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Preserved Spatial Memory Over Brief Intervals in Older Adults

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Two studies compared young and older adults' memory for location information after brief intervals. Experiment 1 found that accuracy of intentional spatial memory for individual locations was similar in young and older participants for set sizes of 3 and 6. Both groups also encoded individual locations in relation to the larger configuration of locations. Experiment 2 showed that like young adults, older adults' latency to respond to a test probe in a letter working memory task was negatively influenced by spatial information that was irrelevant to the task. This interference effect indicated preserved incidental memory for spatial information in older adults. Together, these data suggest that initial encoding of spatial information for relatively small numbers of items is largely preserved in healthy older adults and that representations of spatial information persist over short intervals.

The nature of memory deficits associated with aging has received increasing attention over the last 15–20 years. Many studies have now reported age-related differences in long-term episodic memory and working memory (see, e.g., Anderson & Craik, 2000; Balota, Dolan, & Duchek, 2000; Zacks, Hasher, & Li, 2000, for reviews). Furthermore, age-related deficits in memory typically are greater for tests assessing which features go together (binding, context, source, or associative memory) than for tests assessing individual features or item information (e.g., Benjamin & Craik, 2001; Chalfonte & Johnson, 1996; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Naveh-Benjamin, 2000; Schacter, Kaszniak, Kihlstrom, & Valdiserri, 1991; Wegesin, Jacobs, Zubin, Ventura, & Stern, 2000; see Spencer & Raz, 1995, for a review of earlier work). For example, Mitchell, Johnson, Raye, Mather, and D'Esposito (2000) presented three items (line drawings) successively, each in a different cell of a 3 × 3 grid, and participants had to remember the information over an 8-s unfilled delay interval. In different blocks of trials, participants were tested for which locations were filled, which objects were seen, or which objects were in which locations (combination or feature binding trials). Older adults did not differ significantly from young adults on either item or location information, but they were impaired on combination trials. Such findings suggest that the encoding processes for features are less disrupted during aging than are the encoding processes that create relations among different features (e.g., item and location).

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Although such findings tend to focus experimental and theoretical attention on age-related binding or source memory deficits (e.g., Bayen & Murnane, 1996; Benjamin & Craik, 2001; Glisky, Polster, & Routhieaux, 1995; Glisky, Rubin, & Davidson, 2001; Hedden & Park, 2003; Henkel, Johnson, & De Leonardis, 1998; Johnson & Chalfonte, 1994; Mitchell, Johnson, Raye, & D'Esposito, 2000; Naveh-Benjamin, 2000; Schacter, Osowiecki, Kaszniak, Kihlstrom, & Valdiserri, 1994; Smith, Park, Earles, Shaw, & Whiting, 1998; Spencer & Raz, 1994; Wegesin et al., 2000), it would also be useful to have evidence from a broader range of situations investigating similarities and differences in how young and older adults encode various individual features. The present studies address this issue.

We focused here on investigating the encoding of spatial information. The intervals typically used in working memory tasks are long enough (e.g., 8–12 s) that age differences in intervening processing, say rehearsal strategies, may make a substantial contribution to memory performance beyond any initial encoding differences there may be. Thus, because our main interest was in the initial encoding of spatial information, we used very short retention intervals (< 2 s). For generality, we used two paradigms that were quite different from each other. In Experiment 1, we used a procedure that relied on intentional encoding of spatial information and probed for absolute spatial memory and also indirectly assessed memory for configural relations. In Experiment 2, we used an incidental location memory task in which irrelevant spatial information interferes with performance on a task involving memory for letters.

Experiment 1

In Experiment 1, we tested memory for spatial location after a 1,600-ms interval for set sizes of three and six locations. We also investigated memory for relational information. Other than studies assessing associations between words (e.g., Naveh-Benjamin, 2000), most studies looking at relational memory investigated the binding of items with other types of information (e.g., item and location or color, Chalfonte & Johnson, 1996; item and location, Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000). Here, we examined whether participants encoded relations among locations. Previous research with young participants found that memory for a filled location was better when the test probe was embedded in the same configuration of filled locations shown in the study display than when it was embedded in a changed configuration (Jiang, Olson, & Chun, 2000). This suggests that young participants encoded a single location in relation to other locations. Parallel to the binding of item and location information, this integration of location with other locations can be called *configural binding*. Do older participants have deficits in binding among locations, or do they show intact configural binding?

To investigate this question, we used a change-detection paradigm (e.g., Jiang et al., 2000; Luck & Vogel, 1997; Olson & Jiang, 2002) in Experiment 1. In this task, as shown in Figure 1, a visual display was briefly presented to the participants (the study display), and after a short delay interval, another visual display was presented (the test display). Each study display contained either three or six green squares placed at random locations. In the test display, one of the elements had a box around it, and this was the target item; the other items were context items. The test display either had context items in the same configuration as the study display (the unchanged configuration condition) or had context items reorganized such that the configuration changed (the changed configuration condition). In both conditions, the target could appear in either the same location or in a different location compared with the study display. The task was to detect whether the target item had changed location. To do this accurately across changes in the global configuration required memory for absolute location. Comparing performance across the unchanged and the changed configuration conditions assesses whether the location of the target item is encoded relative to the configuration of the context items.

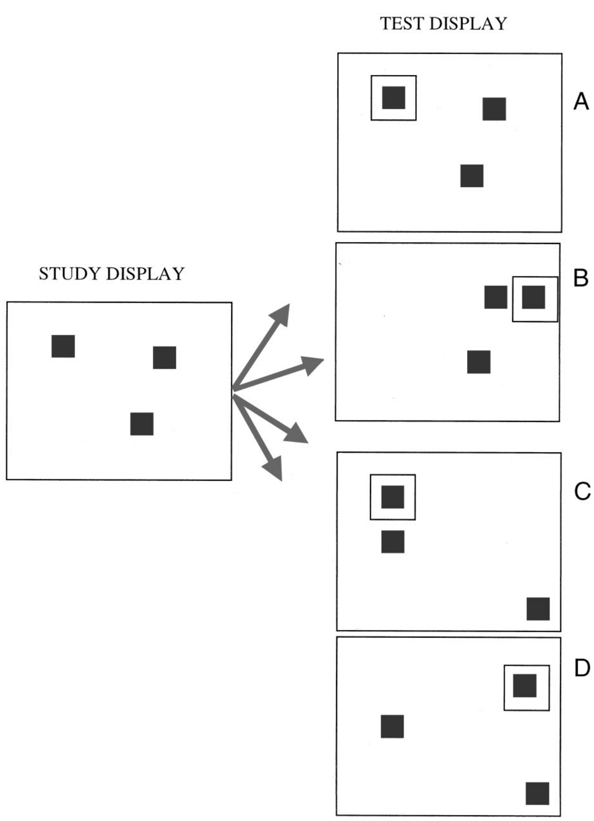

Figure 1. A sample display for set-size three used in Experiment 1. All items in the study and test displays were green, and the target item on the test display had a red box around it. The four conditions are illustrated in the probe task. A: Unchanged configuration, target in same location. B: Unchanged configuration, target in different location. C: Changed configuration, target in same location. D: Changed configuration, target in different location.

Method

Participants. Participants were 17 young (7 men; ages 18–26 years, $M = 21$) and 17 older (8 men; ages 65–88 years, $M = 74$) healthy adults. Young adults were students at Yale University, and older adults were recruited from the community. The young adults had slightly less education ($M = 14.5$ years and 16.6 years for the young and older adults, respectively), $t(32) = 2.57$, $p < .03$. All participants reported normal or corrected-to-normal visual acuity and normal color vision. In addition, all participants reported being in good health, with no history of primary degenerative brain disorders, stroke or other serious circulatory problems, severe head trauma, psychiatric diagnosis, or any other serious medical condition. None were taking psychotropic medications. There was no difference between groups on a modified version of the Verbal subtest of the Wechsler Adult Intelligence Scale (WAIS; both *M*s = 25; maximum possible = 30). Older adults scored high on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975; $M = 29$ out of 30).[1] None of the participants were aware of the purpose of the study.

Stimuli. The experiment was presented on a computer. On each trial, two images were presented sequentially, separated by a blank interval (see Figure 1). The study display contained either three or six green squares (1 cm × 1 cm), which were randomly placed in an invisible matrix the size of the computer screen that had 64 possible locations. Neighboring locations were separated by space so that squares did not touch one another. The test display contained the same number and type of squares. The context items either appeared in the same locations as they had on the study display (the unchanged configuration condition) or were randomly changed to new locations (the changed configuration condition; see Figure 1). The target item tested was designated by a red surround box. In both test conditions, the target item appeared equally often in either the same location or in a different location as compared with its location on the study display; we term this the *target location* variable. The different location was randomly chosen from all unfilled locations. The interstimulus interval between the study and test displays (1,600 ms) was long enough so that there was no pop-out or creation of visual transients between study and test displays. The background of both study and test displays was gray (127 on red, green, and blue phosphors, with 0 being black and 255 being white).

Design. In addition to the between-participants factor (age), two within-subject factors were orthogonally crossed: study set size and test condition. Furthermore, target location changed on half of the trials. These factors created a 2 (age: young, older) × 2 (study set size: three, six) × 2 (test condition: unchanged configuration, changed configuration) × 2 (target location: same, different) mixed design.

Procedure. The experiment began with instructions, followed by a practice block of 10 trials to familiarize participants with the task and procedure. Participants were specifically instructed that the locations of

[1] One older adult had a relatively low score on the MMSE (25), and another older adult had a very low score on the WAIS (11 out of 30). Of interest, their performance on the experimental memory task was quite good. When these participants were removed from the analysis, all effects remained the same.

context items might be different in the test displays and that attention to this would harm performance. All participants reported that they understood the instructions and found the task reasonably easy.

Participants began each trial by pressing the space bar. The trial began with a small white fixation cross lasting 507 ms, followed by a blank interval for 400 ms. The study display was presented for 600 ms. After a blank interval of 1,600 ms, the test display was presented until the participant responded by pressing one key with their right hand for "same" and another with their left hand for "different." Sound feedback was given after each response: three high-pitched beeps for correct, one medium-pitched beep for incorrect. Participants were instructed to respond as accurately as possible without worrying about speed. Trials were presented in random order, and the entire experiment of 80 trials took 15–20 min.

Apparatus. The experiment was conducted on a Macintosh computer using the MacProbe software (Hunt, 1994). The stimuli were presented on a 48.3-cm color monitor with unrestricted viewing distance.

Results and Discussion

Accuracy. Accuracy was defined as the percentage of hits plus correct rejections. Accuracy was analyzed using an analysis of variance (ANOVA) with age as a between-subjects variable and study set size (three or six), test condition (unchanged or changed configuration), and target location (same or different) as within-subject variables. Results are shown in Figure 2.

There was a main effect of condition, $F(1, 32) = 66.18$, $p < .01$, with participants less likely to accurately remember the location of the target square if the configuration changed than if it remained unchanged: old, $t(16) = 5.95$, $p < .01$; young, $t(16) = 5.57$, $p < .01$. There was also a main effect of set size, $F(1, 32) = 41.70$, $p < .01$, with poorer performance at a set size of six. There was no main effect of age, nor did age enter into any significant interactions (all ps $> .10$).

There was no main effect of target location, and target location did not interact with age (ps $> .10$; see Table 1). Target location did interact with condition, $F(1, 32) = 130.92$, $p < .01$, with higher accuracy in the unchanged (93%) than in the changed (63%) condition when the target location remained the same, $t(32) = 12.55$, $p < .01$, and more accuracy in the changed (80%) than in the unchanged (72%) condition when the target location was different, $t(32) = 3.63$, $p < .01$. This pattern suggests a tendency in both groups to respond "same" whenever the configuration did not change and "different" when it changed. If this were the only factor influencing responding, however, performance would be at zero for the target same–changed condition and for the target different–unchanged condition, which clearly was not the case (see Table 1). More to the point, such an effect, like the main effect of condition, demonstrates that memory for individual locations is influenced by memory for the overall configuration and that young and older adults exhibited the same influence (indicated by the lack of a Condition × Age or a Target Location × Condition × Age interaction; ps $> .10$; see Table 1 for means).

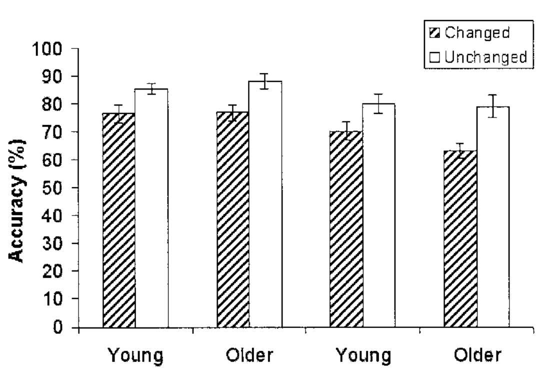

Figure 2. Accuracy (%) in Experiment 1. Bars represent standard error of the mean.

Table 1
Percent Accuracy, Experiment 1

Test condition, target location	Young	Older
Unchanged, different	74.1 (2.8)	69.1 (3.1)
Unchanged, same	94.1 (1.5)	92.4 (2.5)
Changed, different	84.4 (2.6)	76.3 (2.8)
Changed, same	62.4 (2.7)	63.8 (3.0)

Note. Numbers in parentheses are standard error of the means.

Response times. Participants were not instructed to respond as quickly as possible because our primary interest in Experiment 1 was accuracy. Nevertheless, response times were recorded and provide additional information about the relative difficulty of the conditions (see Table 2). There was an Age × Condition × Set Size interaction, $F(1, 32) = 6.60$, $p = .02$. Subsequent analyses indicated there was a significant Age × Condition interaction at the set size of six, $F(1, 32) = 4.43$, $p = .04$, but not at the set size of three, $F(1, 32) = 0.38$, $p = .54$. As is clear in Table 2, older adults were generally slower than young adults, especially when the configuration was changed for a set size of six.

Overall, the results of Experiment 1 suggest two things. First, accuracy in very short-term spatial memory was relatively preserved in older adults under these conditions. This reinforces the finding from Mitchell, Johnson, Raye, Mather, and D'Esposito (2000; see also, Mitchell, Johnson, Raye, & D'Esposito, 2000) that accuracy in working memory for a small set of locations maintained over an 8-s delay was not affected by age. However, we would not conclude that, in general, there are no age-related effects in very short-term memory tasks. Although not significant, there was a small age difference in accuracy for the set size of six (see Figure 2), and, for the set size of six, older adults were disproportionately slower to respond when the configuration was changed (see Table 2). These findings suggest that with a sufficiently large set size and speeded instructions, older adults might show disproportionately poorer accuracy as well as disproportionately slower response times. This seems likely because with even larger loads,

Table 2
Response Times (in Milliseconds), Experiment 1

	Set size of three		Set size of six	
Group	Unchanged	Changed	Unchanged	Changed
Young	948 (48)	1,083 (65)	1,052 (55)	1,107 (70)
Older	1,713 (79)	1,804 (90)	1,848 (108)	2,182 (160)

Note. Numbers in parentheses are standard error of the means.

in addition to relatively automatic perceptual processes, encoding should require reflective processes (e.g., shifting attention from one location to another, refreshing previously attended locations), and older adults have particular difficulty with such reflective, or more deliberate, processes (e.g., Craik, 1986; Craik & Jennings, 1992; Johnson, Mitchell, Raye, & Greene, 2004; Johnson, Reeder, Raye, & Mitchell, 2002; Smith et al., 1998).

Second, these results suggest that both older adults and young adults remember location configurally, as shown by the significantly poorer performance in the changed configuration as compared with the unchanged configuration condition. Furthermore, older adults showed the configuration advantage to the same degree as young adults. Thus, for both age groups, memory for an individual location was bound to the larger spatial context, similar to results reported previously for young adults (Jiang et al., 2000; Olson & Marshuetz, in press) and for middle-aged participants (Chun & Phelps, 1999). Therefore, although binding of item to location may be deficient in older adults (e.g., Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000), short-term binding of location to location—configural binding—appears to be preserved, at least for low loads at very short intervals.

Experiment 2

Experiment 1 showed that older adults had intact intentional memory for individual spatial locations over a 1,600-ms interval and that location is encoded in relation to other locations. Experiment 1 leaves open the possibility that older adults' memory for spatial information over brief intervals depends on specific efforts to encode spatial information. To explore incidental spatial encoding, we used a task that has recently been shown to result in incidental encoding of spatial information in young adults (Zhang & Johnson, 2004) in Experiment 2.

The *Simon effect* (Simon & Rudell, 1967) refers to the finding that response times are faster when stimulus and response locations are congruent, compared with when they are incongruent, even though stimulus location is irrelevant to the task. In a classic demonstration, Craft and Simon (1970) presented a red or a green light to the left or the right of the center of a display. Participants were instructed to respond with a left-hand key to the green light and a right-hand key to the red light. Response times were faster when the green light was presented to the left than to the right. Conversely, response times were faster when the red light was presented to the right as compared with the left. Essentially, the Simon effect is a phenomenon in which spatial location, a dimension that participants presumably are not paying conscious attention to, influences the speed of their responses to perceptual stimuli. A recent aging study with a perceptual Simon task found a larger Simon effect in elderly participants relative to young participants (Van der Lubbe & Verleger, 2002). However, that study was more concerned with the effect of aging on an inhibitory process resolving perceptual interference as opposed to the initial encoding of spatial information in the context of a memory task.

The procedure used by Zhang and Johnson (2004) can be thought of as a mnemonic version of the perceptual Simon task. In this task (see Figure 3), participants were shown two letters in the study display and were asked to hold them in mind across a short blank delay. The two letters were presented either to the left or to the right of a central fixation dot. In the test display, a single probe letter was shown at the center of the screen, and participants were required to judge whether the probe was one of the two memorized letters. Critically, they indicated their responses by pressing a key on the left side of the keyboard or a key on the right side of the keyboard. Zhang and Johnson found that participants' response times were influenced by the left–right congruency of the study letters, either to the left or right of fixation, and the response key, either to the left or right of egocentric space. Like the perceptual Simon effect, location of the study letters was incidental to the memory task. In addition, Zhang and Johnson found that the congruence effect occurred in the opposite direction for the "yes" and the "no" responses. When participants were making a "yes" response, the spatially congruent trials were faster than the spatially incongruent trials; when they were making a "no" response, the spatially congruent trials were slower than the spatially incongruent trials. The presence of this pattern is taken as evidence for the incidental encoding of spatial location information.

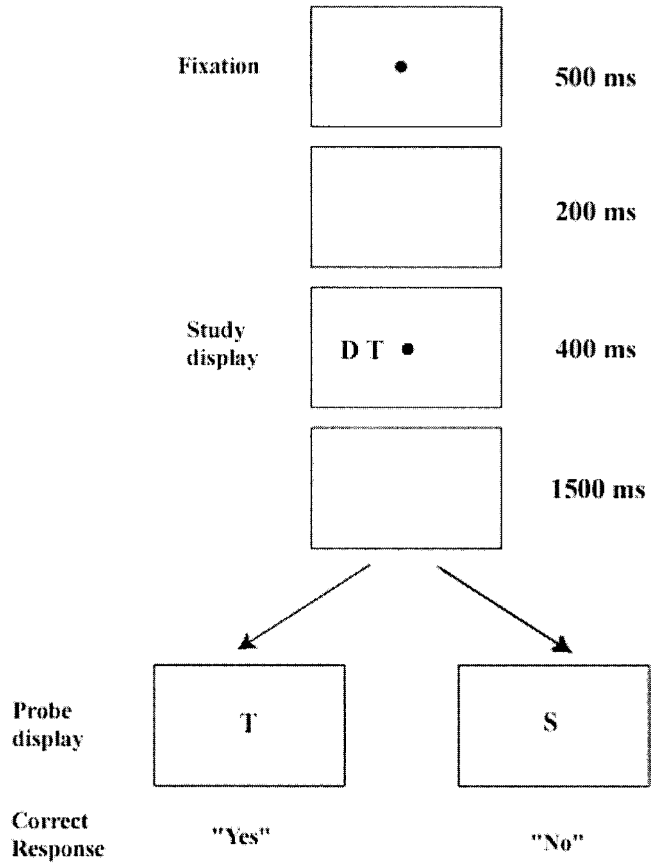

Figure 3. Procedure and sample stimuli (D, T, and S) for Experiment 2.

In the current study, we asked, Does incidental encoding of spatial information differ across age groups? For the young group, we expected to replicate Zhang and Johnson's (2004) results by finding an interaction between response type and congruence, that is, a positive congruence effect for the "yes" responses and a negative effect for the "no" responses. Of interest was whether this interaction pattern was the same or different for older adults. If older adults showed the same or greater congruence effect, it would indicate that incidental encoding of spatial information was intact. If they showed a reduced or absent congruence effect, it would indicate that there was a deficit in incidental encoding of spatial information.

Method

Participants. Participants were 21 young (10 men; ages 18–26 years, $M = 21$) and 17 older (5 men; ages 60–88 years, $M = 73$) healthy adults. Participants were from the same population as those tested in Experiment 1, but no participant served in both studies; they were screened on the same health criteria noted in Experiment 1. The young adults had less education than the older adults ($M = 15.1$ years and 16.4 years for young and older adults, respectively), $t(36) = 3.24$, $p = .003$. There was no difference between groups on a modified version of the Verbal subtest of the WAIS (young $M = 23$, older $M = 25$ out of 30; $p > .20$). Older adults scored high on the MMSE ($M = 29$ out of 30). None of the participants were aware of the purpose of this study.

Stimuli. As shown in Figure 3, the fixation stimulus was a dot presented at the center of the screen. On each trial, two different letters were randomly drawn from a pool of 21 consonants and used in the study display. The two letters in the study display were either to the left or to the right of the screen center. Each letter was a black uppercase letter, Courier font, at size 64. The probe letter, in the same font and size as the study letters, was always in the center of the test display. For a "yes" trial, the test probe was randomly drawn from these two letters; for a "no" trial, the test probe was a letter drawn from the pool but different from either of the two studied letters. The background was white.

Design. The design was a 2 (age: young, older) × 2 (response type: yes, no) × 2 (congruence: congruent, incongruent) mixed factorial with response type and congruence as within-subject factors and age, of course, a between-subjects factor. The congruence and the response type factors were orthogonal to each other.

Procedure. The experiment began with instructions, followed by a practice block of 12 trials to familiarize participants with the task. Participants were instructed to fixate on the central dot and hold the two memory letters in mind across the delay interval and then decide whether the test probe was in the memory set. Participants completed three testing blocks of 32 trials each. The experiment took about 15 min.

Figure 3 shows an example trial. On each trial, after the 500-ms fixation display and a 200-ms blank screen, the study display was shown for 400 ms. After a 1,500-ms delay, the test display came up and remained on the screen until a response was made. If the probe was a letter shown in the study display (as shown on the left in Figure 3), the participant was to make a "yes" response via right-hand keypress (the "," key). As the locations of the study letters (left) and response key (right) were different, this trial would be coded as an incongruent trial. If the probe was a letter not shown in the study display (as shown on the right in Figure 3), a correct "no" response would require a left-hand keypress (the "v" key), which would be congruent with the location of the study letters. Consequently, this trial would be coded as a congruent trial.

The next trial started 1,500 ms after the response was made. Both speed and accuracy were emphasized. To be consistent with response options in another unrelated task that preceded this one, we did not counterbalance the response type to response key mapping across participants. A previous study showed that response counterbalancing is not critical to the observed congruence effect (Zhang & Johnson, 2004).

Apparatus. The apparatus was similar to that used in Experiment 1. The software VisionShell (Raynald Comtois, available at http://www.visionshell.com/) was used for stimulus presentation and response recording.

Results and Discussion

The mean error rate was low—1.7% for the older adults and 3.2% for the young adults ($p = .08$; see Table 3). An ANOVA with response type, congruence, and age as factors revealed no significant main effects or interactions, except a Response Type × Congruence interaction, $F(1, 36) = 7.53$, $p < .01$. For the yes trials, the error rate was 2.0% for the congruent trials, lower than the 4.1% for the incongruent trials. This pattern was reversed for the no trials, with 2.2% errors for the congruent trials and 1.9% errors for the incongruent trials.

A second ANOVA on the median response times for correct responses (see Table 3) revealed a significant main effect of age, $F(1, 36) = 52.83$, $p < .01$, and of response type, $F(1, 36) = 24.72$, $p < .01$. The young group (557 ms) was faster than the older group (853 ms), consistent with a general cognitive slowing typically found (Salthouse, 1996). Collapsing across the two groups, "yes" responses (666 ms) were faster than "no" responses (714 ms), an effect that has been well documented in the literature (e.g., Sternberg, 1975). The main effect of congruence was significant, $F(1, 36) = 9.64$, $p < .005$, but it did not interact with age ($p > .20$). The only significant interaction effect was that between response type and congruence, $F(1, 36) = 17.58$, $p < .01$. For the "yes" responses, the congruent trials (661 ms) were faster than the incongruent trials (671 ms), but for the "no" responses, the pattern was the opposite—the congruent trials (734 ms) were slower than the incongruent trials (693 ms). This pattern was consistent with the Response Type × Congruence interaction from the error rate analysis. The Response Type × Congruence interaction pattern was not different across the two age groups, because the three-way interaction between response type, congruence, and age was not significant ($p > .50$). This pattern can be seen in Figure 4, where the congruence effect (response time for the incongruent trials minus response time for the congruent trials) is shown separately for the two response types for each age group.

Interpretation of these results is clear. First, we replicated the basic findings of Zhang and Johnson (2004): A spatial congruence effect was observed for the young adults, and the effect was in opposite directions depending on response type. Second, and more important, the older adults also showed a congruence effect with a pattern similar to that of the young adults. These results indicate that older adults incidentally encoded spatial information that was then retained over a brief interval, influencing their performance on a task in which location was irrelevant. In other words, older adults demonstrated preserved short-term incidental memory for spatial location.

Table 3
Response Times (in Milliseconds) and Error Rates, Experiment 2

	Response time		Error rate (%)	
Test condition	Young	Older	Young	Older
Yes, congruent	533 (21)	819 (42)	2.7 (0.82)	1.2 (0.46)
Yes, incongruent	546 (23)	825 (37)	5.5 (1.12)	2.4 (0.62)
No, congruent	592 (25)	909 (38)	2.3 (1.00)	1.9 (0.70)
No, incongruent	559 (22)	859 (35)	2.4 (0.88)	1.4 (0.69)

Note. Numbers in parentheses are standard error of the means.

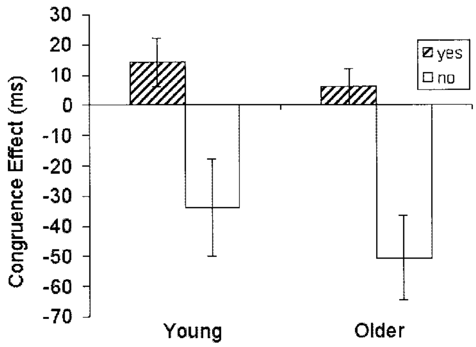

Figure 4. Results of Experiment 2, with the congruence effect (response time [RT] for the incongruent trials minus RT for the congruent trials) plotted by age and response type. Bars represent difference scores with standard error of the mean.

General Discussion

The purpose of these studies was to compare encoding of spatial information in young and older adults. The findings suggest that initial encoding of spatial information for relatively small numbers of items is largely preserved in healthy older adults and that representations of spatial information persist over short intervals—1,600 ms in Experiment 1 and 1,500 ms in Experiment 2. Experiment 1 used an intentional encoding paradigm testing very short-term memory for whether one of three or six locations changed between study and test. We found that older and young adults showed similar accuracy levels in their memory for individual locations and that both groups encoded locations relative to other locations (configurally). Although participants were explicitly tested for individual locations in Experiment 1, it could be argued that the configural component of the memory task was incidental because participants were not asked to remember configural information. Greater age differences in configural memory might be expected with explicit instructions to learn such information (binding or associative instructions), presumably because this would induce differences between age groups in the reflective processes engaged or reveal differences in the efficacy of those processes (e.g., Chalfonte & Johnson, 1996; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Naveh-Benjamin, 2000).

Experiment 2 used a letter working memory task in which encoding of spatial information was clearly incidental to the task, and the test for location information was implicit. We found a spatial congruency effect, with faster response times (a Simon-like effect) when the key for a "yes" response matched the side on which the target stimuli had been presented (for "no" responses, spatially incongruent trials were faster). Of importance, there was no evidence that older adults showed a reduced congruency effect compared with young adults, indicating that, like younger adults, they incidentally encoded spatial information that was not relevant to the task.

Older adults often perform as well as young adults on tests of implicit memory, including both perceptual and conceptual priming (for more thorough discussions and recent examples, see Koutstaal, 2003; Lazzara, Yonelinas, & Ober, 2002; for recent counterexamples, see Maki, Zonderman, & Weingartner, 1999; Pilotti, Meade, & Gallo, 2003; for a recent review and meta-analysis, see Light, Prull, La Voie, & Healy, 2000). With regard to spatial memory, Connelly and Hasher (1993) showed that older adults demonstrate intact location negative priming, in spite of an age-related deficit in identity negative priming, even when location information was irrelevant to the main task (i.e., letter naming, Connelly & Hasher, 1993, Experiment 3). Our findings are consistent with these in suggesting that the initial encoding and representation of spatial information may be robust against the effects of aging. Our Experiment 2 involved only two locations, whereas Connelly and Hasher's study involved four locations, and our Experiment 1 involved three and six locations. Thus, a reasonable working hypothesis is that over some small number of locations, initial perceptual encoding of spatial information is relatively intact in older adults.

We are not suggesting that there are no perceptual encoding limitations in older relative to young participants (in fact, slower perceptual processing or reduced acuity may contribute to the main effect of age on absolute response times in Experiments 1 and 2) but rather that older adults show intact short-term spatial memory under some conditions. We also note that the results of Mitchell, Johnson, Raye, Mather, and D'Esposito (2000; see also Mitchell, Johnson, Raye, & D'Esposito, 2000) suggest that older adults can maintain a small number of representations of location for several seconds and that they can use such information on more explicit tests of location memory. Assuming that older adults will, however, begin to show deficits in spatial information in very short-term memory, working memory, and long-term memory tasks as the number of items is increased or as the retention interval is increased (e.g., Chalfonte & Johnson, 1996), further work should be aimed at clarifying what additional processing is required under such conditions and precisely how such processing might be disrupted in aging.

It is interesting to note that about half of the young and older adults tested in Experiments 1 and 2 also took part in a short-term single-word recognition study with immediate old–new tests intermixed with delayed old–new tests, where the delay was filled by one or two intervening trials (up to 36 s; Raye, Johnson, Mitchell, Higgins, & Bloise, 2004). The older adults showed a greater deficit compared with the young adults on the delayed than on the immediate test, presumably because the delayed test was more likely to require reactivation (Johnson, 1992). These findings suggest that the good performance of the older adults reported here for very short-term location memory is not simply because they were an unusually "select" group of older adults.

One implication of the present findings is that the well-established age-related deficits in long-term memory for the location of items (e.g., Bruce & Herman, 1986; Caldwell & Masson, 2001; Chalfonte & Johnson, 1996; Light & Zelinski, 1983; Naveh-Benjamin, 1987; Park, Puglisi, & Lutz, 1982; Park, Puglisi, & Sovacool, 1983; Perlmutter, Metzger, Nezworski, & Miller, 1981; Pezdek, 1983; Sharps & Gollin, 1987; Zelinski & Light, 1988) are not likely a consequence simply of disrupted initial encoding and very short-term retention of individual locations. Spatial information (i.e., what locations are filled) seems to be picked up incidentally and encoded normally in a configural fashion by older adults as they perceptually attend to items. However, older adults may be slower to shift attention from one item to the next (Hartley, Kieley, & McKenzie, 1992), leading to deficits under high memory load conditions. They may also be slower to reflectively refresh justattended information (Johnson et al., 2002), resulting in less benefit from such reflective processing on long-term memory. Such slowing (e.g., Salthouse, 1996) of fundamental component cognitive processes like shifting or refreshing (Johnson, 1992; Johnson & Hirst, 1993) could potentially have a cumulative effect as more items must be processed and as different types of features (e.g., item and location) must be bound together. This could contribute to long-term memory deficits in remembering locations of objects.

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