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Aging and Integrating Spatial Mental Models

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Previous research examining the process of integrating spatial information has suggested that older adults retain an ability to use mental models despite declines in working memory capacity. In the current study of both older and young adults, the authors assessed whether mental model performance declines when working memory limitations affect the ability to retain the information needed to initially construct a model. Participants were presented with 3 spatial descriptions that could have been integrated to form a single mental model (e.g., K. Ehrlich & P. N. Johnson-Laird, 1982). Descriptions were continuous (i.e., AB–BC–CD) or discontinuous (i.e., AB–CD–BC) in various stimulus formats: sentences, word diagrams, and pictures. Across the experiments, older adults showed difficulty integrating information, especially in the discontinuous condition, unless pictures were used. The results suggest that older adults' use of mental models can be compromised when spatial information is presented verbally rather than visually.

Keywords: mental model, spatial, working memory, integration, picture

The ability to understand the structure of a situation can be an important process in daily life, whether it occurs while one is interacting with an environment or reading a text. The construction of spatial mental representations requires effort and can take the form of a mental model (e.g., Zwaan & Radvansky, 1998). A mental model is a representation of a described situation reflecting the current state of affairs (Johnson-Laird, 1983; van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). These representations are important because people can use them to draw inferences about the interrelations of separate pieces of information. Previous studies have shown that young adults can construct and use mental models from spatial descriptions by integrating separate pieces of information about a given state of affairs (Byrne & Johnson-Laird, 1989; Ehrlich & Johnson-Laird, 1982; Radvansky & Zacks, 1991). The aim of the current study was to assess the degree to which this ability is affected by aging.

Mental Models and Aging

Compared with young adults, older adults place a greater emphasis on mental model representations rather than on surface-form or text-base representations (Radvansky, 1999; Radvansky, Zwaan, Curiel, & Copeland, 2001). For example, in narrative comprehension, older adults show clear deficits in their memory for the text itself, but they have been shown to be proficient at constructing integrated representations when reading a text (e.g., Radvansky, Copeland, & Zwaan, 2003). Recent research has shown that older adults, while reading, construct mental model representations using perceptual symbols (Dijkstra, Yaxley, Madden, & Zwaan, 2004). The observed effects of mental model use were equal to, if not stronger than, those for young adults. This unexpectedly superior performance of older adults at the mental-model level may reflect preserved rudimentary perceptual processing routines.

A number of studies have examined whether aging has any effect on spatial mental models. These studies have focused on topics such as the organization of concepts in memory based on spatial locations (Radvansky, Zacks, & Hasher, 1996), the ability to make categorical inferences (Gilinsky & Judd, 1994), memory for spatial relations in text (Radvansky, Copeland, & Zwaan, 2003), effects of spatial distance (Morrow, Leirer, Altieri, & Fitzsimmons, 1994; Morrow, Stine-Morrow, Leirer, Andrassy, & Kahn, 1997), and the ability to update a situation model after a spatial shift (Radvansky, Copeland, Berish, & Dijkstra, 2003). The results of these studies reflect a common finding. Specifically, older adults typically show a preserved ability to use spatial mental models in the face of other cognitive declines (e.g., Radvansky et al., 2001).

Of particular concern for the current study is the ability of older adults to integrate separate pieces of information into a single mental model and then use that model effectively later. It has been shown that given enough time and exposure, older adults can effectively integrate information into mental models on the basis of spatial locations (Radvansky et al., 1996, 2005). This was shown using a fan effect task in which people were presented with sets of facts that could be organized by locations. Older adults showed patterns of performance similar to those of young adults in the sense that little-to-no effect of interference was observed for information that could be integrated around a common location, although clear interference effects were observed when multiple locations, and hence multiple mental models, were involved.

Some studies in the area of logical reasoning have focused on the ability to use mental models to integrate from separate facts

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(Fisk & Sharp, 2002; Gilinsky & Judd, 1994). These studies examined whether older adults have more difficulty integrating information than young adults. In these studies, people were given two-premise categorical syllogisms that required the construction of either one or three mental models. Performance for one-model syllogisms was high for both young and older adults, with young adults performing slightly better. Thus, older adults showed an ability to integrate information into a single model. For the three-model syllogisms, however, Gilinsky and Judd (1994) observed a larger decline in performance for the older adults relative to the young adults. Fisk and Sharp (2002) did not observe as steep a decline in performance for the older adults compared with the young adults, but it should be noted that the young adults in their study performed worse overall than those in other studies of categorical syllogisms (Copeland & Radvansky, 2004; Gilinsky & Judd, 1994).

Taken together, these studies are important because they show that older adults are able to construct and use mental models, but they may have difficulties when multiple mental models need to be coordinated. The aim of the current study was to address the ability to integrate information into a mental model and use that information when needed. To do this, people were presented with information about a spatial layout. This differs from the previous fan effect studies in that information was presented once rather than repeatedly until it was memorized. Second, the decisions made by people, in contrast to the categorical reasoning studies, required using a single integrated model rather than multiple competing models.

This study is of further interest because previous studies of memory processing have not had a prominent working memory load at the text-base level. The studies of aging effects in categorical reasoning (Fisk & Sharp, 2002; Gilinsky & Judd, 1994), although difficult, did not require older adults to maintain information in working memory before integrating it. That is, the premises were presented together and remained visible until a decision was made. For the fan effect studies (Radvansky et al., 1996, 2005), the information to be learned was presented repeatedly. That is, the information was learned over a number of trials and could thus be stored in long-term memory. The current study differed from these in that people needed to retain either surface or propositional text-base information in working memory prior to constructing a working mental model of the described state of affairs.

The involvement of working memory in constructing mental models is important because studies have consistently shown that older adults have relatively smaller working memory capacities. For example, Chen, Hale, and Myerson (2003) observed significant negative effects of aging for a working memory task involving spatial locations. Other studies have shown that older adults have larger deficits for spatial working memory than for verbal working memory (e.g., digit span; Myerson, Emery, White, & Hale, 2003; Verhaeghen et al., 2002). The current study examined the contribution of working memory to older adults' ability to retain and integrate information.

Experiment 1

The purpose of Experiment 1 was to determine whether older adults could accurately integrate spatial information presented in sentences (Ehrlich & Johnson-Laird, 1982). In Experiment 1, people were presented with three sentences, one at a time, that each described the spatial relation of two objects; this presentation was followed by a set of eight displays (i.e., choices). The task was to integrate the information from the sentences into a single spatial arrangement. The sentences could be presented in a continuous or a discontinuous manner. In a continuous description, there is some overlap from sentence to sentence. That is, the second and third sentences each contain an item that was described in the previous sentence. Thus, people can integrate the information as they progress. In a discontinuous description, two new items presented in the second sentence are not mentioned in the first. Thus, people cannot integrate as they progress and must instead retain the information from the first two sentences until they read the third sentence, when they can finally integrate the information.

Past research (e.g., Ehrlich & Johnson-Laird, 1982; Radvansky & Copeland, 2004a) with young adults has been consistent with this distinction between the continuous and discontinuous items. Young adults are typically more accurate for continuous than for discontinuous descriptions. In addition, young adults show a slowdown in reading times, particularly for the third sentence, in the discontinuous condition. This increase in reading time for the third sentence occurs at the point when the reader finally has an opportunity to integrate the information.

In the current study, we expected, on the basis of previous work (e.g., Gilinsky & Judd, 1994; Radvansky, Copeland, & Zwaan, 2003), that older adults would have lower overall scores. However, we believed it was possible that they would still show the same pattern of performance as the young adults. Specifically, we hypothesized that both young and older adults would be faster and more accurate for continuous descriptions, consistent with the idea that both groups are constructing mental models with similar facility.

An alternative idea is that older adults would have difficulty with this task, especially for the discontinuous descriptions. For these descriptions, people must retain a propositional text-based memory of the sentence before an integrated mental model can be constructed. Older adults are known to have difficulty with memory for information of this type (e.g., Radvansky et al., 2001). Because of this difficulty and limitations on working memory, there could be a spillover into the mental model level. Specifically, problems maintaining verbatim or propositional representations in working memory could lead older adults to have inaccurate or missing information when they review all three pieces of information to construct a mental model. Therefore, performance for the older adults would worsen disproportionately in the discontinuous condition. Previous work has shown that working memory is more related to processing at the text-base than at the model level (Radvansky & Copeland, 2004b). Thus, it would not be surprising for older adults, who typically have smaller working memory capacities, to have more difficulty retaining the propositional representations before being able to integrate.

This idea is consistent with the results of a developmental study involving a similar spatial relation task (Morra, 1989). In that study, children did not show signs of integrating information or constructing mental models. Instead, because of their poorer verbal working memory capacities relative to adults, they had difficulty with simply retaining a propositional text-base representation. Likewise, because older adults have relatively poor verbal working

memory capacities, they may also have difficulty retaining these representations and thus would have trouble constructing accurate mental models.

Other studies examining nonspatial reasoning have also shown aging effects related to working memory capacity. For example, Salthouse (1992) provided young and older adults with sets of statements that could be integrated. Working memory was shown to be a key contributor to aging effects when people had to keep track of rule statements (e.g., "R and S do the opposite. Q and R do the same. If Q increases, what happens to S?"). Also, a study by Sedek and von Hecker (2004) showed that working memory deficits are related to aging decrements in a linear-ordering reasoning task (e.g., "Bob is taller than Steve. Steve is taller than Tom. John is taller than Bob. Is John taller than Tom?").

Method

Participants. We recruited 36 young adults from the University of Notre Dame who ranged in age from 18 to 22 years (M = 20.2, SD = 1.1). Then 36 older adults were recruited from the South Bend community; their ages ranged from 62 to 87 years (M = 72.9, SD = 6.2). Young (Y) and older (O) adults were similar in terms of education (M_Y = 13.8, SD_Y = 1.1; M_O = 13.3, SD_O = 1.7), $t(70) = 1.59$, $p = .116$, and had similar scores on the Shipley Vocabulary Test (Zachary, 1986; M_Y = 31.1, SD_Y = 3.7; M_O = 31.5, SD_O = 4.1), $t < 1.00$. The young adults (M = 20.7, SD = 5.4) scored higher than the older adults (M = 12.3, SD = 4.1) on a measure of processing speed (pattern comparison; Salthouse & Babcock, 1991), $t(70) = 7.49$, $p < .001$. On the operation span test (Turner & Engle, 1989), the young adults (M = 18.9, SD = 10.9) had larger working memory spans than the older adults (M = 8.4, SD = 5.4), $t(70) = 5.19$, $p < .001$. The data from an additional two older adults were replaced because of excessively low performance on the vocabulary test.

Materials. The materials for the integration task were based on a study by Ehrlich and Johnson-Laird (1982) and consisted of two parts: (a) a three-sentence description of a four-object spatial layout (relation of two objects was described in each sentence) and (b) eight different spatial layouts for the set of four objects. There were a total of 16 trials, 8 in each of two conditions. The first was the continuous condition, in which the second and third sentences referred to an object that was mentioned in the previous sentence as well as a new object, as in the example below.

1. The rose is above the lily.
2. The lily is to the left of the orchid.
3. The tulip is below the orchid.

In the discontinuous condition, the second sentence did not refer to either object from the first sentence. The third sentence related an object from the first sentence to an object from the second sentence.

4. The rose is above the lily.
5. The tulip is below the orchid.
6. The lily is to the left of the orchid.

We created eight spatial layouts by manipulating the arrangement of the four objects so that only one was consistent with the description. In addition to the spatial layouts, a legend was presented indicating which direction was above, below, left, and right. An example of a set of spatial layouts is shown in Figure 1.

Procedure. The sentences were presented one at a time, and participants could advance to the next sentence by pressing the space bar. After the third sentence, eight spatial layouts were displayed on the screen. Choices were made by pressing the number corresponding to the appropriate layout. No feedback was provided. Participants were instructed to take as much time as necessary to read the descriptions and to select the layout that was consistent with the description that preceded it. There was no time limit for reading or selecting a spatial layout. Before beginning,

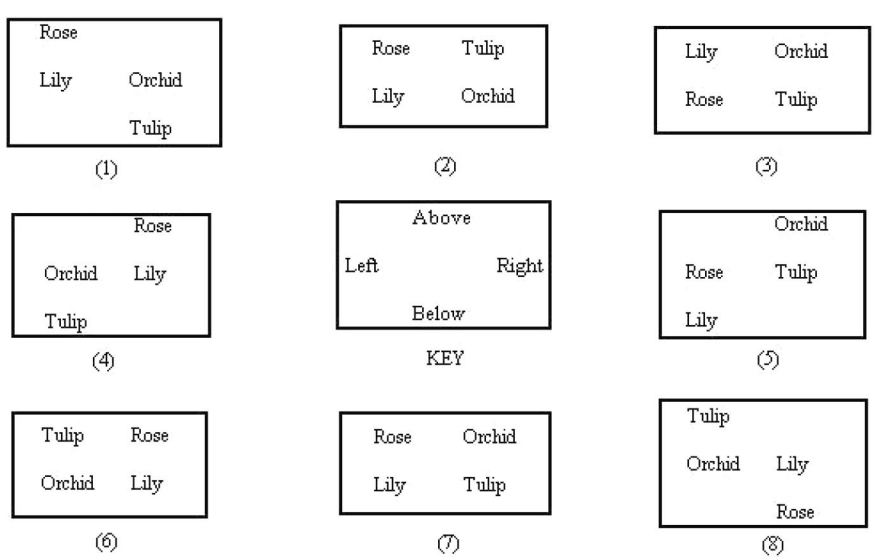

Figure 1. Example of eight-choice display for Experiments 1, 2, and 3.

participants were shown two example trials (one in each condition) by the experimenter and were allowed to ask any questions about the task; there were no practice trials.

Results and Discussion

In this section, we first examine the reading times of the participants for the learning phase of the experiment and then compare accuracy and response times for the identification task. For the young adults, the general pattern of results replicated previous work. However, for the older adults, there were important differences in their performance relative to the young adults.

Learning (reading times). The reading times are listed in Table 1; reliability estimates were computed for the continuous and discontinuous conditions for Sentence 1 (Cronbach's $\alpha_{Continuous}$ = .85, $\alpha_{Discontinuous}$ = .81), Sentence 2 ($\alpha_{Continuous}$ = .88, $\alpha_{Discontinuous}$ = .75), and Sentence 3 ($\alpha_{Continuous}$ = .82, $\alpha_{Discontinuous}$ = .76). A 2 (young vs. old) × 2 (continuous vs. discontinuous) × 3 (Sentence 1 vs. Sentence 2 vs. Sentence 3) mixed analysis of variance (ANOVA) was conducted, for which the first factor, Age, was between subjects, and the other factors, Condition and Sentence, were within subjects. Overall, reading times were faster for the continuous than for the discontinuous condition, $F(1, 70) = 31.64$, $MSE = 2.35$, $p < .001$. The main effect of Sentence was also significant, $F(1, 70) = 16.51$, $MSE = 6.72$, $p < .001$. Although the main effect of Age was not significant, $F(1, 70) = 1.29$, $MSE = 34.31$, $p = .26$; the Age × Condition, $F(1, 70) = 36.17$, $MSE = 2.35$, $p < .001$; Age × Sentence; $F(1, 70) = 33.78$, $MSE = 6.72$, $p < .001$; and Condition × Sentence interactions were significant, $F(1, 70) = 40.65$, $MSE = 1.70$, $p < .001$. Most important, the Age × Condition × Sentence interaction was significant, $F(1, 70) = 22.78$, $MSE = 1.70$, $p < .001$. We explored this interaction further by breaking down performance for each condition.

For the continuous condition, the older adults spent more time reading than the young adults, $F(1, 70) = 7.27$, $MSE = 17.31$, $p < .01$. Also, the effect of Sentence was significant, $F(1, 70) = 57.85$, $MSE = 3.07$, $p < .001$. There was no difference between Sentence 1 and Sentence 2, $F < 1$, but Sentence 3 was read more quickly than both Sentences 1 and 2, $F(1, 71) = 49.63$, $MSE = 3.57$, $p < .001$, and $F(1, 71) = 47.50$, $MSE = 3.43$, $p < .001$, respectively. Finally, the interaction for Age and Sentence was significant, $F(1, 70) = 12.76$, $MSE = 3.07$, $p < .01$. Both groups showed the same general pattern in that the young and older adults showed no differences in reading time between Sentences 1 and 2, both Fs < 1, but both age groups read Sentence 3 more quickly than Sentence 1, $F(1, 35) = 28.74$, $MSE = 0.87$, $p < .001$, and $F(1, 35) = 36.39$, $MSE = 5.26$, $p < .001$, for the young and older adults, respectively, and Sentence 2, $F(1, 35) = 55.51$, $MSE = 0.59$, $p < .001$, and $F(1, 35) = 26.42$, $MSE = 5.74$, $p < .001$, for the young and older adults, respectively. Even though they showed similar patterns, the young adults read faster than the older adults for both Sentence 1, $F(1, 70) = 12.21$, $MSE = 8.48$, $p < .01$, and Sentence 2, $F(1, 70) = 6.05$, $MSE = 10.37$, $p < .05$, respectively, but they did not differ for Sentence 3, $F < 1$.

In the discontinuous condition, there were no main effects for Age and Sentence, both Fs < 1, but the interaction was significant, $F(1, 70) = 42.35$, $MSE = 5.35$, $p < .001$. For the young adults, Sentence 1 was read faster than Sentence 2, $F(1, 35) = 12.30$, $MSE = 2.41$, $p < .01$, which was read faster than Sentence 3, $F(1, 35) = 4.94$, $MSE = 3.38$, $p < .05$. However, a different pattern was observed for the older adults: Sentence 3 was read faster than Sentence 2, $F(1, 35) = 13.23$, $MSE = 2.64$, $p < .01$, which was read faster than Sentence 1, $F(1, 35) = 11.70$, $MSE = 2.92$, $p < .01$. Thus, the young adults read Sentence 1 more quickly than the older adults, $F(1, 70) = 11.00$, $MSE = 8.73$, $p < .01$; the two age groups did not differ for Sentence 2, $F < 1$, and the older adults read Sentence 3 more quickly than the young adults, $F(1, 70) = 13.44$, $MSE = 9.81$, $p < .001$.

The reading time pattern for the young adults is consistent with the findings of past research (Ehrlich & Johnson-Laird, 1982; Radvansky & Copeland, 2004a). The increase in reading times for the third sentence in the discontinuous condition suggests that the young adults were integrating information as they read the sentences. However, the older adults showed a radically different pattern. First, particularly for the discontinuous condition, they were spending less time reading the third sentences than the young adults were. Nearly all of the extant research suggests that older adults would spend more time learning and reading than they did. This pattern of data suggests that older adults were not extending effort to process the text in the same fashion as the young adults were.

Identification accuracy. The mean accuracy scores for both groups are presented in Table 2; reliability estimates were computed for the continuous (α = .74) and discontinuous (α = .54)

Table 1
Young and Older Adults' Learning Times (s) for the First, Second, and Third Displays of the Continuous and Discontinuous Conditions in Experiments 1, 2, and 3

	Experiment 1						Experiment 2						Experiment 3					
	Display 1		Display 2		Display 3		Display 1		Display 2		Display 3		Display 1		Display 2		Display 3	
Group/condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young																		
Continuous	6.0	2.0	6.2	2.0	4.8	1.9	4.1	2.7	4.0	1.8	3.8	1.5	4.3	2.4	3.8	2.1	2.8	1.4
Discontinuous	6.2	1.9	7.5	2.7	8.5	3.7	3.6	1.7	4.5	2.7	7.3	4.6	4.0	1.7	4.1	3.0	4.4	3.4
Older																		
Continuous	8.4	3.6	8.1	4.1	5.2	2.1	8.0	4.2	6.5	2.8	5.6	3.0	8.0	3.1	6.7	3.8	4.2	2.0
Discontinuous	8.5	3.7	7.2	3.0	5.8	2.4	7.6	3.4	7.7	4.5	7.3	4.9	7.7	3.1	6.7	3.5	5.7	3.7

Table 2
Young and Older Adults' Accuracy (%) for the Continuous and Discontinuous Conditions in Experiments 1, 2, and 3

	Experiment 1		Experiment 2		Experiment 3	
Group/condition	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young						
Continuous	68	27	82	25	73	30
Discontinuous	47	25	64	32	53	35
Older						
Continuous	24	18	45	24	43	25
Discontinuous	17	13	16	16	34	33

Note. Chance is 12.5%.

conditions. Overall, the young adults were more accurate than the older adults, $F(1, 70)$ 79.39, $MSE = .063$, $p < .001$. People were more accurate for the continuous than for the discontinuous condition, $F(1, 70) = 26.28$, $MSE = .028$, $p < .001$, and the interaction between Age and Condition was also significant, $F(1, 70) = 7.58$, $MSE = .028$, $p < .01$. The interaction reflects a large difference between the conditions for the young adults, $F(1, 35) = 24.37$, $MSE = .035$, $p < .001$, but only a marginally significant difference for the older adults, $F(1, 35) = 3.88$, $MSE = .020$, $p = .06$.

The expected pattern was observed for the young adults, but the outcome for the older adults was surprising. We expected that both young and older adults would perform better for the continuous than for the discontinuous condition, consistent with past research (Ehrlich & Johnson-Laird, 1982; Radvansky & Copeland, 2004a). However, the older adults performed very poorly overall on the spatial integration task. Although their accuracy was better than chance (chance = 12.5%), $t(35) = 3.77$, $p < .01$, for the continuous condition, and $t(35) = 2.19$, $p < .05$, for the discontinuous condition, their performance was still extremely poor and very close to chance in the discontinuous condition.

To examine whether time spent learning was related to identification accuracy, we conducted correlations between these two measures. For the continuous condition, the correlation was weak and not significant ($r = .10$, $p = .80$). However, for the discontinuous condition, the correlation was stronger and significant ($r = .44$, $p < .001$). That is, taking more time to integrate the information for the final sentence in the discontinuous condition was positively related to accuracy in the identification task.

The influence of working memory span ($\alpha = .73$) on accuracy was also considered. We conducted a regression analysis using age and working memory span as predictors for separate analyses of accuracy in the continuous and discontinuous conditions. For the continuous condition, age was a significant predictor ($b = -.70$, $p < .001$) but working memory span was not ($b = .02$, $p = .85$). However, this may have been driven more by the performance of the young than that of the older adults. There was no relation between span and accuracy for the young adults ($r = -.07$, $p = .68$), but there was for the older adults ($r = .34$, $p < .05$). For the discontinuous condition, both age ($b = -.42$, $p < .001$) and working memory span ($b = .33$, $p < .01$) were significant predictors. This suggests that working memory span is an important factor for the older adults' accuracy performance.

To further examine this issue, we conducted regression analyses to determine how much working memory accounted for the age-related variance. For the continuous condition, age alone accounted for 50% of the variance ($r = .71$, $p < .001$), and after we controlled for working memory, age accounted for 41% of the variance ($r = .64$, $p < .001$). Thus, working memory accounted for 18% of the age-related variance. For the discontinuous condition, age alone accounted for 36% of the variance ($r = .60$, $p < .001$). When we controlled for working memory, the percentage was 18% ($r = .43$, $p < .001$). Thus, in the discontinuous condition, working memory accounted for 49% of the age-related variance. This shows that working memory capacity contributes to performance, especially in the discontinuous condition.

Identification response times. The response time data is listed in Table 3; reliability scores were computed for the continuous ($\alpha = .76$) and discontinuous ($\alpha = .74$) conditions. Overall, people were faster to respond for the continuous than for the discontinuous condition, $F(1, 70) = 15.47$, $MSE = 30$, $p < .001$, and the young adults were faster than the older adults, $F(1, 70) = 75.85$, $MSE = 102$, $p < .001$. The interaction was not significant, $F < 1$. These results are consistent with patterns observed with young adults in other studies (Ehrlich & Johnson-Laird, 1982; Radvansky & Copeland, 2004a).

Overall, in Experiment 1, the older adults did not perform very well. This was most evident in the accuracy and the learning data. Perhaps in Experiment 1, it was too difficult for the older adults to maintain the information from the sentences because there was too much information to retain in working memory. In the continuous condition, older adults with larger working memory spans were better able to retain the information and integrate it. However, for the more taxing discontinuous condition, older adults, regardless of memory span, had too much difficulty retaining the information and may have given up by the time they reached Sentence 3. Our goal in Experiment 2 was to investigate whether reducing the amount of information would lessen the working memory load. We accomplished this goal by using word pairs rather than sentences.

Experiment 2

In Experiment 2, we used diagrams of words instead of sentences for the learning portion of the task. This reduced the amount of text presented on the screen and introduced explicitly spatial information. The benefit of using diagrams, rather than sentences, has been shown by Boudreau and Pigeau (2001). In their study,

Table 3
Young and Older Adults' Response Times (s) for the Continuous and Discontinuous Conditions in Experiments 1, 2, and 3

	Experiment 1		Experiment 2		Experiment 3	
Group/condition	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young						
Continuous	9.4	4.3	9.3	7.1	10.9	6.1
Discontinuous	13.1	6.3	12.7	7.4	15.1	10.2
Older						
Continuous	24.2	9.9	28.0	14.6	26.9	15.2
Discontinuous	27.6	10.4	28.4	13.9	28.2	10.0

participants completed an inference generation task in which they had to validate statements that could be inferred from premises. In that study, people were faster to inspect premises and respond when using diagrams rather than sentences. Thus, the use of diagrams should make the task easier for both the young and older adults by decreasing the working memory load. Therefore, the deficits seen in older adults' text-base processing should be less evident, particularly in the discontinuous condition.

The diagrams used in Experiment 2 consisted of two words spatially arranged, as described in the sentences used in Experiment 1. For example, instead of the sentence, "The rose is above the lily," the following diagram was used:

Rose
Lily

We expected that by using diagrams, the older adults would be better at retaining the information necessary for integration. Moreover, the form of the information in the learning phase of this task more closely resembled the form used in the identification phase. Thus, performance should improve more generally.

Method

Participants. We recruited 36 young adults from the University of Notre Dame who ranged in age from 18 to 26 years (M = 20.4, SD = 1.6). The 36 older adults were recruited from the South Bend community and ranged in age from 61 to 89 years (M = 72.5, SD = 6.7). None of these people participated in Experiment 1. The older adults (M = 16.2 years, SD = 2.4) had more education than the younger adults (M = 13.9 years, SD = 1.2), $t(70) = 5.18$, $p < .001$, and the older adults (M = 34.5, SD = 3.6) scored higher on the Shipley vocabulary test than young adults (M = 31.2, SD = 2.9), $t(70) = 4.27$, $p < .001$. The young adults (M = 21.0, SD = 5.5) scored higher than the older adults (M = 11.3, SD = 3.5) on a measure of processing speed (pattern comparison), $t(70) = 8.91$, $p < .001$. Also, the young adults (M = 20.4, SD = 11.1) had larger working memory spans (operation span) than the older adults (M = 11.3, SD = 5.0), $t(70) = 4.51$, $p < .001$.

Materials and procedure. The materials and procedure were similar to those used in Experiment 1, except that in this experiment, the sentences used in Experiment 1 were replaced with diagrams consisting of pairs of words in different spatial arrangements. For example, instead of a sentence such as "The rose is above the lily," people saw a display consisting of two words:

7. Rose
   Lily

This was followed by two more displays, such as the ones illustrated below:

8. Lily Orchid

9. Orchid
   Tulip

Each two-word display was centered on the screen and was presented until the participant pressed the space bar to move on to the next item. There were eight trials each in the continuous and discontinuous conditions, and the identification section was the same as in Experiment 1. As in Experiment 1, before beginning, participants were shown two example trials (one from each condition) by the experimenter and were allowed to ask any questions about the task.

Results and Discussion

We conducted the same set of analyses in Experiment 2 as we performed in Experiment 1. Overall, similar patterns were observed for the young and older adults. However, the young adults' overall performance was better than it was in Experiment 1, when sentences were used.

Learning. The viewing times are listed in Table 1; reliability estimates were computed for the continuous and discontinuous conditions for Diagram 1 ($\alpha_{Continuous}$ = .89, $\alpha_{Discontinuous}$ = .84), Diagram 2 ($\alpha_{Continuous}$ = .87, $\alpha_{Discontinuous}$ = .93), and Diagram 3 ($\alpha_{Continuous}$ = .86, $\alpha_{Discontinuous}$ = .82). As in Experiment 1, a 2 (young vs. old) × 2 (continuous vs. discontinuous) × 3 (Diagram 1 vs. Diagram 2 vs. Diagram 3) mixed ANOVA was conducted, for which the first factor, Age, was between subjects, and the other factors, Condition and Diagram, were within subjects. The main effect of Condition was significant, $F(1, 70) = 26.35$, MSE = 4.05, $p < .001$, with people spending less time viewing diagrams in the continuous condition. The main effect of Age was also significant, $F(1, 70) = 17.09$, $MSE = 42.12$, $p < .001$, with young adults spending less time viewing diagrams than older adults. There was no main effect of Diagram, $F < 1$. The Age × Condition interaction was not significant, $F < 1$, but the Age × Diagram, $F(1, 70) = 13.35$, $MSE = 12.36$, $p < .001$, and Condition × Diagram interactions, $F(1, 70) = 50.98$, $MSE = 3.25$, $p < .001$, were significant. Of note, the Age × Condition × Diagram interaction was significant, $F(1, 70) = 5.35$, $MSE = 3.25$, $p < .05$. As in Experiment 1, we explored this interaction further by breaking down performance for each condition.

For the continuous condition, the main effect of Age was significant, $F(1, 70) = 24.18$, $MSE = 17.05$, $p < .001$, with the young adults spending less time viewing diagrams. The main effect for Diagram was also significant, $F(1, 70) = 14.39$, $MSE = 4.68$, $p < .001$. Participants spent more time viewing Diagram 1 than Diagram 2, $F(1, 71) = 5.73$, $MSE = 4.45$, $p < .05$, and spent more time viewing Diagram 2 than Diagram 3, $F(1, 71) = 7.30$, MSE = 1.37, $p < .01$. Finally, the Age × Diagram interaction was also significant, $F(1, 70) = 8.04$, $MSE = 4.68$, $p < .01$. For the young adults, viewing time for Diagram 1 did not differ from those for Diagrams 2 and 3, Fs < 1, and the viewing times for Diagrams 2 and 3 also did not differ, $F(1, 35) = 1.23$, $MSE = 0.85$, $p = .28$. The older adults spent more time viewing Diagram 1 than Diagram 2, $F(1, 35) = 7.40$, $MSE = 6.06$, $p < .05$, and more time viewing Diagram 2 than Diagram 3, $F(1, 35) = 6.45$, $MSE = 1.85$, $p < .05$. The young adults had shorter viewing times for all three diagrams: $F(1, 70) = 22.10$, $MSE = 12.62$, $p < .001$, for Diagram 1; $F(1, 70) = 19.86$, $MSE = 5.50$, $p < .001$ for Diagram 2; and $F(1, 70) = 11.14$, $MSE = 5.78$, $p < .01$, for Diagram 3.

For the discontinuous condition, the main effect of Age was significant; the young adults spent less time viewing the diagrams, $F(1, 70) = 10.69$, $MSE = 29.12$, $p < .01$. Also, the main effect of Diagram was significant, $F(1, 70) = 9.13$, $MSE = 10.93$, $p < .01$. Although the viewing times for Diagrams 1 and 2 did not differ, $F(1, 71) = 2.63$, $MSE = 3.40$, $p = .11$, participants spent less time viewing Diagrams 1 and 2 than Diagram 3: $F(1, 71) = 7.79$, $MSE = 12.81$, $p < .01$, for Diagram 1 and $F(1, 71) = 5.83$, MSE =

8.40, $p < .05$, for Diagram 2. The Age × Diagram interaction was also significant, $F(1, 70) = 13.25$, $MSE = 10.93$, $p < .01$. The young adults spent less time viewing Diagram 1 than Diagram 2, $F(1, 35) = 8.75$, $MSE = 1.52$, $p < .01$, and less time viewing Diagram 2 than Diagram 3, $F(1, 35) = 16.88$, $MSE = 8.43$, $p < .001$. For the older adults, there was no difference in viewing time across the diagrams, all Fs < 1. Also, the young adults spent less time viewing Diagrams 1 and 2 than did the older adults, $F(1, 70) = 39.74$, $MSE = 7.17$, $p < .001$, and $F(1, 70) = 13.82$, $MSE = 13.81$, $p < .001$, respectively, but the viewing times for young and older adults did not differ for Diagram 3, $F < 1$.

Similar to Experiment 1, older adults did not spend more time learning Diagram 3 in the discontinuous condition than the young adults did. The pattern of learning times in the discontinuous condition showed that the time spent by young adults steadily increased from Diagram 1 to Diagram 3. What is surprising is that, in contrast, the times for the older adults did not differ across diagrams in the discontinuous condition. Thus, it appears that the young adults were attempting to integrate information after learning all of the spatial relations (i.e., when the third diagram was presented). However, for the older adults, this indicator was not present. They did not appear to be exerting the effort necessary to successfully perform in this condition.

Identification accuracy. The mean accuracy scores for both groups are listed in Table 2; reliability estimates were computed for the continuous ($\alpha = .75$) and discontinuous ($\alpha = .83$) conditions. Overall, people were more accurate for the continuous than the discontinuous condition, $F(1, 70) = 63.69$, $MSE = .031$, $p < .001$. The young adults were more accurate than the older adults, $F(1, 70)$ 68.29, $MSE = .095$, $p < .001$. The interaction was marginally significant, $F(1, 70) = 3.19$, $MSE = .031$, $p = .078$. Both the young and older adults were more accurate in the continuous condition, $F(1, 35) = 26.06$, $MSE = 1$, $p < .001$, and $F(1, 35) = 37.74$, $MSE = 1$, $p < .001$, respectively. Of importance, the older adults' accuracy performance in the discontinuous condition was so poor that it did not significantly differ from chance (12.5%), $t(35) = 1.43$, $p = .16$.

Although performance for the young adults improved overall, there were mixed results for the older adults. The older adults did improve in the continuous condition, relative to Experiment 1, which showed they were able to construct integrated representations of spatial information and then use them to identify a diagram later. However, the older adults' accuracy performance in the discontinuous condition was not significantly different from chance. Thus, when the older adults had to retain multiple pieces of information (i.e., the first two diagrams) in working memory before integrating, they had a great deal of difficulty.

As in Experiment 1, we examined correlations between time spent viewing the final diagram and accuracy performance. As in Experiment 1, this relation was weak and not significant for the continuous condition ($r = .05$, $p = 1$). Also, as in Experiment 1, the relation for the discontinuous condition was positive, but in this experiment, it was only marginally significant ($r = .23$, $p = .10$). Thus, for the discontinuous condition, there is evidence suggesting that longer viewing times for the final diagram are positively related to accuracy performance.

Regression analyses for the identification accuracy in both the continuous and discontinuous conditions were conducted with age and working memory span ($\alpha = .75$) as the predictor variables. For the continuous condition, both age ($b = -.44$, $p < .001$) and working memory span ($b = .37$, $p < .001$) were significant predictors. For the discontinuous condition, again, both age ($b = -.49$, $p < .001$) and working memory span ($b = .40$, $p < .001$) were significant predictors of accuracy. Thus, a smaller working memory capacity seems to contribute to the diminished performance of the older adults beyond the effects of aging.

As in Experiment 1, we conducted regression analyses for both the continuous and discontinuous conditions to determine how much of the age-related variance was accounted for by working memory. For the continuous condition, age alone accounted for 39% of the variance ($r = .62$, $p < .001$) and 23% of the variance ($r = .48$, $p < .001$) when we controlled for working memory. Here, working memory accounted for 41% of the age-related variance. For the discontinuous condition, age alone accounted for 47% of the variance ($r = .69$, $p < .001$) and, when we controlled for working memory, 31% of the variance ($r = .56$, $p < .001$). Thus, working memory accounted for approximately 33% of the age-related variance. The pattern for the discontinuous condition was somewhat similar to the pattern in Experiment 1, but surprisingly, working memory contributed more for the continuous condition.

Identification response times. Reliability scores were computed for the continuous ($\alpha = .90$) and discontinuous ($\alpha = .88$) conditions. Overall, people were faster (see Table 3) to respond for the continuous than the discontinuous condition, $F(1, 70) = 6.94$, $MSE = 19$, $p < .05$. The young adults were faster to respond than the older adults, $F(1, 70) = 44.92$, $MSE = 238$, $p < .001$. The interaction was significant, $F(1, 70) = 4.07$, $MSE = 19$, $p < .05$. Young adults were faster to respond in the continuous than the discontinuous condition, $F(1, 35) = 13.23$, $MSE = 16$, $p < .01$, but there was no such difference for the older adults, $F < 1$. Again, the younger adults' performance replicated previous work. The older adults, however, were not spending additional time for the discontinuous condition, suggesting that they were not increasing their effort to compensate for the difficulty of that material.

In Experiment 2, we used word diagrams, whereas in Experiment 1 we presented the information in sentences. Both of these tasks were based on verbal information. Thus, it appears as though older adults have difficulty processing verbal information for a short period of time. This difficulty then makes it harder for the older adults to construct a mental model representation. In Experiment 3, nonverbal materials were used to explore the spatial integration task.

Experiment 3

The goal of Experiment 3 was to assess whether performance for the older adults would improve with the use of pictures. In Experiment 2, despite our trimming the amount of text, presenting the material in a spatial manner, and increasing the similarity between the materials during learning and identification, performance was still poor for the older adults. Diagrams were used in Experiment 2, but these were diagrams of words. Hence, this may have encouraged older adults to rely more on a verbal encoding. As noted before, the retention of verbal information in working memory has been shown to give older adults difficulty. In comparison, in Experiment 3, we used pictures to reduce the likelihood that participants would code the diagrams verbally. Recent re-

search has shown that the use of perceptual symbols (e.g., visual images) is consistent with mental model representations (Dijkstra et al., 2004; Zwaan, 1999) and that older adults show stronger effects for mental model representations when pictures are used. Thus, one possible outcome would be that older adults might use pictures to construct a spatial mental model more efficiently than when presented with verbal information, as was done in Experiments 1 and 2. When presented with pictures, people no longer have to derive the perceptual symbols; it is provided by the stimuli. Thus, their performance should increase when presented with pictures rather than with verbal information.

A second possibility would be that older adults would continue to perform poorly. A number of studies have suggested that older adults, relative to young adults, show larger working memory deficits for visuospatial data than for verbal information (e.g., Chen, Hale, & Myerson, 2003; Myerson, Emery, White, & Hale, 2003; Verhaeghen et al., 2002). Thus, in Experiment 3, it was possible that older adults would perform poorly in both the continuous and discontinuous conditions.

Method

Participants. We recruited 30 young adults from the University of Southern Mississippi who ranged in age from 18 to 28 years ($M = 20.1$, $SD = 2.1$). The older adults were recruited from the South Bend community and ranged in age from 61 to 89 years ($M = 73.0$, $SD = 7.2$). None of these individuals had participated in Experiments 1 or 2. The older adults ($M = 16.7$ years, $SD = 2.1$) had more education than the young adults ($M = 13.5$ years, $SD = 1.0$), $t(58) = 7.52$, $p < .001$. The older adults ($M = 34.5$, $SD = 3.7$) also scored higher on the Shipley vocabulary test than younger adults ($M = 25.0$, $SD = 3.9$), $t(58) = 9.52$, $p < .001$. The young adults ($M = 17.1$, $SD = 6.3$) scored higher than the older adults ($M = 11.6$, $SD = 3.3$) on a measure of processing speed (pattern comparison), $t(58) = 4.20$, $p < .001$. The young adults ($M = 13.1$, $SD = 5.1$) scored higher on the measure of working memory (operation span) than the older adults ($M = 11.5$, $SD = 4.6$), but the difference was not significant, $t(58) = 1.30$, $p = .20$.

Materials and procedure. There were only two changes from Experiment 2. First, instead of words, colored shapes were used in the displays. These were simple objects, such as a red square, blue triangle, or green star. The same four colors were used for each trial: red, green, blue, and yellow. However, none of the shapes was repeated across trials (e.g., a star was presented in only one trial, but the color green was used for every trial). The second change was that there were eight trials, four in each condition. As in Experiments 1 and 2, participants before beginning the experiment were shown two example trials (one from each condition) by the experimenter and were allowed to ask any questions about the task.

Results and Discussion

Learning. Viewing times are listed in Table 1; reliability estimates were computed for the continuous and discontinuous conditions for Diagram 1 ($\alpha_{\text{Continuous}} = .80$, $\alpha_{\text{Discontinuous}} = .84$), Diagram 2 ($\alpha_{\text{Continuous}} = .90$, $\alpha_{\text{Discontinuous}} = .86$), and Diagram 3 ($\alpha_{\text{Continuous}} = .78$, $\alpha_{\text{Discontinuous}} = .87$). As in Experiments 1 and 2, a 2 (young vs. old) × 2 (continuous vs. discontinuous) × 3 (Diagram 1 vs. Diagram 2 vs. Diagram 3) mixed ANOVA was conducted for which the first factor, Age, was between subjects, and the other factors, Condition and Diagram, were within subjects. The main effect of Age was significant, $F(1, 58) = 17.39$, $MSE = 34.61$, $p < .001$; the young adults spent less time viewing the diagrams than the older adults did. The main effect of Condition was also significant, $F(1, 58) = 8.32$, $MSE = 2.33$, $p < .01$; people spent less time viewing the continuous diagrams. The main effect of Diagram was significant, $F(1, 58) = 44.78$, $MSE = 3.84$, $p < .001$. Whereas the Age × Condition interaction was not significant, $F < 1$, the Age × Diagram, $F(1, 58) = 21.25$, $MSE = 3.84$, $p < .001$, and the Condition × Diagram interactions, $F(1, 58) = 16.24$, $MSE = 3.38$, $p < .001$, were. Of interest, the Age × Condition × Diagram interaction was not significant, $F < 1$. As in Experiments 1 and 2, these comparisons were broken down for further investigation.

For the continuous condition, there was a main effect of Age, $F(1, 58) = 21.23$, $MSE = 14.83$, $p < .001$, in that the young adults spent less time viewing the diagrams. There was also a main effect of Diagram, $F(1, 58) = 88.37$, $MSE = 2.38$, $p < .001$. People spent more time viewing Diagram 1 than Diagram 2, $F(1, 59) = 6.96$, $MSE = 3.54$, $p < .05$, and more time viewing Diagram 2 than Diagram 3, $F(1, 59) = 46.91$, $MSE = 1.94$, $p < .001$. The Age × Diagram interaction was significant, $F(1, 58) = 16.64$, $MSE = 2.38$, $p < .001$. For the young adults, viewing time for Diagram 1 and Diagram 2 did not differ, $F(1, 29) = 1.65$, $MSE = 2.18$, $p < .21$, but they spent more time viewing Diagram 1 than Diagram 3, $F(1, 29) = 16.03$, $MSE = 2.10$, $p < .001$, as well as more time viewing Diagram 2 than Diagram 3, $F(1, 29) = 18.75$, $MSE = 0.82$, $p < .001$. The older adults spent more time viewing Diagram 1 than Diagram 2, $F(1, 29) = 5.42$, $MSE = 4.84$, $p < .05$, and more time viewing Diagram 2 than Diagram 3, $F(1, 29) = 35.62$, $MSE = 2.58$, $p < .001$. In addition, the young adults spent less time viewing each diagram than did the older adults: $F(1, 58) = 27.09$, $MSE = 7.54$, $p < .001$, for Diagram 1; $F(1, 58) = 12.86$, $MSE = 9.51$, $p < .01$, for Diagram 2; and $F(1, 58) = 10.22$, $MSE = 2.84$, $p < .01$, for Diagram 3.

For the discontinuous condition, there was a main effect of Age, $F(1, 58) = 13.00$, $MSE = 22.11$, $p < .01$, in which the young adults spent less time viewing the diagrams. The main effect of Diagram was only marginally significant, $F(1, 58) = 3.37$, $MSE = 4.83$, $p = .07$. Participants spent marginally significantly more time viewing Diagram 1 than Diagram 3, $F(1, 59) = 2.98$, $MSE = 5.46$, $p = .09$, but viewing times for Diagrams 1 and 2 did not differ, $F(1, 59) = 2.33$, $MSE = 2.14$, $p = .13$, nor did viewing times differ for Diagrams 2 and 3, $F < 1$. The Age × Diagram interaction was significant, $F(1, 58) = 8.68$, $MSE = 4.83$, $p < .01$. For the young adults, there were no differences in viewing times across diagrams, all Fs < 1. The older adults spent significantly more time viewing Diagram 1 than Diagram 2, $F(1, 29) = 6.66$, $MSE = 2.15$, $p < .05$, and marginally significantly more time viewing Diagram 2 than 3, $F(1, 29) = 3.39$, $MSE = 3.93$, $p = .08$. Finally, young adults spent less time than the older adults viewing Diagram 1, $F(1, 58) = 32.11$, $MSE = 6.38$, $p < .001$, and Diagram 2, $F(1, 58) = 9.41$, $MSE = 10.41$, $p < .01$, but did not differ for Diagram 3, $F(1, 58) = 2.15$, $MSE = 12.32$, $p = .15$.

In contrast to Experiments 1 and 2, older adults spent more time learning all of the displays than did the young adults. Notably, this included the third display for the discontinuous condition. Older

adults typically take more time to process information than do young adults; thus this finding signifies that older adults were not overburdened in this version of the task (as opposed to Experiments 1 and 2). Thus, when the information was visually based, older adults were better able to retain and integrate it than when verbally based material was presented.

Identification accuracy. The mean accuracy scores for both groups are listed in Table 2; reliability estimates were computed for the continuous ($\alpha = .69$) and discontinuous ($\alpha = .70$) conditions. Overall, people were more accurate for the continuous than for the discontinuous condition, $F(1, 58) = 16.50$, $MSE = .04$, $p < .001$. The young adults were more accurate than the older adults, $F(1, 58) = 11.83$, $MSE = .15$, $p < .001$. The interaction did not reach significance, $F(1, 58) = 2.28$, $MSE = .04$, $p = .14$.

Performance for the young adults was consistent with Experiments 1 and 2. For the older adults, their accuracy for the continuous condition was similar to their performance in Experiment 2. This is not very surprising, because in this condition people can integrate as they encounter new information and thus there is not that great of a memory load. Therefore, using materials that are easier to retain (i.e., pictures) did not improve performance in this condition. However, in Experiment 3, accuracy for the discontinuous condition was well above chance. Thus, for nonverbal materials, older adults were able to retain multiple diagrams before integrating. This performance is much improved relative to their performance for verbal material. The older adults' performance in this experiment, relative to those in Experiments 1 and 2, shows that they can process and retain nonverbal material much easier than verbal material.

The correlation between viewing time for the final diagram and accuracy performance was weak and not significant for the continuous condition ($r = -.03$, $p = 1$). For the discontinuous condition, the correlation was positive and significant ($r = .40$, $p < .01$). This pattern is consistent with the same relations examined in Experiments 1 and 2.

As in Experiments 1 and 2, regression analyses were conducted to determine whether age and working memory span ($\alpha = .70$) were significant predictors of accuracy for the continuous and discontinuous conditions. For the continuous condition, both age ($b = -.41$, $p < .001$) and working memory span ($b = .36$, $p < .01$) were significant. For the discontinuous condition, working memory span ($b = .35$, $p < .01$) was a significant predictor, but age ($b = -.19$, $p = .13$) was not. Thus, when both age and working memory span were included in the analysis, working memory span was an important predictor of performance. This suggests that working memory deficits for the older adults contribute to their lower levels of performance, relative to the young adults, in the integration task.

Regression analyses were also conducted to determine what percentage of the age-related variance was explained by working memory. For the continuous condition, age alone accounted for 24% of the variance ($r = .49$, $p < .001$). When we controlled for working memory, age accounted for 20% of the variance ($r = .45$, $p < .001$). Thus, working memory accounted for approximately 15% of the age-related variance in this condition. This pattern is similar to what was observed in Experiment 1. For the discontinuous condition, age alone accounted for 7% of the variance ($r = .26$, $p < .05$) and for 4% ($r = .20$, $p = .13$) when we controlled for working memory. Thus, working memory accounted for 42% of the age-related variance for the discontinuous condition. This is consistent with both Experiments 1 and 2.

Identification response times. Reliability estimates were computed for the continuous ($\alpha = .85$) and discontinuous ($\alpha = .68$) conditions. Overall, people were faster (see Table 3) to respond for the continuous than for the discontinuous condition, $F(1, 58) = 4.88$, $MSE = 46$, $p < .05$. The young adults were faster to respond than were the older adults, $F(1, 58) = 33.60$, $MSE = 189$, $p < .001$. The interaction was not significant, $F(1, 58) = 1.34$, $MSE = 46.047$, $p = .252$. This pattern is consistent with the idea that both age groups integrated data more easily in the continuous condition than in the discontinuous condition.

Overall, the improved performance in Experiment 3 seems to be a result of using pictures instead of text. Experiment 2 examined whether diagrams would improve performance for the older adults because there was less text, the data were presented in a spatial manner, and the materials were similar during learning and identification. However, these changes did not improve the older adults' performance in the discontinuous condition; it was not until the text was completely removed in Experiment 3 that their performance improved.

General Discussion

This study investigated the ability of young and older adults to integrate spatial information. The three experiments were all based on a task used by Ehrlich and Johnson-Laird (1982), but we used three different presentation formats: sentences, word diagrams, and pictures. In all three experiments, the young adults outperformed the older adults and consistently showed accuracy, response time, and viewing time differences for the continuous and discontinuous descriptions. In contrast, the older adults did not show a clear difference between the conditions, nor did they show performance clearly better than chance until Experiment 3, in which pictures were used.

In terms of accuracy performance, the young adults showed a consistent pattern of performing better in the continuous condition than in the discontinuous condition. However, for the older adults, the pattern was not consistent. In Experiment 1, constructing spatial representations from the sentence descriptions was difficult for the older adults, regardless of the condition. Thus, there was not a large difference in performance across the conditions. In Experiment 2, spatial presentation of the material helped the older adults' performance, but in the discontinuous condition, the older adults still had difficulty. In Experiment 3, the pictures were easier to process, and thus performance improved in the discontinuous condition. In comparison, for the continuous condition, use of stimuli that were easier to remember did not improve performance.

Performance in the discontinuous condition was particularly important because for this condition, participants not only had to integrate information, but they also needed to retain information before integration was possible. For all of the presentation formats, young adults were able to integrate spatial information in the discontinuous condition. When sentences or word diagrams were used, older adults had difficulty with the discontinuous condition; they were not able to integrate effectively. This is consistent with findings of a study by Light, Zelinski, and Moore (1982) in which older adults had much more difficulty with relational reasoning

(e.g., "Bob is taller than John," "John is taller than Fred") when terms in consecutive premises did not overlap.

Of interest, whereas the young adults had longer viewing times for the third display in the discontinuous condition than for the third display in the continuous condition, the older adults did not show this pattern consistently. One possibility for this pattern is that the older adults were having difficulty retaining the verbatim or text-base representations of the first two displays, so they did not exert much effort when reaching the third display. This explanation seems likely because, overall, the older adults had smaller working memory capacities, which would lead to difficulty retaining the verbal information in Experiments 1 and 2, particularly in the discontinuous condition.

A second possibility is that the older adults tended to use a different strategy than the young adults. Instead of trying to integrate the information in the discontinuous condition, they may have tried to move through the items at a quicker (than normal) pace in an attempt to minimize the loss of information from working memory. The greater demands on working memory in this condition caused them to try to compensate by progressing at a faster pace. Thus, it could be that older adults were giving up on the idea of integrating as they progressed by increasing their pace for the final display in the discontinuous condition. This is a possible explanation because even in Experiment 3, when older adults' performance improved, their accuracy was still below 50%. This possibility could be addressed in future studies with the use of interviews or verbal protocols.

An additional possibility is that older adults did not adequately understand the task and thus did not attempt to integrate the data whenever possible during learning. Along this same line, maybe the older adults did not attempt to integrate until after viewing the recognition choices (i.e., after viewing all the learning displays). This explanation is consistent with the long response times in the identification task. However, this was not supported by the task itself or by other aspects of the results. For this task, there would be no advantage for participants to wait to integrate data after advancing beyond the final learning display because then the information on the screen would no longer be available to aid in retention. As for the results, older adults clearly did better in the continuous condition, when they could integrate at each learning stage. If they always waited to integrate, performance should not have been different for the continuous and discontinuous condition. Also, older adults seemed to be able to integrate in Experiment 3 when pictures were used. It is possible, though, that older adults were not always integrating in Experiment 3. Even when pictures were used, older adults did speed up as they viewed the successive displays. This would suggest, as observed in young adults by Radvansky and Copeland (2006), that because memory for pictures is better than for text, people are tempted to rely on individual (i.e., nonintegrated) memories, rather than constructing integrated mental models. Thus, if older adults were not integrating in any of the experiments, they may have had better success in Experiment 3 simply because of superior memory for pictures. This is a possibility; however, as stated earlier, if this was always occurring, there should not have been a difference in performance for the continuous and discontinuous conditions.

The results of the current study are informative because previous studies investigating the use of mental models have generally shown that older adults are able to construct and use them. However, the results also suggest that whereas older adults can construct mental models, they have difficulty if the conditions are not favorable. Specifically, in previous studies, information has been presented continuously and simultaneously (e.g., Gilinsky & Judd, 1994) or has been repeatedly presented over many trials (e.g., Radvansky et al., 1996). In these studies, older adults show evidence of integrating information and using mental models. In the current study, though, people had to retain the information in working memory before integrating. Older adults, who as a group have smaller working memory capacities, had difficulty using mental models under these circumstances. In the current study, we developed this idea by illustrating that working memory capacity may only be indirectly related to the use of mental models (e.g., Radvansky & Copeland 2004a; 2004b). That is, it appears as though working memory capacity may be more related to the processing and retention of information at the text-base level or, in the case of pictures, at the surface level. Only under certain circumstances, such as when these representations need to be retained to construct a mental model, are deficits clearly observed in older adults' use of mental models.

It is possible, however, that older adults were constructing mental models as they viewed each display in the task. That is, instead of having difficulty retaining text-base or surface information, people, older adults in particular, had difficulty retaining the mental models that they had created for each display. This explanation does not seem likely for a number of reasons. First, constructing mental models is effortful. The older adults, relative to the young adults, did not spend much additional time viewing the successive displays. Also, the relatively fast viewing times for the final display in the discontinuous condition, especially in Experiments 1 and 2, suggest that the older adults were not taking the time needed to integrate the information, which would be expected if they were indeed using mental models. Finally, as discussed earlier, previous studies have shown that older adults tend to be able to construct and use mental models at a proficient level (e.g., Radvansky et al., 2001).

In addition to working memory limitations, another possible reason that older adults may have had difficulty with this task was that the materials in this study were more abstract than those used in previous aging studies that investigated mental model use. For example, studies of older adults' use of mental models during text comprehension have presented stories that are rich with spatial, temporal, and causal information (e.g., Radvansky et al., 2001). Also, some studies have shown that older adults incorporate functional relations into their mental models (e.g., Radvansky, Copeland, & Zwaan, 2003). In the current study, the spatial relations were arbitrary and nonmeaningful, which could have contributed to the older adults' difficulty.

A final idea to consider is the finding that the older adults performed much better when presented with pictures as opposed to sentences. Initially, this might appear to contradict studies that have shown higher costs for older adults, relative to younger adults, for performance on visuospatial compared with verbal tasks (Jenkins, Myerson, Joerding, & Hale, 2000; Verhaeghen et al., 2002). However, although older adults did show dramatic improvement when pictures were used, all of the experiments in the current study involved spatial processing. The major difference in Experiment 3 was that it was assumed that there was little-to-no involvement of verbal processing. It is possible that people coded

the information verbally, but the pattern of results does not support this idea. These findings are more consistent with recent studies that have examined the use of perceptual symbols and mental models (Dijkstra et al., 2004; Zwaan, 1999). That is, older adults have been shown to rely on perceptual symbols when comprehending information. Thus, when pictures were provided, older adults could construct a perceptual representation, leading to improved performance. This is also consistent with recent research with mental models and the fan effect (Radvansky & Copeland, 2006), which shows that people are faster and more accurate at learning information presented as pictures than sentences. In the current study, if the pictures could be more easily retained, then that would facilitate integration.

This study examined aging effects on an integration task (Ehrlich & Johnson-Laird, 1982). In Experiments 1 and 2, both young and older adults performed better for continuous rather than discontinuous conditions when verbal materials were used. However, the older adults had accuracy scores in the discontinuous condition that were near chance in Experiments 1 and 2. In Experiment 3, when pictures were used, older adults' performance increased dramatically. These results suggest that older adults have much more difficulty retaining verbal information than visual information in working memory when the goal is to construct an integrated spatial mental model.

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