2 were Type A models that involved just nonshared age effects. That is, there were just direct paths from age to the first-order latent factors. Models 1 and 2 are illustrated in Figure 4.

Models 3 and 4 used the same indicator variables as Models 1 and 2, except that Models 3 and 4 were Type B models (see Figures 1–3). That is, first-order latent factors were linked to age through a common factor. Thus, all age effects in these models were shared. The only difference between Models 3 and 4 was that Model 4 added a fourth indicator variable (multiplication verification 2 slopes, as used in Model 2) for the first-order semantic slopes factor. Models 3 and 4 are illustrated in Figure 5.

Models 5 and 6 were analogous to Models 3 and 4, except that Models 5 and 6 included all significant direct paths from age to first-order factors or to indicator variables. Models 5 and 6 included a common factor but also included direct paths from age to the first-order semantic slope factor and the semantic and episodic intercept factor. A direct path from age to the Vocabulary indicator variable was also included in Models 5 and 6 (see Type C, Figure 3). Models 5 and 6 are illustrated in Figure 6.

We describe the fits of Models 1 through 6 at the bottom of Table 6 using criteria suggested by Hatcher (1994). In particular, a good fit is characterized by a ratio of chi-square and degrees of freedom of less than 2, CFI (comparative fit index) of .90 or greater, and NNFI (nonnormed fit index) of .90 or greater. Models 1, 2, 5, and 6 met these criteria, but Models 3 and 4 did not. The key aspect that differentiated the better fitting models from the poorer fitting models was that the better fitting models all included direct paths from age to first-order factors (Types A and C), but the poorer fitting models contained just indirect paths from age to the first-order factors (Type B; refer to Figures 1–3). Models 5 and 6 were the best fitting models. These hierarchical, common factor, mixed Type C models contained both direct (nonshared) and indirect (shared) age effects. However, as Figure 6 illustrates, the present Models 5 and 6 contained standardized path loadings greater than 1 and the direct path

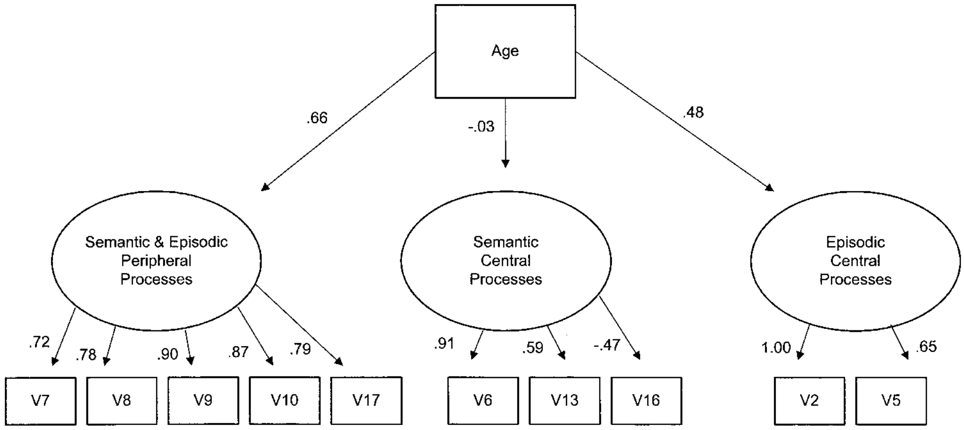

Figure 4. Model 1, an independent factors model (all direct age effects). Indicator variables: V2 = hybrid visual search for digits; V5 = hybrid visual search for words; V6 = lexical decision 1; V13 = WAIS-R Vocabulary scores; V16 = lexical decision 2; V7 = memory search for digits; V8 = hybrid visual search for digits; V9 = multiplication verification 1; V10 = memory search for words; V17 = lexical decision 2.

from age to the first-order Semantic Central Processes factor had a negative path loading. Although standardized path loadings greater than 1 are typically interpreted as evidence for a mis-specified model, this outcome in aging research can actually provide evidence for correlated first-order factors that result in model overfitting (Hall & Allen, 2000). In the present Models 5 and 6, even though we could explain the seemingly aberrant path loadings by alluding to correlated indicator variables (Pedhazur, 1982) resulting in model overfitting, we cannot so readily explain why there was a significant negative path from age to the first-order central episodic factor. This loading suggested that episodic memory slopes became less steep with increasing adult age—a result that was clearly at odds with the observed positive path loadings from age to the Episodic Central Processes factor in Models 1 and 2 (see Figure 4) as well as the correlation matrix (see Table 3; there was a positive correlation between age and episodic slopes). These results suggest that although Models 5 and 6 showed quite good fits, they were most likely mis-specified as the result of model overfitting. Consequently, the present structural equation Models 1 and 2 appeared to be the best fitting proper models for the present data (see Table 6). Models 1 and 2 suggest that all age effects were nonshared in these data. Models 5 and 6 did fit the best, but these models resulted in unacceptable standardized path loadings that appeared to be the result of a mis-specified model because of model overfitting. Finally, Models 3 and 4 did not fit acceptably well. Thus, the present data could not be accounted for with a model in which all age effects were shared.

The addition of the multiplication verification indicator variable on the Semantic Central Processes factor (Models

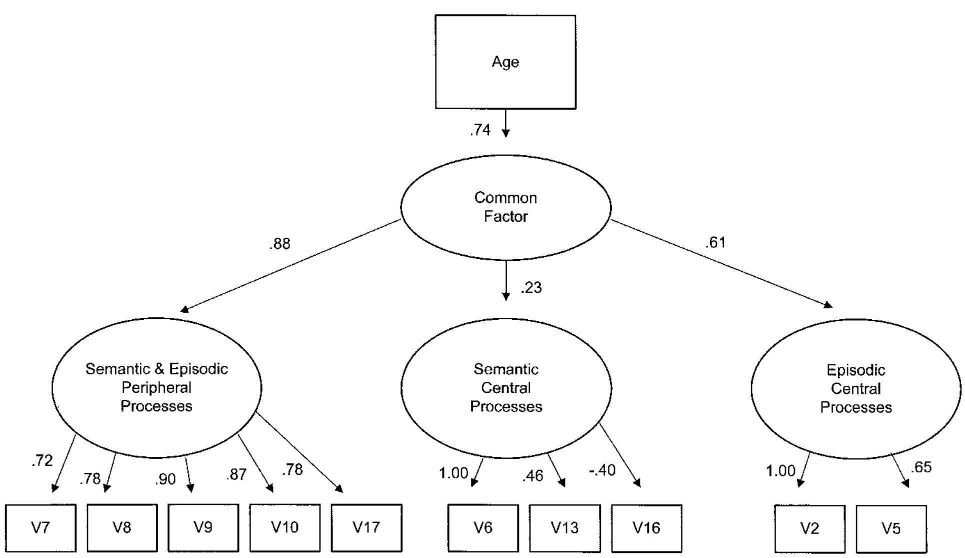

Figure 5. Model 3, a hierarchical, common factor model (all indirect age effects). Indicator variables: V2 = hybrid visual search for digits; V5 = hybrid visual search for words; V6 = lexical decision 1; V13 = WAIS-R Vocabulary scores; V16 = lexical decision 2; V7 = memory search for digits; V8 = hybrid visual search for digits; V9 = multiplication verification 1; V10 = memory search for words; V17 = lexical decision 2.

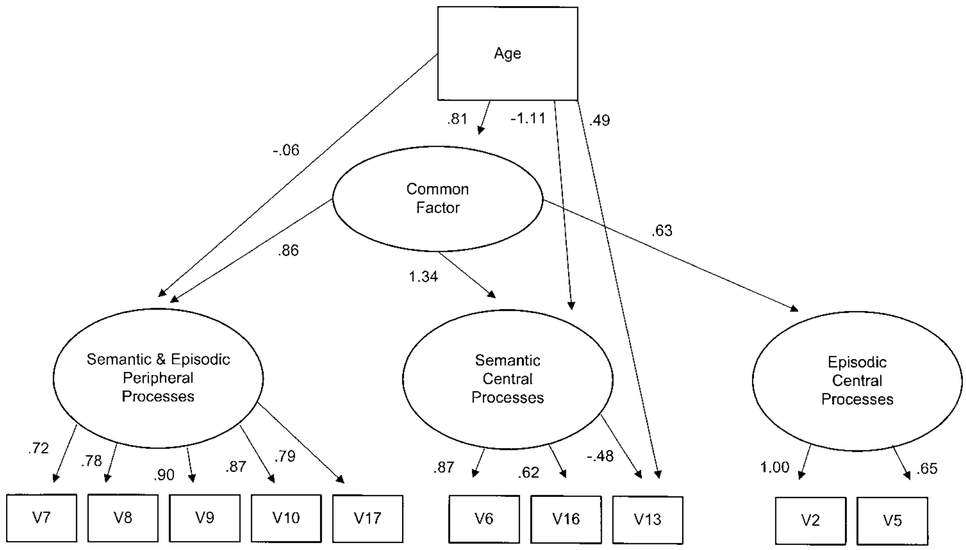

Figure 6. Model 5, a hierarchical, common factor, mixed model with both direct (nonshared) and indirect (shared) age effects. Indicator variables: V2 = hybrid visual search for digits; V5 = hybrid visual search for words; V6 = lexical decision 1; V13 = WAIS-R Vocabulary scores; V16 = lexical decision 2; V7 = memory search for digits; V8 = hybrid visual search for digits; V9 = multiplication verification 1; V10 = memory search for words; V17 = lexical decision 2.

2, 4, and 6) did improve the fit somewhat (compared with Models 1, 3, and 5). We believe that this was an important conceptual addition to the model because it resulted in converging operations of indicator variables. This issue is covered in more detail in the Discussion.

Discussion

In the present study we tested 40 younger adults and 40 older adults on the same four tasks. There were two episodic tasks—hybrid visual search and memory search—using both words and digits as stimuli, for a total of four episodic data sets. There were also two semantic memory tasks—lexical decision and multiplication verification—using words and digits, respectively. There were two sessions each for the semantic memory tasks for a total of four semantic memory data sets (five tasks when WAIS-R Vocabulary scores were included). We used the correlation matrix resulting from the 80 within-subject data sets to examine age differences across memory type and processing stage using factor analysis and structural equation modeling. Our goal in the present investigation was to test different versions of generalized and process-specific models of cognitive aging (see Figures

Table 6. Loadings of Variables on Constructs and Fit Statistics for Structural Equation Models

Construct and Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Peripheral Processes (intercepts)						
Memory search for digits	.72	.72	.72	.72	.72	.72
Hybrid visual search for digits	.78	.78	.78	.79	.78	.78
Memory search for words	.87	.87	.87	.87	.87	.87
Multiplication verification 1	.90	.90	.90	.90	.90	.90
Lexical decision 2	.79	.79	.78	.79	.79	.79
Semantic Central Processes						
Lexical decision 1	.91	.91	1.00	1.00	.87	.87
Lexical decision 2	.59	.59	.46	.45	.62	.62
WAIS-R Vocabulary scores	−.47	−.47	−.40	−.40	−.48	−.48
Multiplication verification 1		.01		.008		.009
Episodic Central Processes						
Hybrid visual search for digits	1.00	1.00	1.00	1.00	1.00	1.00
Hybrid visual search for words	.65	.65	.65	.65	.65	.65
Fit Statistics						
Chi square	74	85	93	103	49	59
N	80	80	80	80	80	80
df	41	52	40	51	39	49
CFI	.93	.93	.88	.88	.98	.98
NNFI	.90	.91	.84	.85	.97	.97
RMSEA	.10	.09	.13	.11	.06	.05

Note: CFI = comparative fit index; NNFI = nonnormed fit index; RMSEA = root mean square error of approximation.

1–3) by replicating and extending the Mitchell (1989) study on age differences in semantic and episodic memory tasks.

Using exploratory factor analysis, we tested the hypothesis that there would be a single peripheral factor for both episodic and semantic memory tasks but that there would be separate latent factors for episodic memory task slopes and semantic memory task slopes. Also, we were especially interested in examining age differences in episodic and semantic memory across processing stage using causal (structural equation) modeling, because Mitchell (1989) did not present such models and such models are critical in determining whether a general factor/hierarchical, common factor model (Salthouse & Czaja, 2000; Salthouse, Hambrick, & McGuthry, 1998) or a factor specific/hierarchical, common factor, mixed model (Allen et al., 2000) is optimal.

Task Reliability of Slopes and Intercepts

We computed intercepts (peripheral processes) and slopes (central processes) using task difficulty to predict response latency for all 80 participants separately as a function of age and memory type (episodic vs semantic memory). Other researchers have cautioned that slopes and intercepts cannot be readily compared because of uninterpretable intercepts and spuriously high correlations between intercepts and slopes (e.g., Cerella, 1991). In particular, this can happen when the distance between 0 and the minimum value of X is very large (as is frequently the case when regressing older adults' RTs on younger adults' RTs in Brinley plot analyses). However, such is not the case in the present data set, because the x-axis reflects the number of specific processing steps, and the intercept provides a plausible estimate of the speed of executing "control" (peripheral) processes. The observed correlations between slopes and intercepts for the same task in the present study are quite modest (for the eight experimental tasks involving RT, −.188, .349, −.080, −.467, .052, −.108, −.085, and .216; see Table 2). The −.467 correlation is not an issue for the present structural equation modeling, because this slope factor is not retained. This results in the use of only one slope-intercept pair with a statistically significant correlation (and this is quite modest—$r = .349$), so we do not deem it necessary to center the present data as was done by Sliwinski and Hall (1998) when analyzing Brinley plots. Consequently, although Cerella's (1991) concern of spurious correlations between slopes and intercepts on a given task can potentially result in a confound, there is no evidence that it resulted in a confound in this study.

Are There Different Latent Constructs of Memory Type and Processing Stage?

If there are both semantic and episodic memory stores that have separate peripheral and central processing stages, then memory type and processing stage should be functionally differentiated when data are analyzed with exploratory factor analysis. In factor analysis terminology, there should be separate latent factors for semantic and episodic memory and for slopes and intercepts.

The present data set of eight RT variables (four semantic and four episodic variables) results in 16 measured variables (eight slopes and eight intercepts) that include RT. WAIS-R Vocabulary scores are also used as a measured variable for semantic memory because this factor is a traditional index of semantic memory. Surprisingly, WAIS-R Digit Symbol Substitution task scores do not load on a single latent factor in either the non-age-partialled or age-partialled exploratory factor analyses (so they are not included in Table 3).

In the non-age-partialled analysis (see Table 4), we find evidence for three separate latent factors: a Peripheral Processes factor (with intercept indicators from both semantic and episodic tasks), a Semantic Central Processes factor (lexical decision slopes and WAIS-R Vocabulary scores), and an Episodic Central Processes factor (slopes from hybrid visual search using digits and words). These results are consistent with the a priori hypotheses concerning memory type and processing stage except for the finding that multiplication verification slopes do not load on the Semantic Central Processes factor. A similar factor pattern emerges when the effect of age is partialled from the variables prior to factor analysis—except for one difference. Namely, a fourth factor emerges when age is partialled: a Multiplication Verification Central Processes factor (the other three factors remain; see Table 5). Both rotated factor patterns exhibit simple structure.

These results suggest that either three (non-age-partialled) or four (age-partialled) underlying constructs explain the present data. It is clear that both semantic task and episodic task intercepts load on the same factor, but that semantic and episodic slopes load on different factors. This pattern of results is consistent with our a priori hypothesis that peripheral processing is shared across memory types but that central processes differ across memory type. Indeed, the present results indicate that semantic memory is probably not a unitary construct—the automatic retrieval of mathematical facts is qualitatively different from the automatic retrieval of words from the mental lexicon. Consequently, we do find evidence of separate latent factors across memory type and processing stage. Again, these results replicate and extend Mitchell's (1989) earlier study.

Are There Shared or Nonshared Age Differences Across Memory Type and Processing Stage?

We have two reasons for developing structural equation models of the present intercept and slope data. First, structural equation modeling provides us with the opportunity to test whether a hierarchical, common factor model (see Figure 2, Type B) for age differences in episodic memory and semantic memory across processing stage (e.g., Salthouse & Czaja, 2000; Salthouse et al., 1998) or whether a multiple processing speed, latent factors (independent factors) model is needed to account for age differences in memory type and processing stage (i.e., the presently hypothesized model). The hierarchical, common factor model predicts shared (or generalized) age effects, that is, that age will show "common" effects on first-order latent factors (i.e., Semantic Central Processes, Episodic Central Processes, and semantic and episodic Peripheral Processes). Alternatively, the independent factors model predicts nonshared age effects, That is, that age will show age effects on first-order latent factors that are independent of a common factor. Thus, structural equation modeling allows us to determine how age is related to the three latent factors that emerge in the exploratory factor analysis.

As noted earlier, Models 5 and 6 are the best-fitting models (see Table 6), but these models result in standardized path coefficients that contradict the path coefficients observed in Models 1 and 2 (and correlations between age and episodic task slopes presented in Table 3). Namely, older adults exhibit significantly steeper slopes for episodic memory tasks, yet Models 5 and 6 exhibit negative path loadings for the path from age to the Episodic Central Processes factor. This predicts that as age increases, episodic slopes decrease—a prediction that is wrong. This model mis-specification was probably the result of model overfitting (Hall & Allen, 2000).

The independent factors Models 1 and 2 actually fit better than the less parsimonious hierarchical, common factors Models 3 and 4. (Parsimony refers to the number of degrees of freedom in a structural equation model—the more degrees of freedom, the more parsimony; see Allen et al., 2000.) Hence, the present data do require direct paths from age to first-order latent factors to achieve an acceptable model fit (see Table 6). However, the present data do not require the presence of a common factor between age and the first-order latent factors to achieve an acceptable fit (see Table 6). The CFI and NNFI indices for the hierarchical, common factor Models 3 and 4 are both below .90, whereas analogous indices for independent factors Models 1 and 2 are both above .90. These results suggest that age effects in the present study are primarily nonshared (direct) in nature. Models 5 and 6 suggest the existence of both shared and nonshared age effects, but, again, these models resulted in contradictory standardized path coefficients.

Conceptual Rather Than Empirical Inclusion

The only difference between Models 1 and 2, Models 3 and 4, and Models 5 and 6 is that the odd models contain three indicator variables for the Semantic Central Processes factor, whereas the even models contain four indicator variables for this factor (i.e., the multiplication verification 2 variable is added; see Table 6). Although the addition of this fourth indicator variable for the Semantic Central Processes factor does slightly improve model fit, without additional conceptual justification it would not be included because this variable did not load on the Semantic Central Processes factor in the empirical, exploratory factor analysis. However, recall that we predicted that both lexical decision and multiplication verification slopes would load on a semantic memory factor. With Models 2, 4, and 6 we are able to develop models with acceptable fits and with converging operations for memory type. That is, in Models 2, 4, and 6, we do have converging operations in the structural equation modeling data for a differentiation across memory type and processing stage (see Roediger, 1984), because there are multiple measures for slopes and for intercepts across age. Consequently, we believe that the even-numbered Model 2 provides initial evidence of a theoretical framework for the relationship among adult age, memory type, and processing stage.

Why Are There Differential Age Differences Across Memory Type?

There are several potential explanations for why there are differential age differences across memory type. First, semantic memory retrieval (e.g., retrieving the code for *ice cream*) tends to be more practiced than episodic memory retrieval (e.g., "What did I have for breakfast today?"). Thus, it could be that age differences are not are prevalent when a task is highly overlearned. However, even when an episodic task is overlearned, there still appear to be age differences. For example, even after considerable practice, older adults continue to show age differences in performance (e.g., Fisk & Rogers, 1991). Another possibility is that semantic and episodic memory are mediated by different neural systems and that brain changes with increased adult age affect episodic memory more than semantic memory (Langley & Madden, 2000; Nyberg & Cabeza, 2000). Finally, differential age effects in semantic and episodic memory for central processing may result because of the different nature of coding and retrieval in semantic and episodic memory. It may be that the retrieval of context-dependent (episodic) information involves more processing steps and thus requires more time than the retrieval of context-independent (semantic) information. Alternatively, this issue can be viewed from a neural network perspective. Allen and colleagues (1998a, 1998b), for example, found that older adults had increased entropy relative to younger adults on a spatial memory scanning task (an episodic memory task). The age-related increase in entropy resulted in increased "computational temperature" in older adults' molar neural networks. By *entropy* we mean the level of disorder in a system, and by *computational temperature* we refer to the temperature of a statistical mechanics system. Performance on a task becomes poorer when the computational temperature of a neural network increases. In the experiments of Allen and colleagues (1998a, 1998b), older adults' increased entropy/computational temperature resulted in an age-related decrease in memory performance. If we assume that computational temperature has a relatively less adverse impact on semantic memory than on episodic memory (perhaps as the result of additional interconnections among nodes in semantic memory, relative to episodic memory), then we can account for the memory type effects observed in the present study. Although all three of these hypotheses remain viable, we believe that latter two are particularly important in accounting for this age difference across memory type.

Conclusion

In the present study we find that age directly mediates performance on two of three process-specific and memory-specific latent factors. To our knowledge, whereas investigators have used structural equation modeling to examine the potential contribution of domain-specific factors to age differences (e.g., Salthouse & Czaja, 2000; Salthouse et al., 1998), ours is the first study that actually develops latent factors based on specific processes (episodic and semantic memory) and processing stages (peripheral vs central processing stages; although for a factor-specific theory of age differences in intelligence, see McArdle & Prescott, 1992). Therefore, we conclude that there are observable process-specific and stage-specific age differences when a structural equation modeling methodology is used.

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