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Effects of Domain Knowledge, Working Memory Capacity, and Age on Cognitive Performance: An Investigation of the Knowledge-Is-Power Hypothesis

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Domain knowledge facilitates performance in many cognitive tasks. However, very little is known about the interplay between domain knowledge and factors that are believed to reflect general, and relatively stable, characteristics of the individual. The primary goal of this study was to investigate the interplay between domain knowledge and one such factor: working memory capacity. Adults from wide ranges of working memory capacity, age, and knowledge about the game of baseball listened to, and then answered questions about, simulated radio broadcasts of baseball games. There was a strong facilitative effect of preexisting knowledge of baseball on memory performance, particularly for information judged to be directly relevant to the baseball games. However, there was a positive effect of working memory capacity on memory performance as well, and there was no indication that domain knowledge attenuated this effect. That is, working memory capacity contributed to memory performance even at high levels of domain knowledge. Similarly, there was no evidence that domain knowledge attenuated age-related differences (favoring young adults) in memory performance. We discuss implications of the results for understanding proficiency in cognitive domains from an individual-differences perspective. © 2001 Academic Press

Key Words: domain knowledge; working memory capacity; memory; individual differences; age; adulthood.

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Perhaps one of the most influential ideas to emerge in cognitive psychology during the past 25 years is the viewpoint referred to as the *knowledge-is-power* hypothesis. The basic argument of the knowledge-is-power hypothesis is that domain knowledge is the primary determinant of success in cognitive endeavors, whereas ''basic'' cognitive abilities play a less important role. Minsky and Papert (1974) alluded to the knowledge-is-power hypothesis in the following passage:

> It is by no means obvious that very smart people are that way directly because of the superior power of their general methods—as compared with average people. Indirectly, perhaps, but that is another matter: a very intelligent person might be that way because of the specific local features of his knowledge-organizing knowledge rather than because of global qualities of his ''thinking'' . . . which might be little different from a child's. (p. 59)

More recently, Feigenbaum (1989) articulated the premise of the knowledge-is-power hypothesis in a principle as follows:

> The Knowledge Principle states that a system exhibits intelligent understanding and action at a high level of competence primarily because of the specific knowledge that it can bring to bear: the concepts, representations, facts, heuristics, models, and methods of the endeavor. A corollary of the KP is that reasoning processes of intelligent systems are generally weak and not the primary source of power (p. 179).

Domain knowledge—a modifiable ''software'' aspect of the cognitive system—is indeed a powerful determinant of cognitive performance (see Glaser & Chi, 1988). For example, domain knowledge facilitates memory for domain-relevant information, such as chess positions (Chase & Simon, 1973), bridge hands (Engle & Bukstel, 1978), dance steps (Allard & Starkes, 1991), maps (Gilhooly, Wood, Kinnear, & Green, 1988), and music (Meinz & Salthouse, 1998). Domain knowledge contributes to success in many other cognitive tasks as well. To illustrate, Voss, Greene, Post, and Penner (1983) found that domain knowledge was the best predictor of performance in solving ill-structured political science problems (e.g., increase crop productivity in the Soviet Union). Finally, domain knowledge facilitates comprehension and memory of text with domain-relevant content. For example, Spilich, Vesonder, Chiesi, and Voss (1979) found that participants knowledgeable about the game of baseball better comprehended a story about a baseball game than did participants who were low in domain knowledge (see Recht & Leslie, 1988, and Walker, 1987, for additional examples). As another example, in a study by Fincher-Kiefer, Post, Greene, and Voss (1988), participants who were either high or low in knowledge of baseball performed a version of the Daneman and Carpenter (1980) reading span task in which the sentences were either baseball-related or neutral. Fincher-Kiefer et al. found that baseball knowledge facilitated working memory span, but only when the sentences were baseball-related.

Nevertheless, an issue stemming from the knowledge-is-power hypothesis that has received very little empirical attention concerns the *interplay* between domain knowledge and ''hardware'' aspects of the cognitive system—factors that are thought to reflect general, and relatively stable, characteristics of the individual. One such factor is *working memory capacity.* Working memory may be defined as a system of processes and stores used to maintain information during processing (Engle, Tuholski, Laughlin, & Conway, 1999), and working memory capacity is often measured with dual-task paradigms such as the Daneman and Carpenter (1980) reading span task. The goal of this task is to read a series of sentences while remembering the final word of each sentence for later recall. Working memory capacity is operationalized as the number of these sentence-final words that can be recalled while being able to demonstrate processing of the sentences. In a similar task, operation span (Turner & Engle, 1989), participants solve a series of arithmetic equations and remember a word following each equation for later recall.

There is now a large amount of evidence to suggest that working memory capacity contributes to proficiency in a wide range of cognitive tasks. For example, measures of working memory capacity, such as reading span and operation span, correlate with performance in tasks such as language comprehension (Daneman & Merikle, 1996), solving math problems (Adams & Hitch, 1997), following directions (Engle, Carullo, & Collins, 1991), taking lecture notes (Kiewra & Benton, 1988), bridge (Clarkson-Smith & Hartley, 1990), and writing (Benton, Kraft, Glover, & Plake, 1984). Furthermore, recent research has established a linkage between working memory capacity and *fluid intelligence,* which is commonly defined as the ability to solve novel problems and adapt to new situations (Cattell, 1943). For example, using structural equation modeling, Kyllonen and Christal (1990) observed near-perfect correlations between working memory capacity and fluid intelligence. Based on this evidence, Kyllonen (1996) proposed that it may be useful to conceptualize working memory capacity as the central information processing component underlying fluid intelligence. Finally, there is evidence to suggest that working memory capacity is relatively stable. For example, with nearly 3 months between measurement occasions, Klein and Fiss (1999) found a test–retest correlation of .66 for the Turner and Engle (1989) operation span task.

Domain Knowledge-Working Memory Capacity Relations

To summarize, evidence suggests that both domain knowledge and working memory capacity contribute to performance differences in a wide range of cognitive tasks. The primary goal of this study was to investigate three possibilities (or descriptive ''models'') concerning the joint effects of these factors on cognitive performance. The models are similar in that each assumes that knowledge is ''power.'' In other words, each model assumes a positive effect of domain knowledge on cognitive performance. The models differ in whether the joint effects of domain knowledge and working memory capacity on cognitive performance are predicted to be additive or interactive.

1. The first model is based on the idea that high levels of domain knowledge can ''compensate'' for low levels of working memory capacity. In other words, as illustrated in Fig. 1A, domain knowledge reduces, and may even eliminate, the effect of working memory capacity on cognitive performance. Ackerman and Kyllonen (1991) alluded to the possibility of compensation: ''There is a relationship between knowledge and working memory capacity such that having specific knowledge can replace having to exercise working memory'' (p. 216). More generally, the idea of compensation is analogous to the notion that the effect of ability characteristics, such as working memory capacity, on cognitive performance decreases as skill acquisition proceeds from initial introduction to the task to development of task-specific knowledge (e.g., Ackerman, 1988; Fitts & Posner, 1967; Fleishman & Hempel, 1956).

2. The second model is based on the idea that although domain knowledge facilitates cognitive performance, working memory capacity is a basic mechanism underlying proficiency in cognitive domains. That is, as illustrated in Fig. 1B, working memory capacity contributes to performance differences even at high levels of domain knowledge. This model is broadly consistent with the view that basic cognitive abilities represent the ''building blocks'' of cognitive activities such as reasoning, problem solving, and comprehension and that individual differences in the efficiency and effectiveness of basic cognitive abilities translate into individual differences in these complex aspects of cognition (e.g., Hunt, 1978; Posner & McLeod, 1982).

3. The final model also predicts that working memory capacity should contribute to differences in cognitive performance even at high levels of domain knowledge. However, as shown in Fig. 1C this model represents what might be thought of as a ''rich-get-richer'' hypothesis, because the prediction is that a high level of working memory capacity *enhances* the facilitative effect of domain knowledge on cognitive performance. That is, according to this model, people with high levels of working memory capacity should benefit from preexisting domain knowledge to a greater extent than people with lower levels of working memory capacity. For example, to the extent that working memory capacity reflects a cognitive resource that can be used to activate information stored in long-term memory and to maintain that activation during performance of some task (e.g., Cantor & Engle, 1993; Just & Carpenter, 1992), then people with high levels of working memory capacity may be able to draw upon more preexisting domain knowledge during cognitive performance than people with lower levels of working memory capacity.

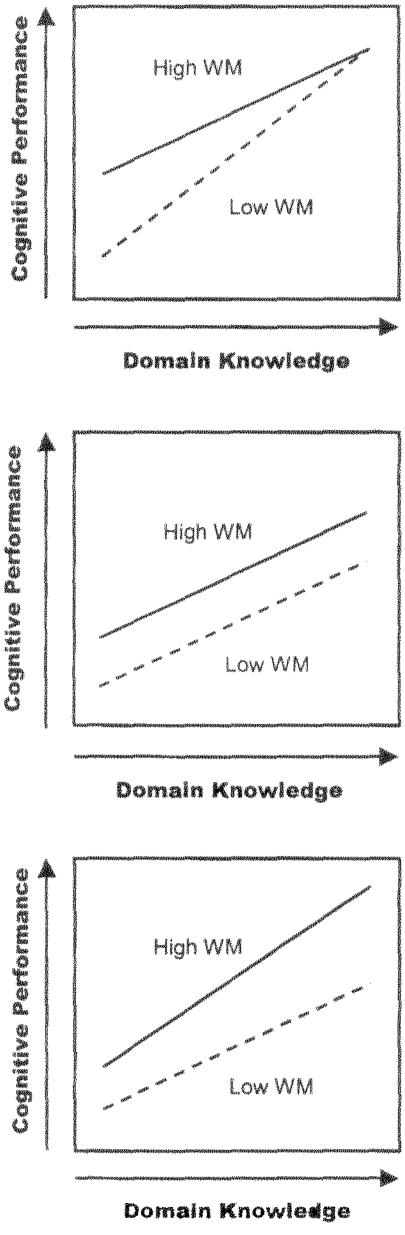

FIG. 1. Possible effects of domain knowledge and working memory capacity on cognitive performance.

Domain Knowledge–Age Relations

An additional goal of this study was to investigate the joint effects of domain knowledge and adult age on cognitive performance. Although research has established that certain aspects of cognition (e.g., perceptual speed, working memory, and reasoning) decline across the adult portion of the life span (see Salthouse, 1991, for a review), many theorists in the literature on aging and cognition have stressed the importance of domain knowledge in cognitive functioning during adulthood. For example, Rybash, Roodin, and Hoyer (1995) suggested that ''Older adults can continue to function effectively when given tasks that allow them to draw upon their expert knowledge . . . in spite of the significant reduction in generalized information processing skills and/or fluid intellectual abilities that accompanies the aging process'' (p. 222). Similarly, Ackerman (1996) proposed that knowledge is the ''core'' of the adult intellect and that beyond the school years the depth and breadth of knowledge is the primary determinant of proficiency in vocational and avocational domains. As a final example, Baltes and colleagues (e.g., Baltes & Baltes, 1990; Marsiske, Lang, Baltes, & Baltes, 1995) have argued that the hallmark of ''successful aging'' is increased engagement in narrow areas of interest and expertise.

Nevertheless, an unresolved issue concerns the joint effects of domain knowledge and age on cognitive performance. We investigated three models concerning this issue. The models are illustrated in Fig. 2 and correspond directly to the models concerning domain knowledge-working memory capacity relations depicted in Fig. 1. The first model is illustrated in Fig. 2A and is based on the idea that domain knowledge attenuates the negative effect of age on cognitive performance. Stated differently, domain knowledge compensates for the effect of age on cognitive performance. The possibility of compensation has been discussed by a number of authors (e.g., Bosman & Charness, 1996; Salthouse, 1995) and was summarized by Allaire and Marsiske (1999) as follows: ''Experiential theorists predict that as individuals age, they develop a rich network of declarative and procedural domain-specific knowledge in areas in which they frequently participate. This specialized knowledge, in turn, decreases the reliance on other mental abilities (e.g., inductive reasoning, working memory, speed) for everyday task performance within those domains . . .'' (p. 628).

The second model, illustrated in Fig. 2B, is based on the idea that although domain knowledge facilitates performance for both young adults and older adults, it does *not* attenuate the negative relationship between age and performance. Instead, the prediction is that age-related performance differences, which may be attributable to age-related decreases in factors such as working memory capacity, should be evident even at high levels of domain knowledge. This model draws upon the notion that declining cognitive abilities represent the building blocks of more complex aspects of cognition and

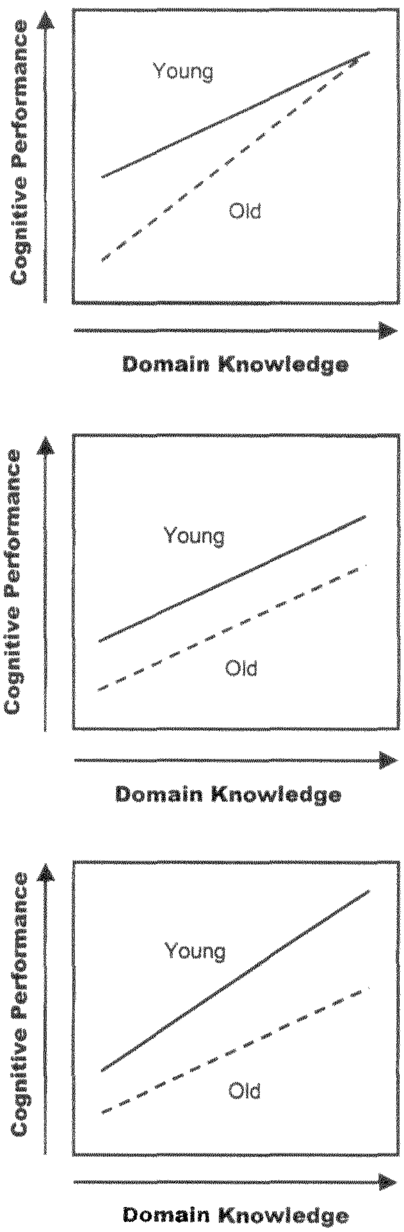

FIG. 2. Possible effects of domain knowledge and age on cognitive performance.

''drive'' age-related decreases in complex cognition. The final model concerning the joint effects of age and domain knowledge on cognitive performance derives from the rich-get-richer hypothesis described above. As illustrated in Fig. 2C, this model predicts that young adults should derive a greater benefit from preexisting domain knowledge in cognitive performance than older adults.

CURRENT RESEARCH

To investigate the above-mentioned goals, we recruited adults from wide ranges of working memory capacity, age, and knowledge about the game of baseball. The participants listened to, and then answered questions about, simulated radio broadcasts of baseball games that were realistic in content and presentation. This task was chosen because both domain knowledge and working memory capacity have been found to contribute to performance differences in tasks involving text comprehension and memory. For example, in a meta-analysis, Daneman and Merikle (1996) found a significant positive correlation (avg. $r = .41$) between working memory capacity and various measures of text comprehension and memory, and many researchers have reported that domain knowledge facilitates text comprehension and memory when the text contains domain-relevant content (e.g., Recht & Leslie, 1988; Spilich et al., 1979; Walker, 1987). In addition, young adults often outperform older adults on tasks involving text comprehension and memory (e.g., Zelinski & Gilewski, 1988). However, as discussed below, it is not clear on the basis of the available evidence whether domain knowledge moderates the effect of age on performance in such tasks. Baseball was selected as the domain for this study because of the availability of participants from the general population with different levels of knowledge about this activity. Next, we review evidence concerning the joint effects of domain knowledge and working memory capacity, and domain knowledge and age, on text comprehension and memory.

Domain Knowledge and Working Memory Capacity

Evidence concerning the joint effects of domain knowledge and working memory capacity on text comprehension and memory is inconclusive. Britton, Stimson, Stennett, and Gülgöz (1998) evaluated the effects of four individual difference characteristics (i.e., metacognitive ability, inference making ability, working memory capacity, and domain knowledge) on the ability to learn from instructional texts. Participants read a text about the Vietnam war, and the measure of comprehension involved rating the relations between pairs of terms from the text. Using structural equation modeling, Britton et al. found a strong direct effect of domain knowledge on text comprehension, whereas the direct effect of working memory capacity was nonsignificant. Britton et al. did not report whether there was a domain knowledge × working memory capacity interaction. In contrast to the Britton et al. study, Haenggi and Perfetti (1992, 1994) found significant effects of both domain knowledge and working memory capacity on accuracy in answering questions about an expository text. However, like Britton et al., Haenggi and Perfetti did not evaluate the interaction between domain knowledge and working memory capacity. Finally, McNamara (1998) found that domain knowledge was the best predictor of comprehension of a text about heart disease, whereas the effect of working memory capacity above and beyond domain knowledge was nonsignificant. The sample size was somewhat small ($N = 42$), however, and it is therefore possible that McNamara failed to detect a small effect of working memory capacity because of low statistical power. McNamara apparently did not evaluate the domain knowledge × working memory capacity interaction.

Numerous studies have examined the effects of domain knowledge and various other cognitive ability characteristics (which correlate positively with measures of working memory capacity) on text comprehension and memory. Walker (1987) found a strong facilitative effect of domain knowledge on memory for information from narrative passages about baseball games, while there was no effect of general cognitive ability (as measured by a test of reasoning ability) and no domain knowledge × ability interaction. In a series of studies, Schneider and colleagues (Schneider & Körkel, 1989; Schneider, Körkel, & Weinert, 1989; Schneider, Bjorklund, & Maier-Brückner, 1996), found that domain knowledge facilitated memory for narrative passages (e.g., about soccer games) with domain-relevant content. There were no effects of cognitive ability (as measured by verbal and nonverbal tests) on memory, and there were no domain knowledge × ability interactions. Hall and Edmondson (1992) reported significant effects of both domain knowledge and verbal ability on memory for information from an expository passage about basketball. Unfortunately, however, Hall and Edmondson did not evaluate the domain knowledge × verbal ability interaction. Recht and Leslie (1988) found a significant effect of domain knowledge on memory for narratives describing baseball games, but there was no effect of reading ability and no interaction. Finally, Adams, Bell, and Perfetti (1995) reported significant effects of domain knowledge and reading ability on recall of information from a story about a football game. In addition, there was a domain knowledge × reading ability interaction in the direction of a greater effect of reading ability for high-knowledge individuals than for low-knowledge individuals. However, because the sample size in the Adams et al. study was very small ($N = 24$), this finding should be interpreted cautiously without replication.

Domain Knowledge and Age

Evidence concerning the joint effects of domain knowledge and age on text comprehension is inconclusive as well. In a study by Morrow, Leirer, and Altieri (1992), pilots and non pilots read passages that described situations either related or unrelated to aviation. Although inspection of the published data revealed that age-related decreases in free recall of the texts were somewhat smaller for pilots than for nonpilots when the passage pertained to aviation, there was no evidence for an age × experience × passage (aviation or nonaviation) interaction. Thus, Morrow et al. concluded that domain knowledge did not attenuate age-related decreases in memory. Morrow, Leirer, Altieri, and Fitzsimmons (1994) devised a task to simulate routine pilot communication with an air traffic controller. Pilots and nonpilots from two age groups (young and older) read air-traffic control commands that contained navigation information about heading (e.g., turn right heading 020), altitude (e.g., climb and maintain 5000 ft.), and speed (e.g., increase speed to 220 knots). The task was to repeat back the commands as accurately as possible. Morrow et al. found the hypothesized age × experience interaction for the heading commands, but not for the altitude and speed commands. Morrow et al. speculated that the absence of the interaction for the latter two commands may have been attributable to the fact that these messages were quite easy to recall even for older nonpilots. To address this possibility, in a second experiment, the length of the messages was manipulated to vary task difficulty. For the short messages, the results of the first experiment were replicated, as the age × experience interaction was significant for the heading command but not for the other commands. For the long messages, however, there were significant age × experience interactions in the direction of smaller age-related differences for pilots than for nonpilots for the speed, altitude, and heading commands.

Results of the Morrow et al. (1994) study suggest that domain-relevant experience (which may be correlated with domain knowledge) can attenuate the negative relationship between age and measures of text memory, at least under certain conditions. Unfortunately, the results of other studies are inconsistent with respect to this possibility. Hultsch and Dixon (1983) found a significant age-related difference in text memory (favoring young adults) when the passages were about entertainment figures more familiar to young adults than to older adults (e.g., Steve Martin) but not when they were about entertainment figures more familiar to older adults than to young adults (e.g., Mary Pickford). Hultsch and Dixon therefore suggested that prior knowledge about entertainment figures moderated age-related differences in memory. By contrast, Arbuckle, Vanderleck, Harsany, and Lapidus (1990) found that although a high level of music experience was associated with better recall for information from a passage about music, the age × experience interaction was nonsignificant. Similarly, Meinz and Salthouse (1998) and Meinz (2000) found that music experience facilitated recall of visually and aurally presented melodies, but there was no evidence for interactions in the direction of smaller age-related decreases in music memory for experienced musicians. As a final example, in a more recent study of pilots, Morrow, Menard, Stine-

Morrow, Teller, and Bryant (2001) found that young pilots had better memory for air-traffic control messages than did older pilots, but there was no evidence for an age × experience interaction.

Limitations of Previous Research

This brief review indicates that evidence concerning the joint effects of domain knowledge and working memory capacity, and domain knowledge and age, on tasks involving text comprehension and memory is sparse and inconclusive. There are at least four limitations of previous research that warrant discussion. First, and most important, what might be considered the most informative comparison with respect to theoretical understanding of the interplay between domain knowledge and working memory capacity—the domain knowledge × working memory capacity interaction—was not evaluated in the above-mentioned studies. Thus, on the basis of the available evidence, it is unclear whether domain knowledge attenuates the effect of working memory capacity on text comprehension and memory or whether working memory capacity enhances the facilitative effect of domain knowledge.

Second, conclusions have often been based on small samples. Use of small sample sizes is problematic because it is possible that small-to-moderate effects of predictor variables (e.g., working memory capacity) were not detected because of low statistical power. Generally, sample sizes of at least 100 are recommended for individual-differences research (e.g., Detterman, 1989). Third, the manner in which various constructs were measured differed from study to study. To illustrate, McNamara (1998) measured working memory capacity with a version of the Daneman and Carpenter (1980) reading span task, whereas Haenggi and Perfetti (1992, 1994) used a task in which the goal was to recall a target word from an earlier portion of a difficult expository text. There is evidence for the construct validity of reading span, as this measure correlates positively with other putative measures of working memory capacity (Engle et al., 1999). However, the validity of Haenggi and Perfetti's task as a measure of working memory capacity is questionable because intuition suggests that this task may tap not only working memory capacity, but also reading skill or ability.

Fourth, researchers have often relied on a single task to measure each intended construct (e.g., working memory capacity; but see Britton et al., 1998, for an exception). This is problematic because it can be assumed that performance on nearly all psychological tasks is influenced not only by the theoretical construct of interest, but by other factors as well, including those related to specific methods and materials and to random error. Psychometrically, a more sound approach is to obtain multiple measures of each intended construct and then to cancel out construct-irrelevant variance by aggregating across the measures. Obtaining multiple measures also allows for assessment of two aspects of construct validity, convergent validity and discriminant validity. Measures exhibit convergent validity if they correlate moderately with each other and discriminant validity if they correlate weakly with measures of other constructs. Assessment of both aspects of validity is necessary to establish the meaning of a construct (e.g., Cook & Campbell, 1979). Finally, obtaining multiple measures permits use of structural equation modeling. Because latent variables, which are free of measurement error, may be used in structural equation modeling, conclusions can be shifted from the level of observed variables closer to the theoretical constructs of interest.

Overview. The major goal of this study was to characterize, at a descriptive level, the interplay between domain knowledge and working memory capacity in the performance of a domain-relevant cognitive task. Toward this end, we investigated three models concerning the joint effects of domain knowledge and working memory capacity on the performance of a task involving text comprehension and memory. The predictions associated with these models can be summarized as follows. The first model predicts an underadditive domain knowledge × working memory capacity interaction such that the effect of working memory capacity on cognitive performance is reduced at high levels of domain knowledge relative to lower levels of domain knowledge. The second model predicts additive effects of domain knowledge and working memory capacity on cognitive performance. The final model predicts an overadditive domain knowledge × working memory capacity interaction such that the facilitative effect of domain knowledge on cognitive performance is greater for individuals with high levels of working memory capacity than for those with lower levels of working memory capacity. An additional goal was to investigate corresponding models concerning the joint effects of domain knowledge and adult age on cognitive performance.

Based on limitations of previous research, we (a) used a relatively large sample, which consisted of participants from wide ranges of domain knowledge, working memory capacity, and age; (b) obtained multiple measures of each intended construct; and (c) performed hierarchical regression analyses to directly evaluate the joint effects of domain knowledge (about baseball) and working memory capacity, and domain knowledge and age, on memory for the simulated radio broadcasts of baseball games. In the hierarchical regression analyses, the specific question of interest was whether effects of domain knowledge and working memory capacity, and domain knowledge and age, on memory performance were additive or interactive. Structural equation modeling was used to supplement results of the hierarchical regression analyses. The primary question addressed through structural equation modeling was whether and to what extent working memory capacity contributed to memory performance independent of domain knowledge. We expected that there would be a strong positive effect of baseball knowledge on memory performance. In fact, the simulated radio broadcasts were realistic in presentation and in content so that participants would be able to capitalize on their preexisting knowledge of baseball. A more interesting question was whether there would be an effect of working memory capacity on memory performance independent of baseball knowledge.

To address two additional issues, variables representing two additional predictor variables, general knowledge and processing speed, were included in the structural equation analyses along with the primary predictor variables—baseball knowledge, working memory capacity, and age. First, general knowledge was included to verify that knowledge about baseball is a form of domain knowledge distinct from less specific expressions of knowledge, such as vocabulary and cultural information. Second, processing speed was included because evidence suggests that, when considered together, this factor and working memory capacity often account for a large proportion of the age-related variance in complex aspects of cognition, including text comprehension and memory (e.g., Kwong See & Ryan, 1995; Van der Linden et al., 1999). Therefore, we predicted that the effect of age on memory performance would be indirect and mediated through speed and working memory capacity and hence that the direct effect of age on memory performance would be small and nonsignificant.

METHOD

Participants

A total of 181 adults ranging in age from 18 to 86 years (M = 46.42, SD = 17.09) contributed complete data. All older adults in the sample were community dwelling. Data for two participants were incomplete because these individuals could not finish the session. Data for one participant were discarded because of an experimenter error. Participants were recruited from the Atlanta, Georgia, metropolitan area using newspaper advertisements and from two state universities in Atlanta. Approximately half of the participants responded to an advertisement that called for people from all levels of interest in the game of baseball to participate in a research project. While it is possible that this advertisement biased our recruitment procedure so that only people with relatively high levels of interest in baseball responded, the other advertisement made no mention of baseball. Furthermore, as discussed below, the participants represented a wide range of interest in and knowledge about baseball. Participants received nominal payment ($25) or extra credit in an introductory psychology course for participating. Power analyses were conducted based on a range of effect sizes [Cohen's (1988) f^2] for a two-way interaction effect in multiple regression, and it was found that a sample size of greater than 170 would provide adequate power ($1 - \beta > .80$) to detect even a small effect, corresponding to an R^2 value of approximately .02.

Background characteristics of the sample are summarized in Table 1. There was an approximately equal number of males (54%) and females (46%) in the sample, although there was a higher participation rate for males (65%) than for females (35%) within the middle-age range. (As discussed under Results, gender was treated as a covariate to determine whether this nonuniformity in the gender distribution across the age range influenced the effect of age on memory performance.) Consistent with previous reports (e.g., Hambrick, Salthouse, & Meinz, 1999), middle-aged adults and older adults reported having more education and being slightly less healthy than younger adults. However, the education and health variables were excluded from subsequent analyses because both correlated nonsignificantly ($p > .01$) with age (rs = .16 and .02, respectively).

TABLE 1
Background Characteristics of Participants

	Age Range		
	18–39	40–59	60+
N	63	68	50
Gender (% female)	58	35	48
Education	3.33 (0.98)	3.65 (1.03)	3.60 (1.05)
Health	1.98 (0.79)	1.85 (0.76)	2.04 (0.83)

Note. Education was rated on 5-point scale (1 = *less than 12 years;* 2 = *high school graduate;* 3 = *some college;* 4 = *bachelor's degree;* 5 = *graduate school*). Health was also rated on 5-point scale (1 = *excellent;* 2 = *very good;* 3 = *good;* 4 = *fair;* 5 = *poor*).

Materials

Working memory capacity. Participants completed two computer-administered tasks designed to measure working memory capacity. (Both tasks were administered individually, and the stimuli were presented in the center of an IBM color monitor.) The first task was the operation span task (Turner & Engle, 1989). The task was to solve a series of simple arithmetic equations while remembering a single target word following each equation for later recall. The equations appeared one at a time, and the number of equations for a given trial varied randomly from two to six, with the provision that there were 3 trials for each of the 5 levels (for a total of 15 trials). Participants read each equation and target word aloud and announced whether the equation was correct (''yes'') or incorrect (''no''). The experimenter then pressed a key causing presentation of the next equation. As a recall prompt, three question marks (???) appeared at the end of each trial, and participants attempted to write down the target words in the correct serial order. Operation span was the total number of words recalled from the perfectly recalled trials.

The second task was the counting span task developed by Case, Kurland, and Goldberg (1982) for children, and modified by Engle et al. (1999) for use with adults. Each display contained three items against a black background: magenta circles, dark blue circles, and dark blue squares. The task was to count aloud the dark blue circles, and after reaching the last dark blue circle, to repeat the total aloud (e.g., one, two, three . . . three). The experimenter then pressed a key causing presentation of the next display. After between two and eight displays, the word recall appeared in the center of the screen, and participants attempted to write down the number of dark blue circles from each display in the correct serial order. For each display, the number of magenta circles (color distractors) varied randomly from one to five, and the number of dark blue squares (shape distractors) was one, three, five, seven, or nine. The number of displays for a given trial varied randomly from two to eight, with the provision that there were 3 trials for each of the 7 levels (for a total of 21 trials). Counting span was the total number of digits recalled from perfectly recalled trials.

Processing speed. Processing speed was measured with two tests of perceptual comparison speed developed by Babcock and Salthouse (1990). In letter comparison, the task was to determine whether two groups of three, six, or nine letters separated by a blank space were the same or different. In pattern comparison, the task was to determine whether two patterns consisting of three, six, or nine line segments separated by a blank space are the same or different. Participants were instructed to write *S* in the blank space if the letters or patterns were the same or *D* if they were different. Participants completed two forms of each test and were allowed to work on each form for 30 s. There were 21 items in a single column on each form of the letter comparison test, and 30 items in two columns on each form of the pattern comparison test. For each form, the score was the number of correct responses minus the number of incorrect responses (to correct for guessing). A single score was then computed for each test by averaging the scores on the two forms.

General knowledge. General knowledge was measured with tests of vocabulary and cultural knowledge. The vocabulary test was developed by Salthouse (1993) and consisted of 20 multiple-choice questions (four-alternative) with 10 questions on each of two pages. The 10 questions on the first page asked for the synonym of a target word, and the 10 questions on the second page asked for the antonym of a target word. Participants were allowed to work on this test for 5 min. The general information test was developed by Hambrick et al. (1999) and consisted of 40 multiple-choice questions on 8 pages (four-alternative), with 5 questions about each of 8 topics as follows: (1) American history, (2) American literature, (3) art and architecture, (4) geography, (5) music, (6) mythology, (7) world history, and (8) world literature. The time limit was 13 min. The score on both the vocabulary test and the general information test was the number of questions answered correctly.

Baseball knowledge. Participants completed three tests with questions about rules, regulations, and terminology of baseball. Baseball knowledge test 1 consisted of 30 multiple-choice questions (four-alternative) on six pages. The following is a sample question: "Trying to get a runner from third base to home plate by bunting is called a(n) ______" (*squeeze play*). The time limit was 10 min. Baseball knowledge test 2 consisted of 40 fill-in-the-blank questions on three pages. The following is a sample question: "The phrase ______ describes when a runner must touch the base they are at before they can advance to the next base after a fly ball" (*tagging up*). The time limit was 13 min. Questions for the baseball knowledge tests were obtained from a test of baseball knowledge developed by Spilich et al. (1979) and from various internet sites devoted to baseball. Baseball knowledge test 3 contained 30 true/false questions on four pages and was designed to be an advanced test of baseball rules and regulations. The following is a sample question: "There is one out with a runner on first base. The catcher catches a foul fly and falls into the dugout. Then he throws the ball to first base before the runner can return. The runner is out" (*false*). The time limit was 10 min. Questions for baseball knowledge test 3 were obtained from a test for baseball umpires published in a collection of paper-and-pencil knowledge tests (Bragdon, 1987). The score for each baseball knowledge test was the number of questions answered correctly.

Baseball self-ratings and baseball experience. To characterize the sample in terms of involvement in the game of baseball, we asked participants to provide ratings of their interest in and knowledge about baseball and to estimate amount of engagement in various baseball-related activities. Baseball knowledge was rated on a 5-point scale with anchor ratings of 1 (*very low knowledge*) and 5 (*very knowledgeable*), and baseball interest was rated on a 5-point scale with anchor ratings of 1 (*very uninterested*) and 5 (*very interested*). Brief descriptions of each rating were provided. Participants also answered nine self-report questions about their involvement in baseball-related activities. The first question asked the participant whether he or she had ever played baseball or softball on an organized team; the second question asked the participant whether he or she had ever coached baseball or softball; the third question asked the participant whether he or she had ever collected baseball memorabilia; and the fourth question asked the participant how many books about baseball he or she owns. The remaining questions asked about involvement in baseball during the past two baseball seasons and to the present. The fifth question asked for the number of baseball games (of all types, including professional, little league, etc.) attended per year; the sixth question asked for the average number of hours per week spent listening to baseball games on the radio; the seventh question asked for the number of hours spent watching baseball games on television; the eighth question asked for the number of hours spent watching television programs about baseball (e.g., highlights); and the ninth question asked for the number of hours spent reading about baseball (e.g., in the newspaper).

Baseball passages and memory tests. Through headphones, participants listened to three narrative passages, each about a half-inning of a different fictitious baseball game. The three baseball passages were similar in structure but about different baseball games (with fictitious players and teams). The passages were recorded by a male sports announcer who worked for a local radio station. In addition, to enhance the realism of the simulated broadcasts, we mixed into the recordings background noise similar to that which might be heard while listening to an actual radio broadcast of a baseball game (e.g., crowd cheering and sound of bat hitting ball). Passages A–C were 659, 669, and 662 words in length, respectively, and the presentation length for each passage was approximately 3.5 min. Each passage described four batters, but the passages varied in the number of outs made and number of runs scored. Characteristics of the passages are presented in Table 2.

Each passage began with setting information (e.g., score, inning, which team was batting, the weather, and the standing of the teams in a particular division), and each of four subsequent paragraphs introduced a new batter and described the sequence of events that occurred during that player's turn at bat. (A highly knowledgeable baseball fan assisted in developing the passages to ensure that they described realistic game scenarios.) For example, in Passage A, the Senators and the Redbirds were tied at two runs apiece going into the bottom-half of the eighth inning. The leadoff batter (Sanchez) was described as a fast runner who was leading the team in stolen bases. This batter reached first base by hitting the ball to centerfield, setting up a classic situation in baseball: the leadoff batter is on first base late in the game with no outs. The second batter (Craik) executed a sacrifice bunt (a play in which the batter's goal is to be put out in order to advance the runner), and the first batter (Sanchez) advanced to second base. The third batter (Jacoby) reached first base, and the first batter (Sanchez) remained on second base. The fourth batter (Snow) hit a fly ball to the outfield. The ball was caught, putting the fourth batter out. However, the runner on first base (Jacoby) advanced to second base, and the runner on second base (Sanchez) advanced to third base. At this point, the manager for the defensive team decided to bring in a new pitcher, and the passage ended.

TABLE 2
Characteristics of Passages

	Passage		
	A	B	C
Passage variables			
Words	659	669	662
Sentences	39	41	40
Presentation length (s)	226	239	231
Words per sentence	16.8	16.3	16.5
Words per minute	174.8	168.1	171.9
Flesch-Kincaid Grade Level	6.6	6.9	7.2
Flesch Reading Ease Score	77.0	74.0	72.8
Game variables			
Batters	4	4	4
Outs	2	2	1
Base advancements	5	5	5
Runs scored	0	1	2
Number of blanks in cloze test	32	32	34
Relevant setting	3	4	4
Irrelevant setting	3	2	4
Relevant player	7	6	6
Irrelevant player	2	2	2
Relevant commentary	6	3	4
Irrelevant commentary	2	6	4
Game action	9	9	10

Participants completed two memory tests following administration of each baseball passage. The first test had two parts and consisted of 12 multiple-choice questions designed to assess whether participants were able to track changes in the status of each game. The first part consisted of two questions on a single page. The first question asked for the number of outs that were made, and the second question asked for the number of runs scored. The second part consisted of 10 questions about the outcome of each turn at bat. There were four pages, with one page devoted to each turn at bat. Within this set of questions, the first question asked about the outcome of the first player's turn at bat. For example, in Passage A, Sanchez was the first batter, and the question for his at bat was stated as follows: "Juan Sanchez was the first batter. Sanchez was ______." The alternatives covered all possible scenarios: (a) was out, (b) was on first base, (c) was on second base, (d) was on third base, or (e) reached home plate safely and therefore scored a run. The next two questions asked about the outcome of the second at bat, both with respect to the second batter and the first batter. In other words, there was a question about the second batter (with the same alternatives as above) and a question about the first batter. This latter question included all possibilities concerning the first batter at the outcome of the second player's turn at bat. For example, Craik was the second batter in Passage A, and the six alternatives for the question about Sanchez (the first batter) were (a) was on base when Craik came up to bat but was then out, (b) was on first base, (c) was on second base, (d) was on third base, (e) reached home plate safely and therefore scored a run, and (f) was not on base when Craik came up to bat because he was out or scored during a previous at bat. The questions for the third and fourth batters followed the same format, and hence there were three questions for the third batter and four questions for the fourth batter. The time limit was 4 min.

The score for each multiple-choice test was computed as follows. The first two questions counted 1 point apiece. For the remaining ten questions, one point per question was awarded, but only for questions that pertained to a batter's progress in advancing around the bases. For example, in Passage A, the second batter (Craik) was out at the conclusion of his turn at bat, and 1 point was awarded for choosing the alternative that indicated this outcome. However, within the set of questions for the third batter (Jacoby) and the fourth batter (Snow), no credit was given for correctly answering that Craik was not on base when he (Jacoby or Snow) came up to bat. This was done to avoid giving participants double credit for answering that Craik was out. The total score for each multiple-choice test was the number of points awarded for the first two questions (maximum of 2 points) plus the number of points awarded for the remaining 10 questions (maximum of 8 points for Passage A, 9 points for Passage B, and 7 points for Passage C).

The second memory test for each passage used a "cloze" format and consisted of a slightly modified transcript of the passage with blank spaces at various places throughout. The task was to fill in as many of the blanks as possible, with a time limit of 11 min. Each cloze test had between 32 and 34 blanks and was designed to assess memory for two basic types of information, information relevant to the fictitious baseball games (designated *game-relevant information*) and information irrelevant to the fictitious baseball games (designated *game-irrelevant information*). There were four types of game-relevant information: relevant setting, relevant player, relevant commentary, and game action. *Relevant setting* information provided an introduction to the game and included the names of the teams, the score, the inning, which team was leading or trailing, and which team was batting. *Relevant player* information refers to attributes of the players potentially relevant to the play of the game; for example, a player's batting average, ERA (earned run average), number of hits allowed, or number of RBIs (runs batted in). *Relevant commentary* refers to statements that were intended to elaborate upon what was happening, what had happened, or what might happen in the game. For example, in Passage A, following execution of a bunt, the narrator commented, "Some people say that bunting is a lost art, but that was a good one. He just squared around and steered the ball right down the baseline." *Game action* information refers to statements that described the events of the game, such as where the ball was hit (e.g., to deep centerfield), how the ball was hit (e.g., a long fly ball), and whether the ball was caught by a defensive player. The following is an example of game action information from Passage A: "Here comes the pitch, and a hard groundball is hit to the left side of the infield. The shortstop dives and stops this one from going into the outfield. . . ."

There were three types of game-irrelevant information. *Irrelevant setting* information refers to facts that were provided in the introduction to the game, but which did not pertain to the status of the game. Examples are the weather conditions and temperature or the standing of the teams in a particular division. *Irrelevant player* information refers to attributes of the players not directly relevant to the game. For example, in Passage A, it was stated that the relief pitcher was from the Bronx, and in Passage B, the narrator commented that the pitcher played in the minor leagues 2 years ago. Finally, *irrelevant commentary* refers to information that was not relevant to the game and not about a particular player. For example, in Passage B, the narrator noted that "The official attendance for today's game is just under 30,000, and 5,000 of the fans today are summer school kids from around the metro." All game action information was considered relevant, and thus there was no irrelevant game action information. The three passages can be found in Appendix A (memory for the underlined information was assessed in the cloze tests).[1]

Each cloze item counted one point, and a lenient scoring criterion was used. For each item, three experimenters (D. Z. Hambrick and two research assistants) decided what responses would be counted as correct. This decision making process was guided by a rational analysis of the content of each item. For example, for items that queried the temperature, leeway of ±2° was given. Therefore, if it was stated that the temperature was 60°, a response falling within the range of 58–62° was counted as correct given that most people living in the Southeast would probably describe temperatures within this range in the same manner (e.g., "cool"). As another example, for player statistics reported in decimal form (i.e., batting averages and earned-run averages), responses were counted as correct if they fell within ±.005 of the stated value. To illustrate, if it was stated that the batting average for a player was .330, then values in the range from .325 to .335 were counted correct. The reasoning was that baseball fans would probably describe batting averages falling within a ±.005 range as similar (e.g., "excellent hitter" for .325–.335). Likewise, for player statistics stated in whole-number form (e.g., number of home runs or runs batted in for the season), a ±2 margin of error was allowed. Hence, if it was stated that a player had 52 home runs for the season, responses in the range from 50 to 54 were counted as correct. As a final example, if it was stated that the ball went to centerfield, then a response of either "centerfield" or "center" was counted as correct, given that both convey the same meaning. It should be noted that only one response was considered correct for certain items. To illustrate, if it was stated that the game was in the 8th inning, that the month was September, or that the Senators were batting, only verbatim responses were counted as correct. For items such as these, there were no alternative responses that seemed to convey the gist of the stated information. Because scoring was objective after the possible correct responses for each item was determined, only a single rater scored the cloze tests.

Practice passage and memory test. The practice passage was a modified version of a narrative passage ("Animal Passage") used by Daneman and Carpenter (1980). The passage described the activities of various animals, and it was read by the person who recorded the baseball passages. Background noise (e.g., running water, leaves rustling, and animal movement) was mixed into the recording to familiarize participants with the task of listening to

[1] Using a description of each type of information, three raters (D. Z. Hambrick and two undergraduate research assistants) classified each item as being representative of one of the seven types of information. The percentage of items receiving the same classification by all three raters was 88% (28/32 items) for Passage A, 91% (29/32 items) for Passage B, and 85% (29/34 items) for Passage C. For all of the remaining items, two of the three raters gave the same classification. These items were given the classification chosen by the agreeing raters.

the narrator's voice against background noise. The volume level for the practice passage was the same as that for the baseball passages. The practice passage was 154 words in length, and the presentation time was approximately 1 min. The memory test for the practice passage used a cloze format and consisted of a transcript of the passage with 10 blank spaces at various points throughout. The task was to fill in as many of the blanks as possible, and the time limit was 3 min.

Procedure

The study took place in a single session of 2.5–3 h, with one to two participants per session. After signing an informed consent form, participants completed (a) a background questionnaire with questions about age, years of education, and health status; (b) the baseball experience questionnaire, and (c) operation span. The practice passage was administered next via headphones connected to a stereo receiver and compact disk player. Before administration of the practice passage, participants were instructed to do their best to keep track of what was happening in the story. After completing the cloze test for the practice passage, participants answered the following three-alternative multiple-choice question: "Did you have any trouble hearing the narrator's voice and distinguishing it from the background jungle noise?" Four participants chose the alternative *some difficulty,* and thus the volume was increased slightly for these participants. All other participants chose the alternative *no difficulty at all,* and therefore no volume adjustments were made. No participants chose the alternative *very much difficulty.* The baseball passages were administered next. Before administration of each passage, the experimenter read the following instructions aloud: "Now you are going to listen to a baseball game, and your task is to keep track of what is happening in the game in terms of the number of outs, which bases are occupied, and the score. Also, pay attention to information about the players and to other information about the game. Now put on your headphones."

For all passages, the volume level was approximately 60 dB. After listening to each baseball passage, participants completed the multiple-choice test, which was followed by the cloze test. For both the multiple-choice and cloze tests, participants were encouraged to check their work or rest if they finished before time expired. After administration of the baseball passages, the following tests and questionnaires were given to all participants in a fixed order of (a) baseball knowledge 1, (b) Cattell series, (c) Cattell classifications, (d) general knowledge, (e) letter comparison, (f) baseball knowledge 2, (g) letter sets, (h) Shipley abstraction, (i) vocabulary, (j) pattern comparison, and (k) baseball knowledge 3.[2]

RESULTS

There were three missing values; these observations were replaced with means based on the total sample. No participant had more than one missing value. Descriptive statistics for the baseball self-ratings and baseball experience measures are displayed in Table 3. As can be seen, the participants represented a wide range of involvement in the game of baseball (although it should be noted that some participants gave implausibly high estimates of baseball experience). For example, self-report estimates of total amount of time spent watching baseball games and programs about baseball on televi-

[2] Four measures of reasoning ability (Cattell series, Cattell classification, letters sets, and Shipley abstraction) were obtained, but they were used as pilot data for a separate research project and are not discussed in the present article.

TABLE 3
Descriptive Statistics for Baseball Self-Ratings and Self-Report Experience Measures

Variable	*M*	*SD*	Range
Baseball interest	3.71	1.22	1–5
Baseball knowledge	3.62	1.17	1–5
Play baseball	0.56	0.50	0–1
Coach baseball	0.32	0.47	0–1
Collect baseball memorabilia	0.28	0.45	0–1
No. of books about baseball owned	5.23	19.23	0–200
No. of baseball games attended/year	9.95	22.70	0–200
Hours watching baseball games on TV/week	6.37	6.51	0–30
Hours watching baseball programs on TV/week	2.34	5.23	0–50
Hours listening to baseball games/week	2.29	3.93	0–25
Hours reading about baseball/week	2.13	3.09	0–20

Note. Baseball interest rated on a 5-point scale (1 = *very uninterested* to 5 = *very interested*). Baseball knowledge rated on a 5-point scale (1 = *very low knowledge* to 5 = *very knowledgeable*). Play baseball (0 = no, 1 = yes). Coach baseball (0 = no, 1 = yes). Collect baseball memorabilia (0 = no, 1 = yes).

sion, listening to baseball games on the radio, and reading about baseball ranged from 0 to 95 h/week ($M = 13.76$, $SD = 15.24$).[3]

Reliability of Measures

Descriptive statistics and correlations among the measures are presented in Table 4. Reliability estimates are displayed along the diagonal of the correlation matrix. Reliability estimates were computed for the letter comparison and pattern comparison tests by boosting the correlation between scores on the two forms of each test using the Spearman–Brown formula, i.e., $n(\text{avg. } r)/(1 + ([n - 1] \text{ avg. } r))$, where n is the number of correlations in the composite variable and avg. r is the average of the correlations. To compute reliability estimates for operation span and counting span, three scores were

[3] An exploratory factor analysis was performed to investigate the possibility that baseball experience was multidimensional. For this analysis, log transformations were performed on the six variables reflecting quantitative estimates of baseball experience: number of books about baseball owned, number of baseball games attended per year, hours per week watching baseball games on television, hours per week watching baseball analysis programs on television, hours per week listening to baseball games on the radio, and hours per week reading about baseball. This was done because, for each of these variables, there was a disproportionate number of small values relative to large values (i.e., the variables were positively skewed). The log-transformed variables and the three dichotomous baseball experience variables (play baseball, coach baseball, and collect baseball memorabilia) were then entered into a principal-axis factor analysis. The results can be summarized by stating that only the first principal component had an eigenvalue greater than 1 (5.22) and that this factor accounted for a large proportion of the variance in the baseball experience measures (58%). No other factors were interpretable. Thus, it can be concluded that the baseball experience questions captured a single dimension of baseball-related experience.

TABLE 4
Correlation Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Age	—	−.08	−.20	−.45	−.50	.43	.28	.25	.17	.13	.06						
2. Operation span		(.78)	.66	.31	.32	.32	.32	.31	.20	.21	.17						
3. Counting span			(.78)	.36	.37	.35	.27	.31	.23	.25	.12						
4. Letter comparison				(.73)	.63	.08	.15	.15	.24	.25	.09						
5. Pattern comparison					(.80)	.04	.12	.13	.19	.22	.11						
6. Synonym vocabulary						(.81)	.75	.70	.35	.40	.13						
7. Antonym vocabulary							(.84)	.71	.24	.29	.13						
8. General information								(.82)	.24	.29	.07						
9. Baseball knowledge 1									(.93)	.93	.41						
10. Baseball knowledge 2										(.97)	.34						
11. Baseball knowledge 3											(.35)						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
12. Multiple-choice A	−.07	.31	.37	.34	.40	.27	.22	.20	.67	.70	.24	(.83)	.73	.70	.70	.60	.71
13. Cloze A	−.16	.34	.42	.39	.36	.35	.31	.31	.72	.76	.32		(.86)	.61	.83	.54	.81
14. Multiple-choice B	−.06	.24	.30	.33	.33	.17	.20	.14	.67	.66	.23			(.80)	.63	.60	.63
15. Cloze B	−.24	.43	.46	.43	.41	.31	.24	.23	.66	.67	.28				(.84)	.56	.84
16. Multiple-choice C	−.16	.27	.33	.32	.39	.12	.09	.08	.54	.52	.29					(.80)	.59
17. Cloze C	−.23	.34	.46	.44	.41	.24	.17	.16	.70	.71	.30						(.84)
M	46.56	11.75	20.77	10.09	16.35	6.57	6.22	20.45	20.16	24.86	16.53	6.14	13.20	7.17	12.55	5.33	12.74
SD	17.03	7.34	11.94	3.01	4.03	3.00	2.95	6.41	7.49	12.68	3.10	2.80	6.13	2.91	5.92	2.67	6.12

Note. $N = 181$. Correlations with an absolute magnitude greater than .20 were significant ($p < .01$). Values in parentheses along the diagonal are reliability estimates.

formed for each task. The scores reflected the number of words (in operation span) or digits (in counting span) recalled from the perfectly recalled trials for the first trial of each list length, the second trial of each list length, and the third trial of each list length.[4] For each working memory task, the reliability estimates were obtained by boosting the average correlation among the three scores using the Spearman–Brown formula. All other reliability estimates are coefficient alphas. It can be seen that the reliability estimates ranged from .35 to .97 and that most of the reliability estimates were greater than .70, indicating adequate reliability.[5] Baseball Knowledge 3 was eliminated from additional analyses because it had very low reliability (.35) and weak correlations with scores on the two other tests of baseball knowledge.

Hierarchical Regression Analyses

Hierarchical regression analyses were conducted to evaluate the main and interactive effects of baseball knowledge, working memory capacity, and age on memory performance. For use as predictor variables in these analyses, unit-weighted composite variables representing baseball knowledge and working memory capacity were created by averaging the z scores for the variables corresponding to these constructs. The reliability of each composite variable was estimated by calculating the average correlation among the z-

[4] Errors in the arithmetic component of the operation span task, and in the counting component of the counting span task, were recorded. To minimize the possibility that relations of working memory span with other variables are influenced by participants who intentionally sacrifice accuracy in the processing component of the working memory task, a common practice in our laboratory is to discard data for participants who do not achieve a criterion-level of accuracy (e.g., 85%). This usually results in elimination of less than 1% of participants. However, in this study, 10 participants (5.5% of the sample) failed to achieve at least 85% accuracy in operation span (<9 errors), and 13 participants (7.2% of the sample) failed to achieve at least 85% accuracy in counting span (<16 errors). Therefore, to avoid discarding a substantial amount of data, all analyses reported in this section were performed both with and without participants who failed to achieve at least 85% accuracy in either span task. Because the results were virtually identical in the separate analyses, only results based on the entire sample are reported.

One possible explanation for the high error rate in the operation span task is that the sample used in this study was more diverse with respect to educational background than samples used in previous research. (The participants in this study were recruited not only from a university subject pool, but also from the general population.) Thus, it is possible that the sample used in this study was less skilled in simple arithmetic than samples consisting entirely of college students. One possible explanation for the high error rate in counting span is that the sample included some older adults with impaired visual acuity. Consistent with this speculation, a number of older adults reported difficulty in discriminating shapes in the counting span task (the correlation between age and number of errors in counting span was .37).

[5] Reliability estimates range from 0 (no reliability) to 1 (perfect reliability). One minus the reliability estimate equals the proportion of variability in test scores due to random error. Typically, reliability estimates greater than .90 are considered "excellent," whereas those in the range from .70 to .90 are considered "adequate" or "acceptable" (see, e.g., Cronbach, 1990).

transformed variables and by boosting this average using the Spearman–Brown formula. The resulting reliability estimates were .96 for baseball knowledge and .79 for working memory capacity, indicating adequate reliability for each composite variable. The composite variables were screened for possible outliers, but none were found.[6]

Each hierarchical analysis was carried out in three steps. Baseball knowledge, working memory capacity, and age were entered in the first step to evaluate the main effect of each predictor variable on memory performance. Cross-product terms representing the baseball knowledge × working memory capacity, baseball knowledge × age, and working memory capacity × age two-way interactions were entered in the second step. A cross-product term representing the baseball knowledge × working memory capacity × age three-way interaction was entered in the third step. For each step, we report the increment in variance accounted for (Inc. R^2) by the variables entered in that step. We also report the squared semipartial correlation (sr^2) for each individual predictor variable, which reflects the proportion of variance in memory performance uniquely accounted for by that variable (see Cohen & Cohen, 1983). (Note that the sum of the sr^2s within a step will not equal the R^2 value when a portion of the variance in memory performance was not uniquely accounted for by a predictor variable.) Within the first step, a significant sr^2 for a predictor variable (e.g., baseball knowledge) would indicate that there was a main effect of that variable on memory performance, controlling for the two other main effects (e.g., working memory capacity and age). Within the second step, a significant sr^2 for a cross-product variable would indicate that there was a two-way interaction, controlling for the other two-way interactions and for the main effects. For the final step, a significant sr^2 would indicate that there was a three-way interaction, controlling for all main effects and two-way interactions.

To illuminate the results, graphs displaying the relation of baseball knowledge to memory performance as a function of both working memory capacity and of age are presented with each hierarchical analysis. The graphs were generated following Cohen and Cohen's (1983) recommended procedure for graphing continuous variable interactions. First, a regression equation was generated with two main effect terms (e.g., baseball knowledge and working memory capacity) and a cross-product term (e.g., baseball knowledge ×

[6] To identify outliers in the data, each composite memory performance variable (i.e., overall memory, game-relevant memory, and game-irrelevant memory) was regressed onto baseball knowledge, working memory capacity, and age in order to obtain a Cook's D statistic for each participant. A Cook's D greater than 1 is generally considered large and indicates that excluding a given participant's data would change the regression coefficients substantially, i.e., that the participant is a possible outlier (see Cook, 1977, for additional information). The maximum Cook's D was .09 for overall memory performance, .08 for game-relevant memory, and .07 for game-irrelevant memory. Thus, it was concluded that there were no outliers in the data set.

working memory capacity). Second, using the unstandardized regression coefficients for the main effects and the interaction, the relation of baseball knowledge to memory performance was evaluated as a function of three levels of working memory capacity (low, average, or high) or three levels of age (young, middle-age, and older). This was accomplished by predicting memory performance for each of two levels of baseball knowledge (low vs high) at each of the three levels of working memory capacity or age. Values used in this step were (a) 1 standard deviation below the mean for low baseball knowledge and 1 standard deviation above the mean for high baseball knowledge; and (b) 1 standard deviation below the mean for low working memory capacity or young, the mean for average working memory capacity or middle-age, and 1 standard deviation above the mean for high working memory capacity or older. Finally, the regression lines were graphed by plotting the predicted values.

Overall Memory Performance

The multiple-choice and cloze memory measures for each passage were highly correlated (see Table 4). Furthermore, when the memory measures were entered into a principal-axis factor analysis, the first factor had an eigenvalue greater than 1 (4.37) and accounted for a large proportion of the variance (72.8%). No other factors met the Kaiser criterion for extraction (i.e., eigenvalue greater than 1). Therefore, a unit-weighted composite variable reflecting overall memory performance was created by averaging the z scores of the two memory measures for each baseball passage. The reliability for this variable was excellent (.97).

The relation of baseball knowledge to memory performance as a function of working memory capacity (top panel) and of age (bottom panel) is displayed in Fig. 3. Review of Table 5 reveals that baseball knowledge, working memory capacity, and age together accounted for 77% [$F(3, 177) = 197.60$, $p < .01$] of the variance in memory performance, and that each variable contributed uniquely ($p < .01$): baseball knowledge ($sr^2 = .549$), working memory capacity ($sr^2 = .045$), and age ($sr^2 = .066$). High levels of baseball knowledge and working memory capacity were associated with superior memory performance. Older age was associated with lower memory performance. The two-way interactions accounted for an additional 1.4% [$F(3, 174) = 3.78$, $p < .05$] of the variance in memory performance, although only the baseball knowledge × working memory capacity interaction was significant ($sr^2 = .007$, $p < .05$). High levels of working memory capacity were associated with a greater positive effect of baseball knowledge on memory performance than were lower levels of working memory capacity. The three-way interaction was nonsignificant ($F < 1$).

Memory for Different Types of Information

The results presented thus far suggest that baseball knowledge was the major predictor of memory performance. Indeed, it uniquely accounted for

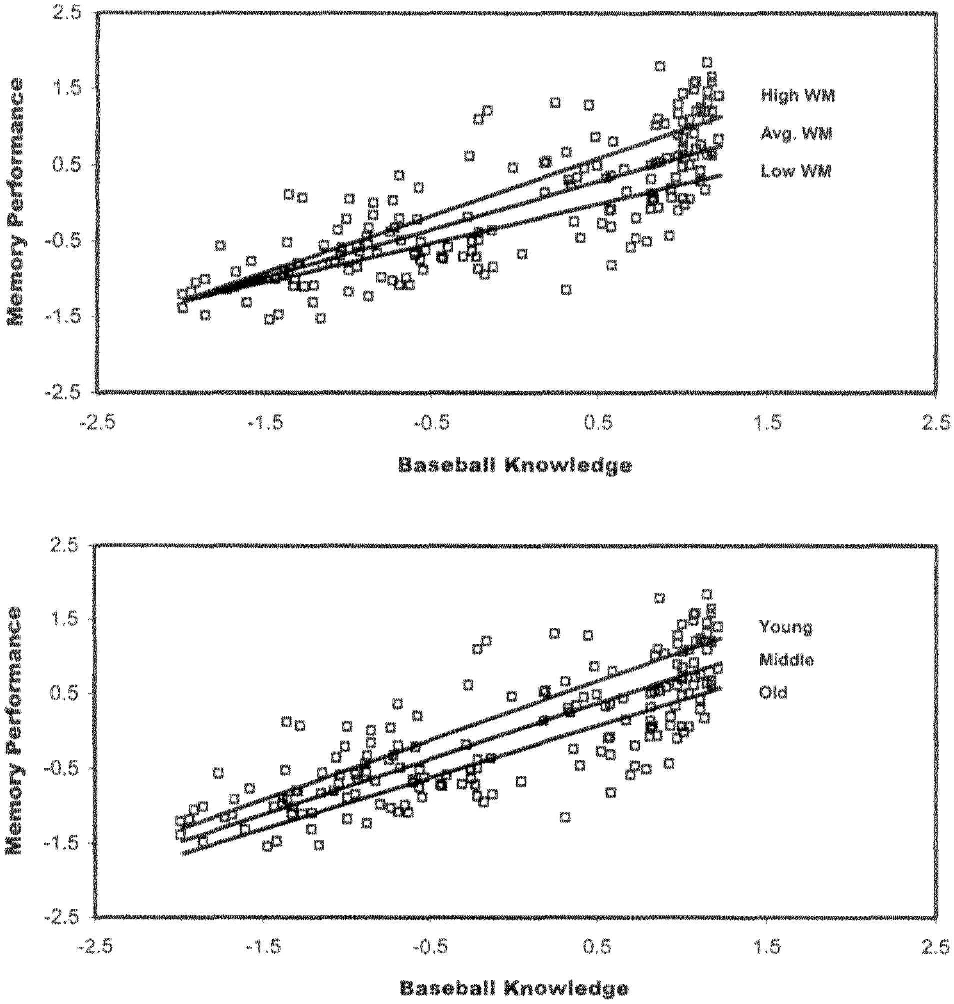

FIG. 3. Relation of baseball knowledge to memory performance as a function of working memory capacity (top) and age (bottom). (Values along each axis reflect the average of *z* scores.)

over half of the variance (i.e., 54.9%). Furthermore, high levels of working memory capacity and young age were associated with superior memory performance, even for participants at the highest levels of baseball knowledge. Finally, there was some evidence that participants high in working memory capacity derived the greatest benefit from baseball knowledge. Nevertheless, it is possible that effects of the predictor variables on memory performance varied depending on the type of information. We predicted that the facilitative effect of baseball knowledge on memory would be stronger for game-

TABLE 5
Hierarchical Regression Analysis Predicting Overall Memory Performance

Criterion variable	Inc. R^2	F value	B	t value	sr^2
Step 1.	.770	197.60**			
BBK			.676	20.55**	.549
WMC			.209	5.88**	.045
Age			−.013	−7.13**	.066
Step 2	.014	3.78*			
BBK × WMC			.091	2.29*	.007
BBK × Age			−.001	−0.63	.000
WMC × Age			−.004	−1.82	.004
Step 3	.000	0.17			
BBK × WMC × Age			.001	0.41	.000

Note. Inc. R^2 = increment in variance accounted for; B = unstandardized regression coefficient; sr^2 = squared semipartial correlation; BBK = baseball knowledge; WMC = working memory capacity.

* $p < .05$.

** $p < .01$.

relevant information than for game-irrelevant information. It is also possible that baseball knowledge reduced the effects of working memory capacity and age on memory performance, but only for game-relevant information. For example, Ericsson and Kintsch (1995) proposed that preexisting domain knowledge facilitates encoding of domain-relevant information into long-term memory and that reliance on temporary maintenance of information via working memory is circumvented when domain knowledge is applicable to the task at hand. A prediction that seems to follow from this proposal is that the effect of working memory capacity on memory for game-relevant information should have been smaller at high levels of baseball knowledge than at lower levels of baseball knowledge. Alternatively, if working memory capacity facilitated use of baseball knowledge in memory for the baseball games, then this effect may have been most pronounced for game-relevant information. The analyses described next were performed to examine these possibilities and involved three steps.

First, we conducted both exploratory and confirmatory factor analyses to determine whether different types of information could be distinguished empirically. Items from each cloze test were summed to form variables representing memory for the types of information described above: (a) relevant setting, (b) irrelevant setting, (c) relevant player, (d) irrelevant player, (e) relevant commentary, (f) irrelevant commentary, and (g) game action. (Recall that all game action information was considered relevant.) The 21 variables (i.e., 7 variables per passage × 3 passages) were then entered into a principal-axis factor analysis. Because each cloze memory test was designed to measure memory for two types of information (i.e., game-relevant and game-irrelevant), we set the number of factors for extraction at two. Next, the factors were rotated using an oblique rotation (promax), thus allowing the factors to correlate. The standardized factor loadings are displayed in Table 6. The first factor was labeled game-relevant memory because the relevant setting, relevant player, relevant commentary, and game action variables had stronger positive loadings on this factor (M = .60) than did the game-irrelevant variables (M = .08). The only exception was the relevant setting variable for Passage B, which had a stronger positive loading on the second factor (.34) than on the first factor (.12). The second factor was labeled game-irrelevant memory because the irrelevant setting, irrelevant player, and irrelevant commentary variables had generally stronger positive loadings on this factor (M = .46) than did the game-relevant variables (M = .08). The only exception was the irrelevant commentary variable for Passage C, which had a slightly stronger positive loading on the first factor (.36) than on the second factor (.24). Thus, 19 of 21 variables loaded on the factors in a manner consistent with the distinction between game-relevant memory

TABLE 6
Loadings of Variables from Cloze Tests on Game-Relevant and Game-Irrelevant Factors

Variable	Game-relevant	Game-irrelevant
Relevant setting (A)	.26	.18
Relevant setting (B)	.12	.34
Relevant setting (C)	.52	.00
Relevant player (A)	.75	.05
Relevant player (B)	.52	.20
Relevant player (C)	.61	.08
Relevant commentary (A)	.65	.10
Relevant commentary (B)	.55	.20
Relevant commentary (C)	.46	.21
Game action (A)	.90	−.15
Game action (B)	.97	−.18
Game action (C)	.85	−.06
Irrelevant setting (A)	−.04	.55
Irrelevant setting (B)	.01	.51
Irrelevant setting (C)	.12	.44
Irrelevant player (A)	−.18	.61
Irrelevant player (B)	.22	.49
Irrelevant player (C)	.11	.35
Irrelevant commentary (A)	.06	.37
Irrelevant commentary (B)	.10	.59
Irrelevant commentary (C)	.36	.24
Eigenvalue	7.75	1.54
Proportion of variance	.37	.07

Note. Factor loadings with an absolute magnitude greater than .30 are underlined.

TABLE 7
Loadings of Variables from Cloze Tests on Latent Variables

Variable	Game-relevant	Game-irrelevant
Relevant setting (A)	.39	
Relevant setting (B)	.36	
Relevant setting (C)	.52	
Relevant player (A)[a]	.78	
Relevant player (B)	.66	
Relevant player (C)	.67	
Relevant commentary (A)	.72	
Relevant commentary (B)	.69	
Relevant commentary (C)	.61	
Game action (A)	.79	
Game action (B)	.84	
Game action (C)	.81	
Irrelevant setting (A)		.45
Irrelevant setting (B)		.48
Irrelevant setting (C)		.53
Irrelevant player (A)[a]		.45
Irrelevant player (B)		.69
Irrelevant player (C)		.46
Irrelevant commentary (A)		.40
Irrelevant commentary (B)		.65
Irrelevant commentary (C)		.54

Note. [a]Observed variable used to scale latent variable.

and game-irrelevant memory. The correlation between the game-relevant memory and game-irrelevant memory factors was .67. A confirmatory factor analysis was performed as a follow-up to the exploratory factor analysis. A two-factor model was specified, with latent variables representing game-relevant memory and game-irrelevant memory. The fit of the model was acceptable [χ^2 (188) = 302.32, CFI = .92, NNFI = .91, SRMR = .06].[7] The results are displayed in Table 7.

Second, based on the preceding results, unit-weighted composite variables representing memory for each type of information were created. The *z* scores of the relevant setting, relevant player, relevant commentary, and game ac-

[7] The χ^2 (chi-square) statistic reflects whether there was a significant difference between the reproduced and observed covariance matrixes. Therefore, *nonsignificant* χ^2 values are desirable. However, when moderate to large sample sizes are used, even a slight difference between the reproduced and observed covariance matrixes can result in a significant χ^2 statistic. The confirmatory fit index (CFI) and nonnormed fit index (NNFI) are less sensitive to sample size; both indexes reflect the proportion of the observed covariance matrix explained by the model. The standardized root mean squared residual (SRMR) reflects the average squared difference between the observed and reproduced covariances. Confirmatory fit index and NNFI values of greater than .90, and SRMR values less than .05, are generally considered indicative of an acceptable fit (Kline, 1998).

TABLE 8
Correlations among Age, Working Memory Capacity, Baseball Knowledge, and Variables Reflecting Memory for Two Types of Information

	1	2	3	4	5
1. Age	—	−.16	.15	−.18	−.38
2. Working memory capacity		(.79)	.25	.47	.46
3. Baseball knowledge			(.96)	.79	.41
4. Game-relevant memory				(.98)	.67
5. Game-irrelevant memory					(.93)

Note. Correlations with an absolute magnitude greater than .20 were significant ($p < .01$). Values in parentheses along the diagonal are reliability estimates.

tion variables were averaged to create the game-relevant memory composite. The *z* scores of the irrelevant setting, irrelevant player and irrelevant commentary variables were averaged to create the game-irrelevant memory composite. The reliability estimates for these composite memory variables were .98 for game-relevant memory and .93 for game-irrelevant memory; hence, both had excellent reliability. (See Table 8 for correlations of baseball knowledge, working memory capacity, and age with game-relevant memory and game-irrelevant memory.) Finally, the effects of baseball knowledge and working memory capacity, and baseball knowledge and age, on memory performance were evaluated, with a separate analysis for each type of information. As before, the question was whether effects of the predictor variables were additive, underadditive, or overadditive. Results of analyses involving game-relevant memory are in Table 9, and results of analyses involving game-irrelevant memory are in Table 10.

TABLE 9
Hierarchical Regression Analysis Predicting Game-Relevant Memory

Criterion variable step	Inc. R^2	F value	B	t value	sr^2
Step 1	.759	185.84**			
BBK			.536	19.72**	.529
WMC			.180	6.13**	.051
Age			−.010	−6.78**	.063
Step 2	.020	5.25**			
BBK × WMC			.108	3.31**	.014
BBK × Age			−.001	−0.68	.001
WMC × Age			−.002	−1.23	.002
Step 3	.000	0.04			
BBK × WMC × Age			.000	0.19	.000

Note. Inc. R^2 = increment in variance accounted for; B = unstandardized regression coefficient; sr^2 = squared semipartial correlation; BBK = baseball knowledge; WMC = working memory capacity.

*$p < .05$.

**$p < .01$.

TABLE 10
Hierarchical Regression Analysis Predicting Game-Irrelevant Memory

Criterion variable step	Inc. R^2	F value	B	t value	sr^2
Step 1.	.448	47.93**			
BBK			.240	6.78**	.143
WMC			.192	5.02**	.078
Age			−.014	−6.86**	.147
Step 2.	.010	1.12			
BBK × WMC			−.031	−0.70	.002
BBK × Age			−.003	−1.48	.007
WMC × Age			−.002	−0.74	.002
Step 3	.003	0.92			
BBK × WMC × Age			.002	0.96	.003

Note. Inc. R^2 = increment in variance accounted for; B = unstandardized regression coefficient; sr^2 = squared semipartial correlation; BBK = baseball knowledge; WMC = working memory capacity.
*$p < .05$.
**$p < .01$.

Game-relevant memory. The relation of baseball knowledge to game-relevant memory as a function of working memory capacity (top panel) and of age (bottom panel) is displayed in Fig 4. Review of Table 9 reveals that baseball knowledge, working memory capacity, and age together accounted for 75.9% [$F(3, 177) = 185.84, p < .01$] of the variance in game-relevant memory and that each variable contributed uniquely ($p < .01$): baseball knowledge ($sr^2 = .529$), working memory capacity ($sr^2 = .051$), and age ($sr^2 = .063$). High levels of baseball knowledge and working memory capacity were associated with superior game-relevant memory. Older age was associated with lower levels of game-relevant memory. The two-way interactions accounted for an additional 2% [$F(3, 174) = 5.25, p < .01$] of the variance in game-relevant memory, but once again only the baseball knowledge × working memory capacity interaction was significant ($sr^2 = .014$, $p < .01$). High levels of working memory capacity were associated with a greater positive effect of baseball knowledge on game-relevant memory than were lower levels of working memory capacity. The three-way interaction was nonsignificant ($F < 1$).

Game-irrelevant memory. The relation of baseball knowledge to game-irrelevant memory as a function of working memory capacity (top panel) and of age (bottom panel) is displayed in Fig. 5. Review of Table 10 reveals that baseball knowledge, working memory capacity, and age together accounted for 44.8% [$F(3, 177) = 47.93, p < .01$] of the variance in game-irrelevant memory and that each variable contributed uniquely ($p < .01$): baseball knowledge ($sr^2 = .143$), working memory capacity ($sr^2 = .078$), and age ($sr^2 = .147$). High levels of baseball knowledge and working mem-

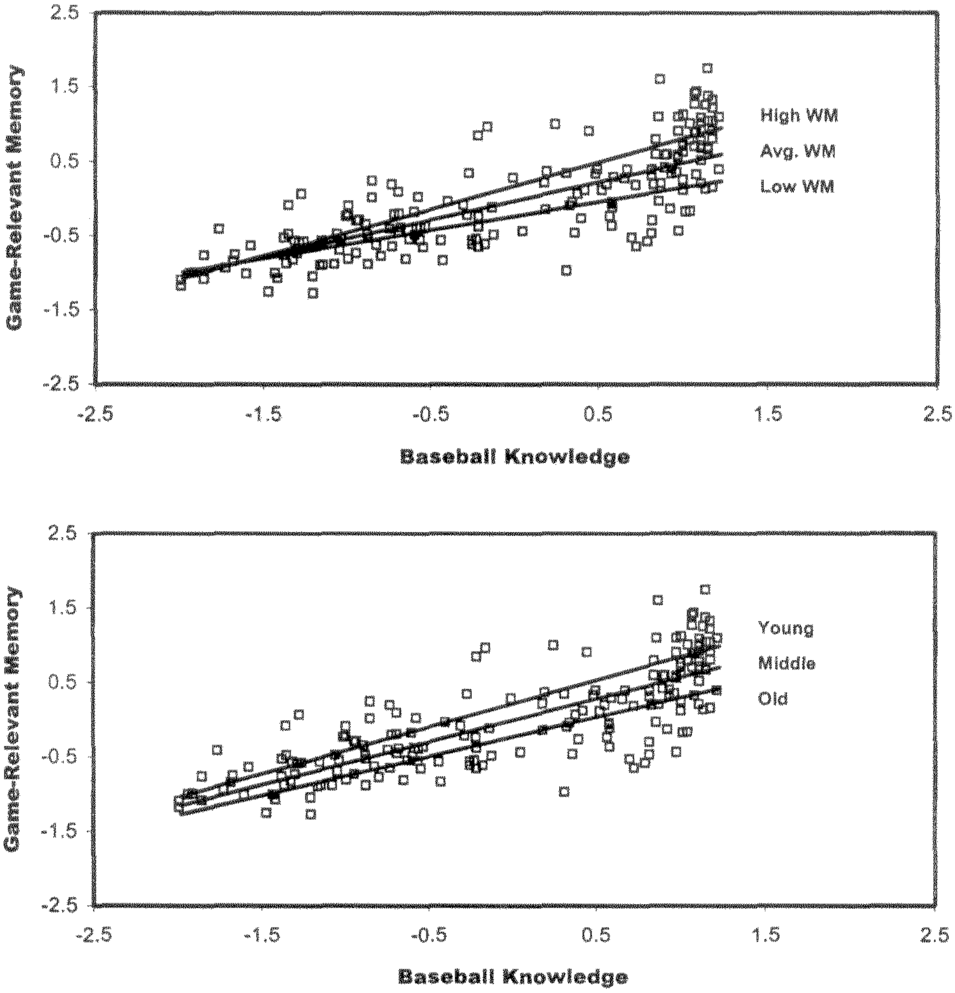

FIG. 4. Relation of baseball knowledge to memory for game-relevant information as a function of working memory capacity (top) and age (bottom). (Values along each axis reflect the average of z scores.)

ory capacity were associated with superior game-irrelevant memory. Older age was associated with lower levels of game-irrelevant memory. Neither the two-way interactions [$F(3, 174) = 1.12$] nor the three-way interaction ($F < 1$) contributed significantly to the prediction of game-irrelevant memory.

Type of information × predictor variable. To investigate the possibility that effects of the predictor variables on memory performance differed for game-relevant information and game-irrelevant information, we performed a hierarchical regression analysis in which type of information (game-rele-

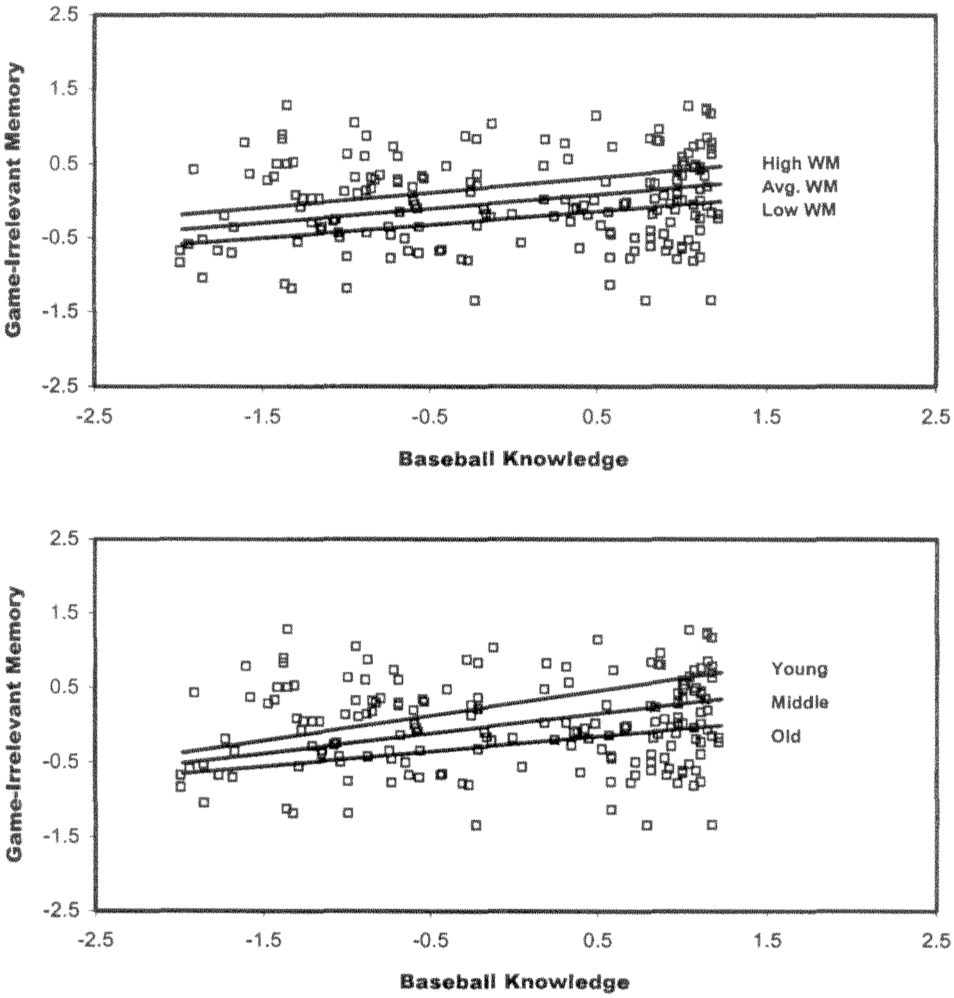

FIG. 5. Relation of baseball knowledge to memory for game-irrelevant information as a function of working memory capacity (top) and age (bottom). (Values along each axis reflect the average of z scores.)

vant vs game-irrelevant) was treated as a within-subjects variable. The interaction of type of information with each predictor variable was assessed. The predictor variables were entered into the hierarchical analysis in the following order: baseball knowledge, working memory capacity, age, baseball knowledge × working memory capacity, and baseball knowledge × age. A significant type of information × predictor variable interaction would indicate that the effect of the predictor variable on memory performance was different for game-relevant information and game-irrelevant information.

The results can be summarized as follows. As expected, there was a type of information × baseball knowledge interaction [$F(1, 175) = 89.23$, $p < .01$]. Baseball knowledge had a stronger positive effect on game-relevant memory than on game-irrelevant memory. However, neither two-way interaction was significant: type of information × working memory capacity ($F < 1$) and type of information × age [$F(1, 175) = 3.04$, $p > .08$]. Thus, it can be concluded that the effects of working memory capacity and age on game-relevant memory and on game-irrelevant memory did not differ statistically. Finally, there was a type of information × baseball knowledge × working memory capacity interaction [$F(1, 175) = 10.20$, $p < .01$]. This was because there was an over additive baseball knowledge × working memory capacity interaction for game-relevant memory but not game-irrelevant memory. The type of information × baseball knowledge × age interaction was nonsignificant ($F < 1$).

Gender Differences

Perhaps because the game of baseball is more popular among men than among women, there was a significant negative correlation between gender and baseball knowledge ($r = -.55$, $p < .01$), indicating that the men in this study knew more about baseball than did the women. To investigate whether taking this gender difference into account would change the results discussed thus far, we repeated the hierarchical regression analyses reported in Tables 5, 9, and 10, with one modification—gender was entered in the first step of each analysis as a covariate. The results can be summarized by stating that the only effect of controlling for gender was to slightly reduce the effect of baseball knowledge on memory performance, although this effect remained significant and sizeable in all cases (e.g., for overall memory performance, $sr^2 = .429$). Changes in the main effects of working memory capacity and age on memory performance were negligible, as were changes in the interactions of working memory capacity and age with baseball knowledge.

Discussion and Summary of Hierarchical Regression Analyses

Domain knowledge about baseball was the strongest predictor of memory for the simulated radio broadcasts of baseball games. Moreover, the positive effect of baseball knowledge on memory performance was stronger for game-relevant information than for game-irrelevant information. However, independent of both baseball knowledge and age, high levels of working memory capacity were associated with superior memory performance. Furthermore, there was no evidence to suggest that baseball knowledge attenuated, much less eliminated, the effect of working memory capacity on memory performance. To the contrary, the positive effect of baseball knowledge on memory performance was greater for participants with high levels of working memory capacity than for those with lower levels of working memory capacity. Additional analyses revealed that this interaction was moderated by type of information. That is, there was an overadditive baseball knowledge × working memory capacity interaction for game-relevant memory but not game-irrelevant memory. This finding is consistent with the speculation that working memory capacity may facilitate the use of preexisting domain knowledge in cognitive performance. Finally, consistent with previous research, there was a negative effect of age on memory performance (e.g., Zelinski & Gilewski, 1988). However, there was no evidence to suggest that baseball knowledge attenuated this effect, and thus the results are inconsistent with the hypothesis that domain knowledge compensates for the effect of age on memory for domain-relevant material.

Structural Equation Analyses

Using the EQS program (Bentler, 1995), structural equation modeling was performed to evaluate the relative contributions of baseball knowledge, working memory capacity, and age to memory performance. The primary question motivating the structural equation analyses was whether working memory capacity contributed to memory performance independent of baseball knowledge. Latent variables representing general knowledge and processing speed were also included in the structural equation model to address two additional questions. One question was whether knowledge about the game of baseball is a form of domain knowledge distinct from less specific expressions of knowledge (e.g., vocabulary) and whether the effect of baseball knowledge on memory performance would be independent of general knowledge. The other question was whether the effect of age on memory performance would be indirect and mediated through processing speed and working memory capacity.

The structural equation analyses were performed in two steps. First, a confirmatory factor analysis was conducted to determine whether the intended constructs were measured. The covariance matrix was used as input, but standardized solutions are presented. The latent variables were scaled by fixing the factor loading of one observed variable per construct to 1.0. The measurement model is presented in Table 11, and correlations among the latent variables are shown in Table 12. The fit of the model was acceptable [χ^2 (80) = 142.78, CFI = .97, NNFI = .96, SRMR = .04], and inspection of the modification indexes revealed no misspecification of the latent variables. Also, the Mardia statistic (1.58) indicated that the assumption of multivariate normality was met in the data, i.e., that there was not a significant degree of multivariate skewness or kurtosis (values greater than 3 are generally considered indicative of nonnormality) (see Kline, 1998). Second, the relations among the latent variables and age were estimated in a structural equation model. The fit of the model displayed in Figure 6 was also acceptable [χ^2 (95) = 199.85, CFI = .95, NNFI = .94, SRMR = .06]. Nonsignificant paths ($p > .05$) were deleted from the model and included processing speed to general knowledge, processing speed to memory performance, gen-

TABLE 11
Loadings of Criterion Variables and Predictor Variables on Latent Variables

Variable	MEM	WMC	SPD	GKN	BBK
Multiple-choice A	.82				
Cloze A[a]	.90				
Multiple-choice B	.74				
Cloze B	.89				
Multiple-choice C	.66				
Cloze C	.90				
Operation span		.76			
Counting span[a]		.87			
Letter comparison[a]			.78		
Pattern comparison			.80		
Synonym vocabulary[a]				.88	
Antonym vocabulary				.85	
General information				.82	
Baseball knowledge 1[a]					.95
Baseball knowledge 2					.98

Note. MEM = memory performance; WMC = working memory capacity; SPD = processing speed; GKN = general knowledge; BBK = baseball knowledge.
[a]Observed variable used to scale latent variable.

eral knowledge to baseball knowledge, and general knowledge to memory performance. Retention of these paths produced no significant improvement of fit in the model.

Major Findings

To reiterate, the primary question addressed through structural equation modeling was whether working memory capacity contributed to the prediction of memory performance independent of baseball knowledge. Inspection of Fig. 6 reveals that it did. That is, there was a direct effect of working memory capacity on memory performance (.30) independent of the effect of baseball knowledge (.76). This indicates that, independent of the large predictive contribution of baseball knowledge, memory performance increased .30 standard deviation units for every 1 standard deviation increase

TABLE 12
Correlations among Latent Variables

	1	2	3	4	5
1. Memory performance	—	.55	.58	.33	.83
2. Working memory capacity		—	.53	.44	.28
3. Processing speed			—	.15	.29
4. General knowledge				—	.39
5. Baseball knowledge					—

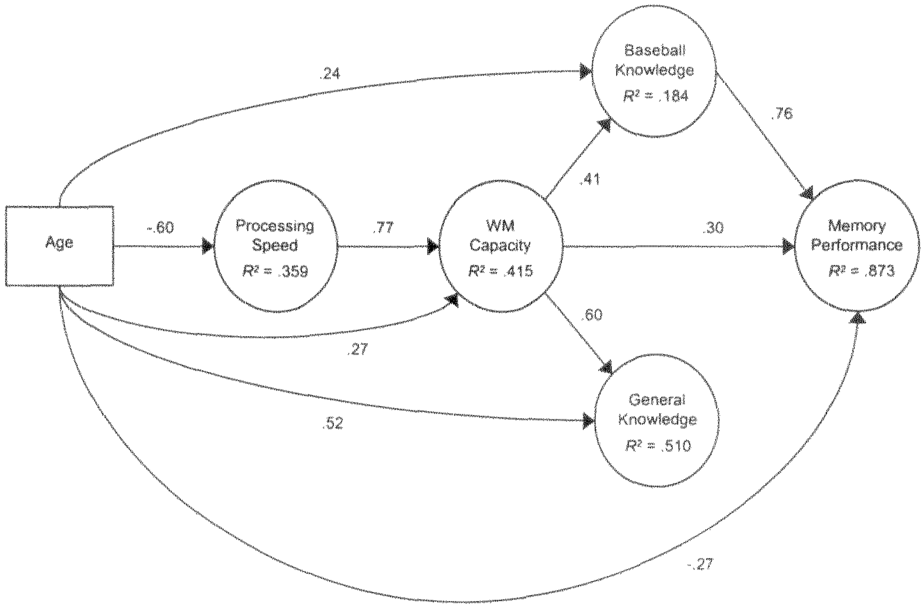

FIG. 6. Structural equation model. Values adjacent to the arrows connecting the variables are standardized regression coefficients.

in working memory capacity. Furthermore, when the path from working memory capacity to memory performance was dropped, there was a significant loss of fit in the structural model, as evidenced by a significant change in the chi-square statistic [$\chi^2_{\text{change}}(1) = 38.52, p < .01$].

Two additional questions were addressed through structural equation modeling. One question was whether knowledge about baseball can be considered a form of knowledge distinct from general knowledge and whether there would be an effect of baseball knowledge on memory performance independent of general knowledge. The results suggest that "yes" is the answer to both parts of this question. That is, latent variables representing baseball knowledge and general knowledge were separable (although positively correlated; see Table 12), and baseball knowledge had a direct effect on memory performance, whereas general knowledge did not. The other question was whether the effect of age on memory performance would be indirect and mediated through processing speed and working memory performance. Inspection of Fig. 6 reveals that although the effect of age on memory performance was partially mediated through processing speed and working memory capacity, there was also a direct effect of age on memory performance (−.27). Thus, processing speed and working memory capacity did not completely account for the effect of age on memory performance.

Additional Findings

Three other aspects of Fig. 6 are noteworthy. First, working memory capacity had positive effects on both baseball knowledge (.41) and general knowledge (.60). One interpretation of this finding, suggested by previous research, is that working memory capacity contributes to knowledge acquisition. For instance, Kyllonen and Stephens (1990) found that working memory capacity predicted knowledge acquisition in a complex learning task. However, an alternative explanation is that acquisition of knowledge leads to the expansion of working memory capacity. More specifically, it has been suggested that acquired knowledge accounts for individual differences in performance on the type of working memory task administered in the present study (e.g., Fincher-Kiefer et al., 1988; Ericsson & Kintsch, 1995; Kintsch, 1998). We cannot rule out this hypothesis, but it is worth noting that the fit of a reconfigured structural model with paths extending from baseball knowledge and general knowledge to working memory capacity [χ^2 (95) = 247.70, CFI = .93, NNFI = .91, SRMR = .16] was worse than the fit of the model in Fig. 6 [χ^2 (95) = 199.85, CFI = .95, NNFI = .94, SRMR = .06], in which these paths went in the opposite direction. Furthermore, in the reconfigured structural model, the effect of baseball knowledge on working memory capacity was nonsignificant (.09). Taken together, these findings seem consistent with previous research in suggesting that working memory capacity may contribute to knowledge acquisition.

Second, the effect of age on working memory capacity was partially mediated through processing speed. That is, there was a negative effect of age on processing speed (−.60), and a positive effect of processing speed on working memory capacity (.77) in turn. Therefore, the indirect effect of age on working memory capacity was −.46 (i.e., $-.60 \times .77 = -.46$). This replicates the finding that age-related decreases in processing speed contribute to concomitant decreases in working memory capacity (e.g., Verhaeghen & Salthouse, 1997). It is not obvious why there was a positive effect of age on working memory capacity (.27) independent of processing speed, but Allen, Hall, Druley, Smith, Sanders, and Murphy (2001) reported a similar finding and suggested that as people grow older they may develop beneficial cognitive strategies (e.g., rehearsal) in order to cope with age-related cognitive decline.

Finally, there was a positive effect of age on both general knowledge (.52) and baseball knowledge (.24). This finding is consistent with the hypothesis that "crystallized" aspects of cognition (e.g., declarative knowledge) remain relatively stable or even increase with age (e.g., Ackerman, 1996; Horn & Cattell, 1967).

GENERAL DISCUSSION

The primary goal of this research was to evaluate three descriptive models concerning the joint effects of domain knowledge and working memory capacity on cognitive performance. The first model is based on the idea that domain knowledge compensates for working memory capacity in cognitive performance. That is, this model predicts that high levels of domain knowledge attenuate the effect of working memory capacity on cognitive performance. The second model stems from the view that working memory capacity represents a basic mechanism underlying cognitive performance and that it contributes to performance differences even at high levels of domain knowledge. The final model predicts a rich-get-richer effect involving working memory capacity, such that people with high levels of working memory capacity derive a greater benefit from domain knowledge than people with lower levels of working memory capacity. An additional goal of this study was to investigate corresponding models concerning the interplay between domain knowledge and adult age in cognitive performance.

Domain Knowledge and Working Memory Capacity

Domain knowledge had a strong facilitative effect on memory performance. That is, independent of working memory capacity and age, baseball knowledge accounted for an impressive 54.9% of the variance in a composite measure of memory performance. Furthermore, the positive effect of baseball knowledge on memory performance was much greater for game-relevant information than for game-irrelevant information. Although we did not set out to explain how domain knowledge facilitates text comprehension and memory, a plausible explanation is based on the concept of a *retrieval structure,* which may be defined as a stable and organized set of retrieval cues that enables long-term memory encoding and retrieval of domain-relevant information (Chase & Ericsson, 1981; Ericsson & Kintsch, 1995). For example, as Spilich et al. (1979) suggested, generic knowledge about how baseball is played may serve as a retrieval structure for encoding and retrieving important changes in a baseball game, such as the number of outs, the number of balls and strikes for a batter, which bases are occupied, and so forth. One possible explanation for why there was a positive effect of baseball knowledge even on memory for game-irrelevant information is that high-knowledge participants were able to associate game-irrelevant information with game-relevant information. Alternatively, the relevance of information from the fictitious baseball games was classified *a priori,* and thus it is possible that high-knowledge participants considered some of the information that we classified as game-irrelevant to be game-relevant.

The preceding results add to a large body of evidence demonstrating that domain knowledge facilitates cognitive performance in general and text comprehension and memory in particular (e.g., Recht & Leslie, 1988; Spilich et al., 1979; Walker, 1987). A more important discovery, however, was that there was an effect of working memory capacity on memory performance. That is, while both hierarchical regression analysis and structural equation modeling revealed that baseball knowledge was clearly the major contributor to memory performance, there was a significant effect of working memory capacity, as well. Furthermore, inconsistent with the possibility of compensation, there was no evidence to suggest that high levels of domain knowledge attenuated, much less eliminated, the effect of working memory capacity on memory performance. To the contrary, for game-relevant information, there was evidence for an overadditive interaction between baseball knowledge and working memory capacity such that participants high in working memory capacity derived a greater benefit from baseball knowledge than participants low in working memory capacity. This finding supports what we have termed the rich-get-richer hypothesis involving domain knowledge and working memory capacity.

Very briefly, one possible explanation for this multiplicative effect of domain knowledge and working memory capacity stems from the idea that integrating new information into preexisting knowledge structures depends on the ability to maintain that information in an activated state for some period of time. More precisely, it could be that domain-specific retrieval structures can be used to encode new pieces of information (e.g., facts about a baseball player) into long-term memory but only if those pieces of information are simultaneously active. To illustrate this proposed explanation, consider the following excerpt from Passage C: ''Now Tom Wilcox steps up to bat. This veteran lead-off hitter has a .275 batting average, and once again he leads the league in stolen bases.'' If the fact that Tom Wilcox is the lead-off hitter were quickly lost, then it would not be possible to integrate this information with the fact that Wilcox has a batting average of .275 and leads the league in stolen bases. Furthermore, if it can be assumed that working memory capacity reflects the ability to maintain information in an activated state during ongoing processing, then coactivation of to-be-integrated information should be more likely in people with high working memory capacity than in people with low working memory capacity. High levels of working memory capacity should thereby amplify the effect of domain knowledge on cognitive performance.

We hasten to add that the present results do not distinguish between alternative accounts of why measures of working memory capacity predict cognitive performance. We have proposed that measures of working memory capacity predict cognitive performance because they tap a general information processing capability, perhaps corresponding to the ability to maintain information in an activated state through the application of controlled attention (e.g., Engle, Kane, & Tuholski, 1999). Alternatively, others have argued that performance in working memory tasks is influenced by acquired skills and knowledge (e.g., Fincher-Kiefer et al., 1988; McNamara & Scott, 2001)—and even that these factors account for the predictive power of measures of working memory capacity (e.g., Ericsson & Kintsch, 1995; Kintsch, 1998). Nonetheless, we believe that the present study represents a first step toward characterizing the interplay between domain knowledge and working memory capacity in cognitive performance. More specifically, this research has identified a potentially interesting phenomenon: While domain knowledge facilitates cognitive performance, working memory capacity may enhance this effect. This research may therefore prompt reconsideration of the view that possible hardware aspects of cognition (e.g., working memory capacity) play an unimportant role in domain-relevant cognitive tasks (e.g., Feigenbaum, 1988).

Domain Knowledge and Age

An additional goal of this study was to evaluate the joint effects of domain knowledge and adult age on cognitive performance. To reiterate, there was no evidence to suggest that domain knowledge attenuated age-related differences in memory performance. Therefore, the results of this study are not consistent with the compensation hypothesis as it applies to the relationship between age and cognitive performance. Instead, the results suggest that there may be conditions under which young adults outperform older adults in cognitive tasks even at high levels of domain knowledge. This discovery agrees with the results of recent research. For example, Morrow et al. (2001) found no evidence to suggest that aviation-related experience (which correlated positively with aviation knowledge) attenuated the negative effect of age on memory for air-traffic control messages. Similarly, Meinz and Salthouse (1998) and Meinz (2000) found no evidence for age × experience interactions on recall of visually presented melodies. Nevertheless, there may be some evidence for compensation in other types of cognitive task. For example, Salthouse (1984) and Bosman (1993) suggested that older typists may be able to compensate for age-related slowing in motor processes by looking ahead in the to-be-typed text. As another example, in a study of chess, Charness (1981) found no evidence for age-related differences in overall skill level, despite age-related decreases in domain-relevant memory (e.g., memory for chess positions). Thus, at the present time, evidence for compensation in the context of aging is mixed.

One other result concerning age warrants discussion. Structural equation modeling revealed that there was a negative effect of age on memory performance independent of working memory capacity and processing speed. What might explain this effect? One possibility is that the young adults in this study were more motivated to perform the memory task than the older adults. Another possibility is that young adults and older adults used different strategies in the criterion task. For example, older adults may have focused on remembering game-relevant information at the expense of game-irrelevant information, whereas young adults may have placed equal emphasis on the two types of information. That age correlated more negatively with game-irrelevant memory ($r = -.38$) than with game-relevant memory ($r = -.18$) lends some credence to this speculation [$t(178) = 3.57$, $p < .01$, for the difference in dependent correlations]. However, this difference should be interpreted cautiously because the interaction between age and type of information was nonsignificant. A final possibility is that older adults had difficulty hearing the fictitious baseball broadcasts against background noise (e.g., sound of crowd cheering). This possibility is suggested by the finding that background noise may sometimes exacerbate the effect of age on memory for auditory stimuli (e.g., Speranza, Daneman, & Schneider, 2000). Whatever the explanation, the finding of a direct effect of age on memory performance suggests that processing speed and working memory capacity may not completely account for age-related differences in some types of cognitive performance.

Summary and Conclusions

The results of this study provide additional support for the view that domain knowledge is a powerful predictor of individual differences in cognitive performance. Indeed, although working memory capacity had a positive effect on performance in the task used in this study, domain knowledge had a much stronger effect. This finding accords with the hypothesis that domain knowledge is an important component of the working memory system in the context of performing domain-relevant cognitive tasks (e.g., Ericsson & Kintsch, 1995). Furthermore, the results of this study are informative about the interplay between domain knowledge and working memory capacity. Inconsistent with the possibility of compensation, there was no evidence to suggest that domain knowledge attenuated the effect of working memory capacity on performance. Instead, participants with high levels of working memory capacity appeared to derive a greater benefit from domain knowledge than did participants with lower levels of working memory capacity. There was also no evidence to suggest that domain knowledge attenuated the effect of age on performance. Thus, it appears that there may be conditions under which age has a negative effect on cognitive performance even at high levels of domain knowledge.

APPENDIX: BASEBALL PASSAGES

Passage A

Good evening baseball fans. You're tuned into WBLG, the baseball radio network. Well, the temperature here at Senators stadium is *a cool 60* degrees, and it's a perfect *September* night for baseball. We've reached the bottom half of the *eighth* inning, and the Senators and Redbirds are tied up at *three* runs apiece. The *Senators* are up to bat, and keep in mind that the winner of the game tonight will move into first place in the *Western* Division. Punch Grubb is pitching for the Redbirds and came into the game with a *2.45* earned run average and 19 wins on the year.

Now Juan Sanchez steps up to bat. This speedy lead-off man has a .240

batting average and leads the team in *stolen bases.* While he steps away to check the grip on his bat, here's some news from around the league: the Cougars are leading the Robins by two in the bottom of the sixth. Now Grubb takes the sign. Here's the pitch, and a swing of the bat sends a *line drive* into *centerfield.* The leadoff man will hold up at first base with a single, and now we can see that Dave Madden is warming up in the bullpen for the Redbirds. This kid from *the Bronx* has been unbelievable this year with *38 saves* and a 1.95 earned run average.

Chip Craik is the next batter of the inning. This veteran is a scrappy clutch hitter with a *.285* batting average, and he leads the team in walks. Now Grubb takes the sign and is getting ready to deliver—and around the infield, the third baseman *creeps in toward home plate,* and the shortstop shifts over to cover second base. Here comes the pitch, and there goes *a bunt down the first baseline.* Grubb charges in and fields the ball, and his only option is to put the batter out at first base. Well, the 700 little leaguers in the crowd tonight *just saw a textbook bunt,* and the runner advances to the next base with no problem. Some people say that *bunting* is a lost art, but that was a good one. He just *squared around and steered the ball right down the baseline.*

We're back to the action as Larry Jacoby comes to bat. He has a .300 batting average, with a *100* RBIs on the year. Not bad *for a rookie.* The shortstop moves into position for a pickoff, and the outfielders swing around to the left. Here comes the pitch, and a *hard groundball* is hit to the *left side of the infield.* The *shortstop* dives and stops this one from going into the outfield, and great defense like this is one reason why the Redbirds have played so well in the second half of the season. The batter reaches first base, but the runner can't advance. In fact, the Redbirds have won *14* out of their last *20* games. On the other hand, the Senators came into the game tonight with five straight losses.

The big Kurt Snow is the next batter of the inning. He is a power hitter with *a whopping 52 home runs* on the year and a *.330* batting average. The catcher *steps out to the mound for a strategy conference with Grubb,* and one thing that Grubb has to be careful about is to not *let his pitches drop low and inside.* Grubb is ready again, and here comes the pitch. A *long fly ball* is hit to *deep centerfield,* and there was the pitch he didn't want to throw. The centerfielder makes a nice catch all the way back at the warning track for the out, but the runners each advance to the next base. Here comes manager Jackie Williams, and he *does not look happy.* Sure enough, he's *decided to bring in his young relief pitcher.* While Madden takes his warm-up pitches, we'll break for a word from our sponsor.

Passage B

Good afternoon baseball fans. You're tuned into WBLG, the big-league radio network. If you just joined us, it's the bottom of the *7th* inning, and the

Hurricanes are trailing the *Bluebirds* 2–1. Thunderstorms are in the forecast, which is what you'd expect for the month of *July* around here: it's hot all day and then *thunderheads build up later in the afternoon.* The *Hurricanes* are up to bat, and Skip Lawson is pitching for the Bluebirds this afternoon. He gave up a *home run* in the fourth inning but has been unstoppable ever since with 7 strikeouts.

Now Ray Nickerson steps up to bat. He's a left-hander pull hitter with a *.325* batting average and *15 home runs* on the year. The rightfielder moves back towards the warning track, and the shortstop swings around to the right. One of the keys to the Bluebirds' success in the first half of the season is *solid play in the outfield.* The Bluebirds' *outfielders* have only four errors on the year—and that's put together. Lawson is ready now. Here comes a fastball, and a swing of the bat sends a *looper* into *shallow leftfield.* The batter will hold up on first base with a single, and that was only the *third* hit that Lawson has allowed all afternoon. This 35-year-old left-hander made *a trip back to the minor leagues two years ago,* but has come back strong with a respectable 3.00 earned run average.

Gabriel Garcia, the number seven hitter in the lineup, is next to bat. He was out earlier this year *with a pulled hamstring,* but has played solid baseball since with a .295 batting average. If you just tuned in, keep in mind that the winner here moves into first place in the Eastern Division behind the Bombers. Now Lawson delivers—and there goes the runner, and a *groundball* is hit into *rightfield.* That was perfect execution. The batter holds up at first base with a single, and here comes the throw to third base. The runner slides in headfirst—and he's safe. Well here's an impressive fact: if the offensive team Hurricanes make the playoffs this year, they'll *hold the record for the most consecutive years in the playoffs.*

Sam Philipe is the next batter of the inning. This kid has struggled all season long with a .200 batting average and no hits for his last *15* times at bat. Now he glances over at Buddy Brockman, the third base coach. Brockman had some health problems back in '95, but he says *he's never felt better.* Here's the pitch from Lawson, and a *weak pop-up* is hit over to *shallow rightfield.* The *first baseman* backs up and makes the catch for the out, and the runners cannot advance. Well, this just in: the official attendance for today's game is just under 30,000, and 5,000 of the fans today are *summer school kids from around the metro.*

Now Gerald Washington steps up to bat. Today he's pinch hitting for the pitcher, and this guy has come through in the clutch several times with *two pinch-hit home runs* and a .270 batting average. As the catcher steps out to the mound for a chat with Lawson, here are some more scores: the Bulls trail the Knights 2–3 in the fourth inning, and the *Wranglers* pummeled the Generals *5–1.* It looks like Lawson is ready again. Now the pitch, and a *long fly ball* is hit to *deep centerfield.* Well that was a mistake by Lawson. The high fastball was his best bet, but he let the pitch *drop low and inside.*

The centerfielder makes a nice catch for the out all the way back at the warning track, and here comes the rain. One runner scores and the other advances to the next base. Umbrellas are going up but it looks like *quite a few of the fans might get rained on.* The umpires are signaling that the game is being suspended, and we'll break for station identification.

Passage C

Hello again baseball fans. You're tuned into WBLG, the big-league radio network, and it's the bottom-half of the *1st* inning. The *Generals* are up to bat, and if you just joined us, the *Clippers* jumped out to a *2-to-nothing* lead in the top-half of the 1st inning. Remember that the winner of this game will take sole possession of *second* place in the *Northern* Division. Martin Sliwinski is pitching for the Clippers this afternoon, and he comes into today's game with two wins and two losses on the season and a *4.50* earned run average.

Now Tom Wilcox steps up to bat. This *veteran* lead-off hitter has a .275 batting average, and once again he leads the league in *stolen bases.* Here comes the pitch from Sliwinski, and a *blooper* is hit into *leftfield.* Well Sliwinski threw a perfect pitch—a *fastball high and inside*—but sometimes the best pitch in the world isn't enough against a good batter. The ball is returned into the infield, and the batter stops at first base with a single. The fans are still *pouring into this stadium,* and it looks like we have an exciting game in store. Although it's still early in the season, both of these teams would like to *get into position to make the playoffs.*

Tony Zonderman is the next batter of the inning. He has a *.225* batting average, and comes into the game with no hits for his last 15 times at bat. You can bet that he would like to break out of this slump today. Now Sliwinski is ready, and he glances over at the runner. Here comes the pitch, and a swing of the bat sends a *line-drive* to *the gap in left-centerfield.* The leftfielder charges over to field the ball, and here comes the throw from the outfield. The runner slides in under the tag at home plate, and he scores. That throw was *just a fraction too late,* and the batter holds up at second base with a double. Now the 18,000 fans are on their feet, and what a beautiful day in the month of *May* for baseball. There's not a cloud in the sky, and the temperature is hovering around *75* degrees.

Now the young Keith Stanovich steps to bat. This kid from *Oklahoma* has demonstrated good power this year with a batting average of *.305* and already 10 home runs. Sliwinski is ready again. Here's the pitch, and a *hard groundball* is hit to the *left side of the infield.* The *shortstop* fields the ball and makes the throw over to first base to put the batter out, and the runner does not advance. While we have a second, here's some news from around the league: the Bearcats are leading the Blizzards *2–nothing* in the bottom of the *second* inning, and the Dukes are trailing the Seminoles 4–1 early in the third.

Back to the action as Angel Cabrera steps up to bat. This big right-hander has been unstoppable this year. He has a *.350* batting average and leads the team in *RBIs*. The catcher steps out to the pitcher's mound for a chat with Sliwinski, and what he's telling Sliwinski is to *keep his pitches away from the outside part of the plate*. The outfielders shift back and around to the left, and the shortstop *moves into position for a pick-off*. Now Sliwinski is ready. Here comes the pitch, and there goes a hit over the *shortstop's head* and into *centerfield*. Well that was obviously not what Sliwinski wanted to do. The runner gets the signal to try for the score. Here comes the throw to home plate from the outfield, and he's safe. The batter holds up at second base with a standup double, and now the *pitching coach is heading out to the mound for a chat with Sliwinski*. We'll take a short pause for station identification here on WBLG, the big-league radio network.

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