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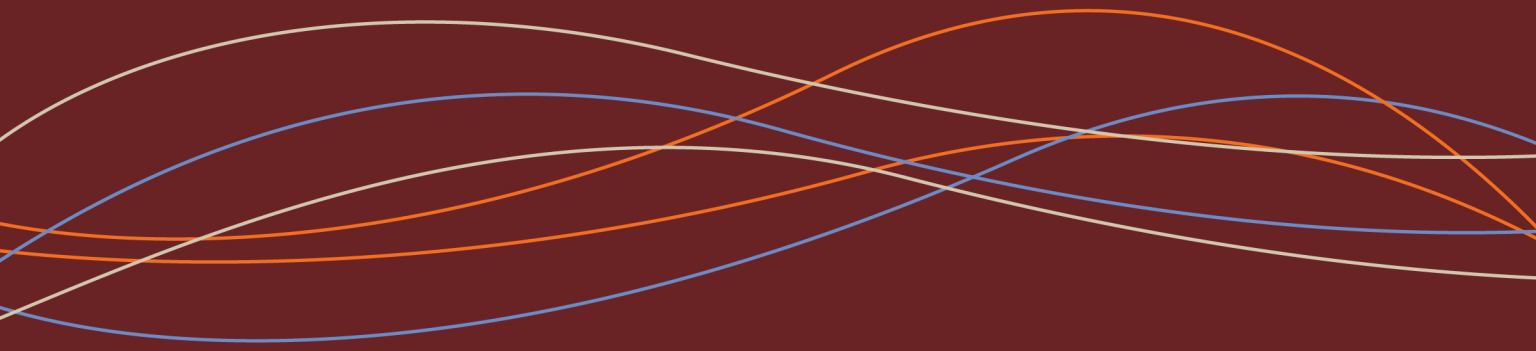

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Effects of Emotional Arousal on Memory Binding in Normal Aging and Alzheimer's Disease

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Previous research suggests that associative memory declines in normal aging and is severely affected by Alzheimer's disease (AD); however, it is unclear whether and how this deficit can be minimized. The present study investigated whether emotional arousal improves associative memory in healthy younger and older adults and patients with probable AD. We examined the effect of arousal on memory for item–location associations. Arousal improved memory for item location similarly across the three groups, whereas valence had no effect in any groups. Overall, our results suggest that arousal has beneficial effects on associative memory in healthy older adults and patients with AD, as previously observed in younger adults.

Memory binding is a person's ability to remember various features of an object, a person, or an event together as a coherent whole. This is an essential component of episodic memory in everyday life; for instance, it is important to remember face–name associations to establish good relationships. Older adults in particular may experience difficulty remembering where they placed their personal belongings, such as car keys and eyeglasses, as a result of impaired recall of associations between items and locations. A number of laboratory studies have indeed demonstrated that older adults have a memory binding deficit compared with their younger counterparts (e.g., Chalfonte & Johnson, 1996; Kessels, Hobbel, & Postma, 2007; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Naveh-Benjamin, 2000; Pezdek, 1983).

People with Alzheimer's disease (AD) face further challenges in remembering associative details. Associative learning deficits are an early sign of AD, and associative learning tasks are used to help detect the disease (Blackwell et al., 2004; Fowler, Saling, Conway, Semple, & Louis, 2002; Lindeboom, Schmand, Tulner, Walstra, & Jonker, 2002; O'Connell et al., 2004). Moreover, associative learning tests can help differentiate AD from other types of dementia, such as vascular dementia and frontotemporal lobar degeneration (Lindeboom et al., 2002), and help predict

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who will develop Alzheimer's disease (Fowler et al., 2002). People with AD have difficulty remembering various types of associative features, including item–location pairs commonly tested in the Paired Associate Learning Subtest of the Cambridge Neuropsychological Test Automated Battery (e.g., Swainson et al., 2001), item–color pairs (Parra et al., 2009), and interactive picture pairs, such as a monkey holding an umbrella (Lindeboom et al., 2002).

Despite the prevalence of memory binding impairments among older adults and people with AD, little research has been conducted on whether and how this deficit can be minimized. However, previous studies with younger adults have demonstrated that emotional content can facilitate associative memory (Doerksen & Shimamura, 2001; Hadley & MacKay, 2006; Kensinger & Corkin, 2003; MacKay & Ahmetzanov, 2005). For instance, for younger adults arousal elicited by target pictures predicts better memory for associations between items and their intrinsic features (picture–location combinations), a relationship that held up for both positive and negative pictures (Mather, Gorlick, & Nesmith, 2009; Mather & Nesmith, 2008; Mather & Sutherland, 2009). However, Mather et al. (2009) found that the presence of an arousing item, regardless of its valence, had no effect on associative memory between that item and another item in the same scene. Therefore, it seems that focused attention on an emotionally salient target improves associative memory for within-item features that were the focus of attention but yields no memory enhancement for between-item associations, as the other item was not the focus of attention. According to the arousal-biased competition theory (Mather & Sutherland, 2011), an emotionally salient stimulus has high priority and therefore often wins the competition for attentional resources. This arousal-induced attentional focus on the target item results in deeper encoding of its associative information, which leads to memory enhancement. In this article, we call associative memory for within-item features that are focal to one's attention *within-item memory binding.* In contrast, we refer to associative memory for between-item features that are not central to one's attention as *between-item memory binding* (see Mather, 2007). Given the theoretical reasons to think that the effects of arousal should be seen only in within-item memory and not in between-item memory binding, the present study focused on investigating the effect of arousal on within-item associative memory.

Does emotional arousal increase within-item memory binding in older adults, as previously observed in younger adults? The previous research investigating this question reveals a mixed picture. Kensinger et al. (2007) examined whether emotional content improves younger and older adults' reality monitoring by having participants see or imagine neutral, positive, and negative items during the study phase and later testing them on whether the items were seen, imagined, or new. In Experiment 1, they found that younger adults showed better memory for the source of negative items than for positive and neutral items, whereas older adults did not show significant differences in reality monitoring for emotional and neutral items. In Experiment 2, with a different imagined task, both age groups showed reality-monitoring enhancement only for negative items. Similarly, another study demonstrated that older adults performed as well as younger adults in making associations between an item, its perceptually neutral information, and its conceptually emotional information (e.g., the Horizon by Mazda was red and was rated as dangerous), whereas they showed impairments in making associations between an item, its perceptually neutral information, and its conceptually neutral information (e.g., the Horizon by Mazda was a red luxury car; May, Rahhal, Berry, & Leighton, 2005).

In a study examining memory for picture locations, Nashiro and Mather (2011) found that whereas younger adults remembered the locations of emotional pictures better than the locations of neutral pictures, older adults did not show this arousal-enhanced memory binding. However, given evidence that the ability to detect emotionally arousing stimuli is relatively stable with normal aging (Knight et al., 2007; Leclerc & Kensinger, 2008; Mather & Knight, 2006) and that the effects of emotional arousal on memory remain similar in normal aging (Denburg, Buchanan, Tranel, & Adolphs, 2003; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002), it seems possible that salience of emotional stimuli also facilitates older adults' memory binding, even if it does so less than for younger adults. Thus, one goal of the current study was to see whether we could find evidence of arousal-enhanced memory bind-

ing in older adults and, if so, whether it would be similar for positive and negative arousing stimuli or appear only for negative stimuli, as in Kensinger et al.'s (2007) study.

Does emotional arousal mitigate within-item memory binding deficits in patients with AD? To minimize these patients' memory deficits, it may be possible to use their remaining skills. Some studies suggest that the ability to process emotional information is more preserved in people with AD than their general cognitive ability (Bucks & Radford, 2004; Koff, Zaitchik, Montepare, & Albert, 1999) and more than in normal controls (Lavenu, Pasquier, Lebert, Petit, & Van der Linden, 1999; Luzzi, Piccirilli, & Provinciali, 2007; Roudier et al., 1998). Furthermore, there is some evidence that their ability to recall emotional items is better than their ability to recall nonemotional items (Kazui, Mori, Hashimoto, & Hirono, 2003; Moayeri, Cahill, Jin, & Potkin, 2000; Satler et al., 2007). However, these findings are challenged by other studies demonstrating that emotional content has no effect on memory in people with AD (Abrisqueta-Gomez, Bueno, Oliveira, & Bertolucci, 2002; Budson et al., 2006). The discrepancy seems to come from the fact that stimuli used in these experiments vary in intensity; prior studies demonstrating emotion-enhanced memory in people with AD used stimuli with high emotional intensity, such as natural disasters and the 9/11 terrorist attack, whereas those showing inconsistent results used stimuli with lower emotional intensity (for a review, see Kensinger, 2006). Taken together, these results suggest that people with AD may benefit from emotional salience of highly arousing stimuli in order to increase within-item memory binding.

To summarize, evidence from previous studies indicates that older adults have memory binding deficits relative to their younger counterparts and that associative memory and learning are even more severely affected by AD. Previous research has also suggested that emotional arousal increases younger adults' within-item memory binding, but it is unclear whether the same effect applies to healthy older adults and patients with AD. Because in previous studies people with AD demonstrated emotional memory enhancement only for materials with high intensity, we selected stimuli previously rated high in arousal (higher than 5 on a scale of 1 to 9, with 1 being *not at all arousing* and 9 being *extremely arousing*). This allowed us to examine the effect of a high level of arousal on item memory and memory binding.

EXPERIMENT 1

METHOD

Participants

We recruited 18 younger adults (M_{age} = 20.72 years, 3 men, 15 women, age range 18–25 years; $M_{education}$ = 14.61 years), 18 adults over 60 years old from various retirement communities who had not been diagnosed with dementia or other cognitive disorders (M_{age} = 72.67 years, 6 men, 12 women, age range 62–83 years; $M_{education}$ = 15.03 years), and 18 patients with a clinical diagnosis of probable AD from Alzheimer's Association early stage support groups in the Lafayette, Mountain View, Santa Cruz, and Rancho Mirage offices in California (M_{age} = 72.44 years, 11 men, 7 women, age range 55–86 years; $M_{education}$ = 16.22 years). Neuropsychological assessments were conducted by their respective physicians, neurologists, psychiatrists, and neuropsychologists. The neuropsychological tests used for the diagnosis of AD varied by clinician and included the Dementia Rating Scale (Mattis, 1988), Neurobehavioral Cognitive Status Examination (Mueller, Kiernan, & Langston, 2001), Wechsler Memory Scale III Logical Memory (Wechsler, 1997), and Delis–Kaplan Executive Function Scale (Delis, Kramer, &, Kaplan, 2001). To confirm the diagnoses of the disease, we asked participants to provide their diagnostic records.

In our experiment, we administered the Consortium to Establish a Registry of Alzheimer's Disease (CERAD) word list memory test (Welsh et al., 1994) to all participants except for one healthy older adult who had time constraints. In this test, participants learned a list of 10 words and were later asked to recall and recognize them. In the standard CERAD, recall and recognition tests are given across three time periods. In the current study, because of time constraints, we administered the tests once immediately after the learning phase; thus, the average scores would have been slightly lower if we had used the standard procedures. There were significant group differences in the proportion of words recalled, M_{young} = .57, range = .30-.80; M_{old} = .46, range = .10–1.00; M_{AD} = .21, range = .00-.50, $F(2, 50) = 18.13$, $MSE = .04$, $p < .001$. There were also significant group differences in corrected recogni-

tion scores (hits – false alarm rates) for words, M_{young} = .97, range = .80–1.00; M_{old} = .84, range = .40–1.00; M_{AD} = .53, range = .00-.90, $F(2, 50) = 29.66$, $MSE = .03$, $p < .001$. Post hoc test revealed that younger and older controls performed significantly better than the AD group on both tests, but there were no significant differences between the younger and healthy older groups.

Because of the differences in gender ratio between the three participant groups, we included gender as a covariate in all analyses. There were no significant effects of gender in any of the analyses; therefore, we will not discuss gender further. Participants received monetary compensation, and the experiments were conducted either in the lab, at participants' homes, or at senior centers, using a laptop.

Materials

We used 64 photographs from the International Affective Picture System (Lang, Bradley, & Cuthbert, 1999) and from other sources. The photographs consisted of matched pairs of neutral and arousing pictures that were similar in appearance, complexity, content, and focus of interest (for examples, see Mather & Nesmith, 2008). We used International Affective Picture System ratings and preratings by 10 undergraduates for picture selection and categorization (neutral, arousing–positive, and arousing–negative). We intermixed the arousing and nonarousing photographs and made two sets of 32 photographs (Set A, Set B), each of which contained an equal number of arousing and nonarousing photographs and had only one version from any matched picture pair. For example, Set A contained a neutral version from photograph pair 1 and therefore did not have the arousing version from that pair. Participants were randomly assigned to view Set A or Set B. Of the 32 photographs seen by each participant, 16 were neutral and 16 were arousing images. Half of the arousing items were positive, and half were negative.

We also used 32 abstract shapes as stimuli, each of which was presented with a photograph. Picture–shape pairs were displayed with our initial purpose of examining memory for pairs as a test of between-item memory binding. However, the results showed that pair memory performance was at floor level for older adults and people with AD. Therefore, we will not discuss this further. We used PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) to present the stimuli and record the participants' responses. The screen was divided into 3×3 grids, the outer eight cells of which were used to present the images. On each slide, one picture and one shape simultaneously appeared in two of the eight cells. One image (either a picture or a shape) was always located higher than the other. Each stimulus type appeared in each location equally frequently.

Procedure

Encoding was incidental; participants were instructed to view the items on the screen as if they were watching a slide show and were not informed about the upcoming memory tests. There were six blocks, each with 16 picture–shape pairs shown one pair at a time. Participants viewed all 32 picture–shape pairs in the assigned set across the first two blocks, which were then repeated in the second two blocks and the third two blocks in the same order. In order to keep the participants engaged, we asked them to do various encoding tasks. In three of the six blocks, each picture–shape pair was presented in two of the eight outer cells for 5,000 ms. Immediately after the two images disappeared, a blue or red dot was randomly presented in one of the eight outer cells of the screen with the question, "Is the dot blue or red?" in the center of the screen. The participants were asked to indicate their answers by pressing one of the keys labeled with a blue sticker or a red sticker. In the other three blocks, the following question appeared in the center of the screen during stimulus presentations: "Is the picture higher (H) or lower (L) than the shape?" The participants responded by pressing one of the keys marked "H" or "L," at which point the next pair was presented. The two questions alternated between blocks, and the order of which question came first was randomized (i.e., half of the participants saw the first 16 picture–shape pairs in Blocks 1, 3, and 5 with the blue–red question and saw the second 16 picture–shape pairs in Blocks 2, 4, 6 with the high–low question. The other half saw the first 16 pairs in Blocks 1, 3, and 5 with the high–low question and saw the second 16 pairs in Blocks 2, 4, 6 with the blue–red question). The types of questions participants received during encoding had no significant effects on their memory performance.

Immediately after the encoding phase, participants completed recall and location memory tests. In the recall test, participants were asked to describe as many pictures as they could remember in as much detail as possible. The location memory test assessed within-item memory binding, or how well participants remembered combinations of pictures and an

intrinsic feature of the picture (its location). The test was a two-alternative forced choice in which each of the 32 pictures was presented in two different locations with number labels (one in its original location and another in a new location). Participants were asked to indicate in which location they believed the picture had appeared in during the encoding trials by pressing one of the keys marked "1" through "8." A pair memory test was given last to examine how well participants remembered picture–shape combinations. As mentioned earlier, these pair memory results will not be presented here because both groups' performance was near floor level.

RESULTS

Item Memory

During free recall, the experimenter documented participants' descriptions of pictures. Two coders later evaluated the accuracy of the descriptions, coding participants' descriptions with numbers that corresponded with each of the pictures. Interrater reliability was .96; the coders discussed discrepancies until mutual agreement was reached. One point was given for each accurately described picture, and the total points were calculated for each participant. The proportion of pictures recalled of each type was computed.

A 3 (group: younger adults, older adults, and adults with AD) × 2 (arousal type: arousing and nonarousing) repeated-measures ANOVA revealed a main effect of group, $M_{young} = .29$, $SE = .02$; $M_{old} = .23$, $SE = .02$; $M_{AD} = .06$, $SE = .02$; $F(2, 51) = 28.27$, $MSE = .02$, $p < .001$, $\eta_p^2 = .53$. Tukey's post hoc analysis showed that younger and older adults recalled a significantly greater proportion of pictures than did the AD group ($p < .001$ for both comparisons), whereas younger and older adults did not differ significantly ($p = .22$). There was a main effect of arousal, indicating that arousing pictures were more likely to be recalled than nonarousing pictures, $M_{arousing} = .29$, $SE = .02$; $M_{nonarousing} = .09$, $SE = .01$, $F(51, 1) = 86.83$, $MSE = .01$, $p < .001$, $\eta_p^2 = .63$. We also found an interaction between group and arousal, $F(52, 2) = 14.16$, $MSE = .01$, $p < .001$, $\eta_p^2 = .36$ (see Table 1 for all means and standard errors). Separate analyses for each group indicated that all groups recalled significantly more arousing than nonarousing pictures; however, the effect of arousal was greater in younger adults, $F(1, 17) = 53.02$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .78$, and healthy older adults, $F(1, 17) = 33.70$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = .67$, than in participants with AD, $F(1, 17) = 5.64$, $MSE = 0.01$, $p < .05$, $\eta_p^2 = .25$.

To examine the effect of valence, we conducted a 3 (group) × 2 (valence: positively vs. negatively arousing) repeated-measures ANOVA. We found a main effect of valence, $M_{negative} = .26$, $SE = .03$; $M_{positive} = .32$, $SE = .02$; $F(1, 51) = 5.84$, $MSE = .01$, $p < .05$, $\eta_p^2 = .10$, indicating that participants across the groups recalled more positive than negative pictures. There was no significant interaction between group and valence (see Table 1).

TABLE 1. Mean (*SD*) Item and Location Memory Accuracy for Arousing (Negative and Positive) and Nonarousing Items

	Younger adults	Older adults	Adults with AD
Recall, Experiment 1			
Arousing	.42 (.04)	.38 (.04)	.08 (.04)
Negative	.41 (.04)	.33 (.04)	.06 (.04)
Positive	.43 (.04)	.42 (.04)	.10 (.04)
Nonarousing	.15 (.02)	.09 (.02)	.04 (.02)
Location, Experiment 1			
Arousing	.89 (.04)	.85 (.04)	.63 (.04)
Negative	.89 (.04)	.89 (.04)	.66 (.04)
Positive	.90 (.05)	.84 (.05)	.59 (.05)
Nonarousing	.86 (.04)	.81 (.04)	.59 (.04)
Recognition, Experiment 2			
Arousing	.88 (.05)	.79 (.05)	.53 (.05)
Negative	.84 (.05)	.78 (.05)	.60 (.06)
Positive	.92 (.05)	.79 (.05)	.46 (.06)
Nonarousing	.81 (.05)	.70 (.05)	.54 (.05)
Location, Experiment 2			
Arousing	.86 (.03)	.82 (.03)	.64 (.04)
Negative	.85 (.05)	.81 (.05)	.68 (.05)
Positive	.87 (.04)	.83 (.04)	.60 (.05)
Nonarousing	.87 (.04)	.70 (.04)	.59 (.04)

Note. *For Experiment 1, the proportion of total items of that type that were recalled is reported; for Experiment 2, corrected recognition (hits – false alarms) is reported. Location memory is the proportion of responses that were correct. AD = Alzheimer's disease.*

Location Memory (Within-Item Memory Binding)

We used a 3 (group) × 2 (arousal type) repeated-measures ANOVA to examine the proportion of location forced-choice responses that consisted of correct responses (Figure 1). There was a main effect of group, M_{young} = .88, SE = .04; M_{old} = .83, SE = .04; M_{AD} = .61, SE = .04; $F(2, 51)$ = 15.17, MSE = .05, $p < .001$, $\eta_p^2 = .37$. Tukey's post hoc analysis showed that younger and older adult controls performed significantly better than the AD group, $p < .001$ for both comparisons, whereas younger and older adults did not differ significantly, $p = .67$. There was a main effect of arousal indicating that arousal increased location memory, $M_{arousing}$ = .79, SE = .02; $M_{nonarousing}$ = .76, SE = .02, $F(2, 51) = 5.28$, MSE = .01, $p < .05$, $\eta_p^2 = .09$, but no interaction between group and arousal, $F(2, 51) = .08$, MSE = .01, $p = .92$, $\eta_p^2 = .003$ (see Table 1).

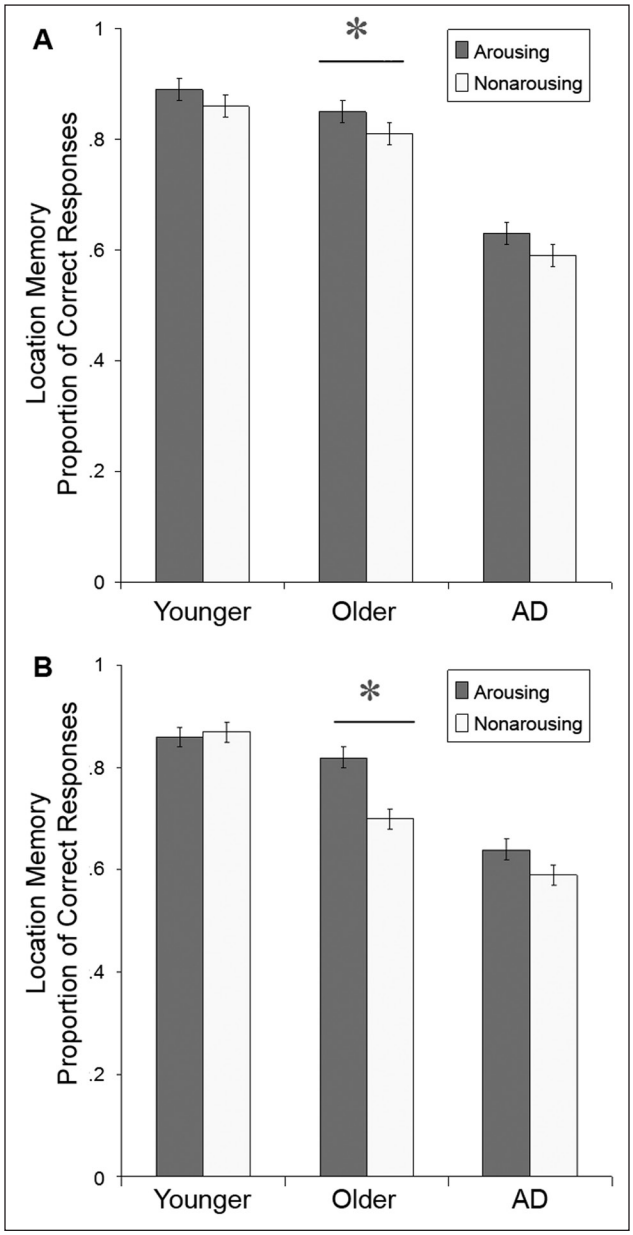

FIGURE 1. (a) Location memory for arousing and nonarousing pictures in younger and older adults and adults with Alzheimer's disease, Experiment 1. (b) Location memory for arousing and nonarousing pictures in younger and older adults and adults with Alzheimer's disease, Experiment 2

The effect of valence on location memory was analyzed with a 3 (group) × 2 (positively vs. negatively arousing) repeated-measures ANOVA. There was no main effect of valence and no interaction between group and valence (see Table 1). The AD group appeared to benefit more from negative than positive context, but the difference was not significant, $p = .25$.

DISCUSSION

All groups recalled a greater number of arousing and nonarousing items. However, the effect of arousal on recall was smaller in the patient group than control groups, suggesting that the benefit of emotional content on item memory is present but does diminish with the disease. Moreover, participants across groups demonstrated similar memory enhancement for the locations of arousing items than the locations of nonarousing items.

In contrast with this finding of consistent arousal-enhanced location memory across age groups, in a previous study we found that healthy older adults showed no arousal-based enhancement in within-item memory binding (Nashiro & Mather, 2011). The encoding procedures in the two studies were identical except that we repeated stimuli twice in the current experiment rather than once in the previous study. Thus, one possible explanation for why the current study found more evidence for arousal-enhanced memory binding than the previous study was that while repeating items more frequently reducing encoding load, repetition increased the effect of arousal on location memory for older adults. Thus, in the second experiment we tried increasing repetition further to see whether we could replicate the current results.

One limitation of Experiment 1 was the unbalanced gender ratio in our sample; we had fewer men than women in the younger and older groups. Our

initial analyses indicated that gender had no effect on item memory and memory binding. However, given previous findings on gender differences in emotional memory at both behavioral and neural levels (e.g., Canli, Desmond, Zhao, & Gabrieli, 2002), it is important to further clarify that our results were not specific to any gender. In Experiment 2, we attempted to have a more balanced gender ratio within and between groups.

EXPERIMENT 2

In Experiment 2, we were interested in replicating and extending the results from Experiment 1. As repetition seemed to increase the effect of arousal for older adults, we increased the number of repetitions from two to three. In addition, in order to further reduce cognitive load during encoding, we presented fewer items (16 pictures instead of 32). With these changes, we aimed to determine whether the memory advantage for arousing stimuli observed in recall in Experiment 1 would replicate for recognition memory and whether the increase in location memory for arousing pictures would replicate.

METHOD

Participants

We recruited 24 younger adults (M_{age} = 19.17 years, 7 men, 17 women, age range 18–21 years; $M_{education}$ = 12.88 years), 24 adults over 60 from various retirement communities who had not been diagnosed with dementia or other cognitive disorders (M_{age} = 74.89 years, 7 men, 17 women, age range 65–89 years; $M_{education}$ = 13.18 years), and 18 patients with a clinical diagnosis of probable AD from Alzheimer's Association early stage support groups in the Lafayette, Mountain View, and Santa Cruz offices in California (M_{age} = 73.50 years, 8 men, 10 women, age range 58–90 years; $M_{education}$ = 16.83 years). Neuropsychological assessments were conducted by their respective physicians, neurologists, psychiatrists, and neuropsychologists. To confirm the diagnoses of the disease, we asked participants to provide their diagnostic records. All participants with AD were diagnosed with mild probable Alzheimer's disease within 2 years before participating in this study. No patient had a history of stroke, head injury, or other neurological illness.

The CERAD was conducted in the same manner as in Experiment 1. One healthy older adult and one person with AD did not complete the tests because of time constraints. Compared with the AD group, younger and older controls had significantly higher scores on the word recall test, M_{young} = .48, range = .20-.80; M_{old} = .45, range = .20-.80; M_{AD} = .16, range = .00-.50, $F(2, 61) = 25.56$, $MSE = .02$, $p < .001$, and on the recognition test (hits – false alarm rates), M_{young} = .89, range = .70–1.00; M_{old} = .86, range = .50–1.00; M_{AD} = .45, range = .00-.90, $F(2, 61) = 31.28$, $MSE = .04$, $p < .001$. There was no difference between the younger and older control groups on either test.

Because of the different gender ratios and levels of education in the two participant groups, we included gender and education as covariates in all analyses. There were no significant effects of gender and education in any of the analyses; therefore, we will not discuss them further. Participants received monetary compensation, and the experiments were conducted in the lab, at participants' homes, or at senior centers, using a laptop.

Materials

We used the same 64 photographs as in Experiment 1, which were divided into Set A and Set B. Participants were randomly assigned to view either set. Half of the assigned set was used as study materials and the other half as lures in the recognition test. Which half of the set was presented during the study phase was randomized, and each set contained an equal number of neutral and arousing photographs. In order to keep the procedure consistent with that in Experiment 1, we presented the 32 shapes used in Experiment 1 together with the photographs.

Procedure

The procedure was the same as that in Experiment 1 except for the following modifications. There were four blocks of trials; in each of these participants viewed the same set of 16 photograph–shape pairs one at a time. Various encoding tasks were given to the participants to keep them engaged. The encoding task in Blocks 1 and 4 were the same as the dot color identification task used in Experiment 1 (participants indicated whether the dot was blue or red between trials). The task in Block 2 was identical to the other encoding task described in Experiment 1 in which participants indicated whether the photograph was higher or lower than the shape. In Block 3, partici-

pants were asked, "Is the photograph bigger (B) or smaller (S) than the shape?" Participants answered by pressing one of the keys marked "B" or "S," at which point the next pair was presented.

Immediately after the encoding phase, participants completed recognition and location memory tests. In the recognition test, we randomly presented 16 studied and 16 nonstudied photographs and asked participants to indicate whether they had seen the pictures in the study session by pressing one of the keys marked "YES" or "NO." The location memory test was the same as that in Experiment 1. A pair memory test was given last, but the results will not be discussed here because performance was near floor on this test.

RESULTS

Item Memory

Corrected recognition scores were calculated (hits – false alarm rates). A 3 (group: younger adults, older adults, and adults with AD) × 2 (arousal type: arousing and nonarousing) repeated-measures ANOVA revealed a main effect of group, $M_{young} = 0.85$, $SE = 0.04$; $M_{old} = 0.74$, $SE = 0.04$; $M_{AD} = 0.53$, $SE = .05$; $F(2, 63) = 12.91$, $MSE = 0.08$, $p < .001$, $\eta_p^2 = .29$. Tukey's post hoc analysis showed that younger and older adults recognized a significantly greater proportion of pictures than did the AD group, $p < .001$ and $p = .004$, respectively, whereas younger and older adults did not differ significantly, $p = .18$. There was a main effect of arousal, $M_{arousing} = 0.73$, $SE = 0.03$; $M_{non-arousing} = 0.68$, $SE = 0.03$; $F(2, 63) = 4.21$, $MSE = 0.02$, $p < .05$, $\eta_p^2 = .06$, but no interaction between group and arousal, $p = .28$. A 3 (group) × 2 (valence: positively vs. negatively arousing) repeated-measures ANOVA revealed no main effect of valence but a significant interaction between group and valence, $F(2, 63) = 3.60$, $MSE = .03$, $p < .05$, $\eta_p^2 = .10$ (see Table 1). Further analyses suggested that the AD group had better recognition memory for negative than positive pictures, $F(1, 17) = 4.21$, $MSE = .04$, $p = .06$, $\eta_p^2 = .20$, although the difference was only marginally significant. Neither younger nor older healthy controls showed a significant difference between memory for negative and positive pictures.

In addition, the hit and false alarm rates were separately examined. A 3 (group: younger adults, older adults, and adults with AD) × 2 (arousal type: arousing and nonarousing) repeated-measures ANOVA of hit rates revealed no significant findings. The same analysis for false alarm rates found a main effect of group, $F(2, 63) = 19.42$, $MSE = .03$, $p < .001$, $\eta_p^2 = .38$ (see Table 2 for all means and standard errors). Tukey's post hoc analysis suggested that people with AD made more false alarms than did the younger and older groups, $p < .001$ for both comparisons, whereas younger and older adults did not differ significantly, $p = .507$. A 3 (group) × 2 (valence: positively vs. negatively arousing) repeated-measures ANOVA of hit rates revealed a main effect of group, $F(2, 63) = 3.41$, $MSE = .06$, $p < .05$, $\eta_p^2 = .10$, suggesting that younger adults obtained significantly more hits than did people with AD. The same analysis for false alarm rates found a main effect of group, $F(2, 63) = 14.58$, $MSE = .04$, $p < .001$, $\eta_p^2 = .32$, suggesting that people with AD made significantly more false alarms than did the two other groups. Overall, we did not find the effects of emotion and valence on false alarm rates in any groups (cf. Gallo, Foster, Wong, & Bennett, 2010; Kapucu, Rotello, Ready, & Seidl, 2008; Thomas & Hasher, 2006). However, this lack of effects of valence on false alarms may have been due to very low false alarm rates in the younger and older groups.

TABLE 2. Mean (*SD*) Item Hit and False Alarm Rates for Arousing (Negative and Positive) and Nonarousing Items, Experiment 2

	Younger adults	Older adults	Adults with AD
Hits			
Arousing	.89 (.03)	.82 (.03)	.75 (.04)
Negative	.85 (.04)	.82 (.04)	.78 (.05)
Positive	.92 (.04)	.82 (.04)	.72 (.05)
Nonarousing	.82 (.04)	.76 (.04)	.78 (.05)
False alarms			
Arousing	.01 (.03)	.04 (.03)	.22 (.03)
Negative	.01 (.03)	.04 (.03)	.18 (.04)
Positive	.00 (.03)	.03 (.03)	.26 (.04)
Nonarousing	.01 (.03)	.06 (.03)	.24 (.03)

Note. *AD = Alzheimer's disease.*

Location Memory

Location memory accuracy was calculated as the proportion of correct responses of the total responses. A 3 (group) × 2 (arousal type) repeated-measures ANOVA revealed a main effect of group, $M_{young} = 0.86$, $SE = 0.03$; $M_{old} = 0.76$, $SE = 0.03$; $M_{AD} = 0.62$, $SE = 0.04$; $F(2, 63) = 15.11$, $MSE = 0.04$, $p < .001$, $\eta_p^2 = .32$. Tukey's post hoc analysis showed that younger and older adults performed significantly better than the AD group, $p < .001$ and $p = .005$, respectively, whereas younger and older adults did not quite differ significantly, $p = .05$. There was a main effect of arousal, $M_{arousing} = 0.77$, $SE = 0.02$; $M_{nonarousing} = 0.72$, $SE = 0.02$; $F(2, 63) = 5.60$, $MSE = 0.02$, $p < .05$, $\eta_p^2 = .08$, but no significant interaction between group and arousal. The results were consistent with those in Experiment 1, indicating an overall arousal-based increase in location memory that did not significantly differ between the groups.

The effect of valence on location memory was analyzed with a 3 (group) × 2 (positively vs. negatively arousing) repeated-measures ANOVA. There was no main effect of valence and no interaction between group and valence (see Table 1).

DISCUSSION

Arousal improved item memory for healthy younger and older adults, but the effect was less for people with AD. The results of location memory were also similar to those in Experiment 1. We found a main effect of arousal but no group × arousal interaction, suggesting that, in general, participants had better memory for the locations of arousing than nonarousing pictures. Valence had little influence on location memory in all groups.

GENERAL DISCUSSION

The current study examined the effect of arousal on item memory and within-item memory binding in healthy younger and older adults and people with AD. A previous study we conducted using similar methods (Nashiro & Mather, 2011) revealed that whereas younger adults showed arousal-enhanced location memory, older adults did not. Given mixed findings in previous research, the current study further probed the effects of arousal on older adults' location memory to see whether there are any benefits of emotional arousal for location memory binding when easier memory tasks were used than in Nashiro and Mather's study.

The results from two experiments revealed that healthy older adults and people with AD remembered a greater number of arousing than nonarousing items, indicating that emotional arousal improves item memory in normal aging and in AD, although the item memory enhancement effect was smaller in the patient group. Importantly, participants across groups had better memory for the locations of arousing than nonarousing pictures, whereas valence had little influence on location memory. The results demonstrate that the effects of emotional salience on within-item memory binding previously found in younger adults (Mather et al., 2009; Mather & Nesmith, 2008; Mather & Sutherland, 2009) are similarly present in older adults with and without AD.

Task difficulty may play a role in determining the size of the arousal effect for older adults with and without AD. In Nashiro and Mather's (2011) study, healthy older participants viewed 32 pictures twice and showed no arousal enhancement in location memory. In Experiment 1 of the current study, we presented the same number of items three times, and older participants showed better location memory for arousing than nonarousing pictures. In Experiment 2 of the present study, we reduced encoding load further by increasing the number of presentations to four and reducing the number of pictures to 16. In Experiments 1 and 2, older adults showed an effect of arousal on location memory, with a larger effect in Experiment 2 (*M*s = .85 and .81 for arousing and nonarousing, respectively, in Experiment 1 and *M*s = .82 and .70 in Experiment 2). One possible interpretation of these results is that combining the benefits of emotional salience and adequate exposure to items in the present study led to location memory enhancement in healthy older adults. Because older adults have age-related memory binding deficits to begin with, they may need more exposure to stimuli than younger adults to benefit from arousing content to increase within-item feature binding. In the case of people with AD, it is unclear whether more exposure to items would benefit them because they showed similar effects of arousal on location memory in Experiments 1 and 2 (*M*s = .63 and .59 for arousing and nonarousing, respectively, in Experiment 1 and *M*s = .64 and .59 in Experiment 2).

Why would arousal increase within-item memory binding? The arousal-biased competition theory (Mather & Sutherland, 2011) proposes that an emotional item has high priority and captures attention when there is no other competing high-priority information. This arousal-induced attention increases within-item feature binding, leading to deeper encoding and thus better retention of bound information (see Mather & Sutherland for further discussion of this issue). Previous research has shown that the ability to detect emotionally arousing stimuli is relatively stable with normal aging (Knight et al., 2007; Leclerc & Kensinger, 2008; Mather & Knight, 2006). Prior evidence also suggests that patients with AD have normal physiological responses to emotional stimuli (Hoefer et al., 2008) and the ability to process emotional information as well as do healthy controls (Lavenu et al., 1999; Luzzi et al., 2007; Roudier et al., 1998). Furthermore, the effects of emotional arousal on memory remain similar in normal aging (Denburg et al., 2003; Kensinger et al., 2002) and are relatively well preserved in AD (Kazui et al., 2003; Moayeri et al., 2000; Satler et al., 2007). Preserved arousal enhancement of memory in both groups seems to compensate for their memory binding impairment when memory tasks are easy, as evidenced by our finding that participants across groups had better location memory for arousing than nonarousing pictures. Presumably, arousing components of items attracted their attention, which strengthened perceptual binding and thereby increased memory for within-item features.

Our results were in line with previous studies suggesting that emotional information embedded in target items improved older adults' source memory (e.g., May et al., 2005; Rahhal, May, & Hasher, 2002). However, there is also counterevidence that neither younger nor older adults showed benefits of emotional content on source memory (Davidson, McFarland, & Glisky, 2006). One possible explanation for this discrepancy is differences in levels of task difficulty across studies. As described earlier, our previous and current results together suggest that healthy older adults benefit more from emotional content when tasks are easy. Therefore, it is possible that studies suggesting no effect of emotion on source memory used tasks that are cognitively challenging for older adults. However, the fact that Davidson et al. failed to replicate previous findings on beneficial effects of emotion on source memory by using similar methods as those in previous studies (Doerksen & Shimamura, 2001; Kensinger & Corkin, 2003) warrants further investigation into discrepancies across studies.

One limitation of the current study was younger adults' possible ceiling effects in location memory, indicating that the tasks were too easy for them, which may have reduced any potential arousal effects. Future studies should use more appropriate levels of task difficulty for each group to avoid this issue. Another limitation of the current study was the small number of stimuli. Although the low number of stimuli was intentionally selected, it might have limited our ability to observe larger effects of emotion on memory performance. Despite these limitations, the current study provides important information about the benefits of emotional arousal on memory binding in older adults and people with AD. These findings may lead to strategies to help reduce memory-binding impairments previously observed in both groups.

NOTES

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