

Effects of Emotional Valence and Arousal Upon Memory Trade-Offs With Aging

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Attention can be attracted faster by emotional relative to neutral information, and memory also can be strengthened for that emotional information. However, within visual scenes, often there is an advantage in memory for central emotional portions at the expense of memory for peripheral background information, called an emotion-induced memory trade-off. The authors examined how aging impacts the trade-off by manipulating valence (positive, negative) and arousal (low, high) of a central emotional item within a neutral background scene and testing memory for item and background components separately. They also assessed memory after 2 study–test delay intervals, to investigate age differences in the trade-off over time. Results revealed similar patterns of performance between groups after a short study–test delay, with both age groups showing robust memory trade-offs. After a longer delay, young and older adults showed enhanced memory for emotional items but at a cost to memory for background information only for young adults in negative arousing scenes. These results emphasize that attention and consolidation stage processes interact to shape how emotional memory is constructed in young and older adults.

Keywords: emotion, aging, memory, trade-off

Unique characteristics of emotional stimuli can lead to qualitative and quantitative differences in memory for emotional relative to non-emotional information; however, the impact may differ between young and older adults. Emotional information strengthens memory quality and longevity in some ways and adversely affects it in other ways. Several factors may interact to produce this outcome. Evidence has shown that the composition and strength of emotional memory is affected by stimulus characteristics such as valence (how positive or negative) and arousal level (how calming or soothing, or how exciting or agitating; Denburg, Buchanan, Tranel, & Adolphs, 2003; Libkuman, Stabler, & Otani, 2004; see Russell, 1980, for discussion of these dimensions). Further, time-dependent cognitive processes may differently affect which types of emotional stimuli are remembered best for young compared with older adults across varying study–test delay intervals (Klein-smith & Kaplan, 1963; Libkuman et al., 2004; Sharot & Yonelinas, 2008). To date there has been lack of consensus of reporting how these factors contribute to differences in a memory trade-off effect in older adults compared with young adults. In this experiment, we examined how varying stimulus valence and arousal characteristics, and delay interval, can affect emotional memory in young and older adults.

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Effects of Aging Upon Emotional Memory

There is conflicting evidence regarding the ways in which emotion affects memory quality and strength as people age. Healthy aging often leads to reduction in general attentional and memorial abilities, although aging may have a lesser impact on memory for information with emotional salience. A number of studies have demonstrated that emotion processing is well maintained in aging (Kensinger, 2008; May, Rahhal, Berry, & Leighton, 2005; reviewed by Mather, 2006), and although older adults have generally attenuated memorial ability, both young and older adults experience an enhancement in memory strength for emotional relative to neutral information (Denburg et al., 2003; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002; Otani, Libkuman, Widner, & Graves, 2007). Despite evidence that older adults' memories can benefit from emotion, the memory strength and composition of young and older adults' emotional memories have varied with several factors across studies.

Attentional focus upon emotional information at the point of encoding strongly influences the content of later memories, including the likelihood that emotional information is subsequently better remembered than neutral information (Hamann, 2001; McGaugh, 2000). Some evidence has shown there is an overall enhancement in memory for emotional stimuli compared with neutral stimuli (D'Argembeau & Van der Linden, 2004; Heuer & Reisburg, 1990; Libkuman, Nichols-Whitehead, Griffith, & Thomas, 1999), but in other instances only certain portions of complex emotional stimuli are better remembered than neutral stimuli (Burke, Heuer, & Reisburg, 1992; Kensinger, Garoff-Eaton, & Schacter, 2007a; Kensinger, Piquet, Krendl, & Corkin, 2005; Libkuman et al., 2004). In general, emotional information in an image is more likely to be detected and attended to at the outset (Ohman, Flykt, & Esteves, 2001; Phelps, 2006). Emotional infor-

mation may act as an “attention magnet,” heightening focus and concentration upon the emotionally arousing features of a stimulus while drawing attention away from less salient features (reviewed by Reisberg & Heuer, 2004). Easterbrook’s (1959) cue-utilization hypothesis proposed that as attention is drawn toward emotionally arousing information, fewer attentional resources are available for processing information peripheral to the central attention-grabbing component. The resultant effect is enhanced encoding of central emotional information, yet relatively reduced encoding of neutral peripheral information. Results from several studies evaluating memory for negative versus neutral scenes have shown that the differential allocation of attention to emotional stimuli can enhance memory for the central emotional item at the expense of memory for peripheral or contextual scene details (reviewed by Buchanan & Adolphs, 2002; Reisberg & Heuer, 2004). This enhancement in memory for emotional items in a scene with an accompanying deficit in memory for background or context is called an *emotion-induced memory trade-off*. In some cases, young and older adults have evidenced a similar magnitude of trade-off in memory for negative versus neutral emotional scenes (Denburg et al., 2003; Kensinger et al., 2005, Experiment 1; Otani et al., 2007). However, results of other studies have reported that a trade-off in emotional memory is more pervasive in older adults than young adults (Kensinger, Gutchess, & Schacter, 2007; Kensinger et al., 2005, Experiment 2), leaving open questions about how aging changes the construction of emotional memories.

There are several reasons to believe that aging may impact the expression of an emotion-induced memory trade-off. Older adults may focus more on their thoughts and feelings toward central emotional items than young adults (Comblain, D’Argembeau, Van der Linden, & Aldenhoff, 2004; Mather & Carstensen, 2003), causing more lingering attention upon emotional stimuli by older adults than young adults. There is also evidence that older adults have difficulty shifting attention flexibly (Hasher, 2007), which may make them less able to direct attention away from the emotional focus and toward the peripheral details. Age-related deficits in visual processing pathways may be another factor contributing to older adults’ increasing difficulties processing complex pictures (Chee et al., 2006). Impairments in coupling objects with context within the visual system could lead to problems remembering complex scenes. Although this alone would not explain the differences in magnitude of the trade-off effect for certain types of emotional scenes over others, it could contribute to older adults’ difficulties forming a coherent representation of both the central and peripheral elements of a scene.

Effects of Valence and Arousal on Memory

Prior studies examining the impact of aging on the trade-off effect have compared memory only for negative arousing or neutral items placed within a context, leaving unresolved questions about the degree to which young or older adults’ memories are affected differently by stimulus valence or arousal level (Libkuman et al., 2004; see also Denburg et al., 2003, for evidence that some types of trade-offs can occur for positive as well as negative stimuli). Examining how the affective qualities of valence and arousal impact older adults’ memories has become an important topic of investigation, because there have been conflicting results regarding the influence of these dimensions on older adults’ mem-

ories. In some research, the dominant effect in both age groups has been one of arousal; young and older adults often remember both positive and negative information well as long as it is high in arousal (Kensinger, 2008; Murphy & Isaacowitz, 2008). In other cases, young and older adults show effects of valence as well as arousal upon memory, not only remembering arousing pictures better than non-arousing ones but also remembering negative pictures better than positive ones (Comblain et al., 2004) or vice versa (Denburg et al., 2003; Kensinger & Corkin, 2004; Leigland, Schulz, & Janowsky, 2004). Despite these suggestions that age may not strongly influence the impact of valence and arousal on memory, there is other evidence that older adults show a “positivity effect” in memory, remembering proportionally more positive information than young adults (Mather & Carstensen, 2005), perhaps because of their tendency to sustain their attention on positive information and to elaborate upon its personal significance (see Isaacowitz, Wadlinger, Goren, & Wilson, 2006; Kensinger & Leclerc, 2009; Mather, 2006). A recent study also suggested that the positivity effect may occur more often for non-arousing than for arousing stimuli (Kensinger, 2008), emphasizing the need to consider both valence and arousal simultaneously when examining age-related changes in emotional memory.

Within the context of the present study, either valence or arousal could influence how the scenes are processed. Most studies (dating back to Easterbrook, 1959) have discussed the trade-off in terms of arousal-induced processing, with processing resources being focused on arousing stimuli, thereby preventing processing of the non-arousing context. Within this framework, valence might not matter in terms of the strength of the trade-off; as long as stimuli evoked arousal, the trade-off might be apparent. However, particularly when examining age differences in the trade-off, we reasoned that valence could be a strong contributor. If older adults’ attention is sustained more readily on positive information than on negative information, this could lead to a stronger trade-off observed for positive than negative scenes in older adults. By contrast, if young adults’ attention is drawn more readily toward negative information (Ohman et al., 2001), they could be expected to show the reverse pattern in memory; there would be a stronger trade-off in memory for negative than positive scenes. For these reasons, we believed it was important to vary stimulus valence and arousal levels when examining effects of emotion upon young and older adults’ memory trade-offs.

Effects of Delay Interval Upon Emotional Memory

As noted above, there has been a lack of agreement in results of past studies investigating age differences in emotional memory. Although considering both valence and arousal simultaneously may help to clarify the pattern of results, another important factor to consider probably relates to the delay interval over which memory is tested. Prior research comparing young and older adults’ memories for emotional information has tended to assess memory only at one delay, and the vast majority of studies have examined memory after relatively short study–test intervals (e.g., a few minutes or hours). Therefore, the duration of study-to-test delay interval has remained a relatively unconsidered factor in prior investigations into emotional memory changes with aging. However, some research suggests that stimulus valence and arousal characteristics may shape the retention of information

differently over long delays compared with short delays, at least for young adults. In particular, the effects of arousal on memory are often exaggerated after longer delays compared with shorter ones (see LaBar & Phelps, 1998; Payne, Stickgold, Swanberg, & Kensinger, 2008; Sharot & Phelps, 2004; Sharot & Yonelinas, 2008). The fact that the memory benefit for emotional items compared with neutral ones can become enhanced after a delay suggests that there are post-encoding actions leading to retention in memory, particularly for emotional stimuli. There may be differential memory strengthening for items that are elaborated and rehearsed (Libkuman et al., 2004) or neurochemical processes that enhance the likelihood that hippocampal processes are elicited to consolidate emotional events (McGaugh, 2000). Of course, encoding processes may influence post-encoding processes such that more deeply encoded items are more likely to be consolidated over the long term (as discussed by Hamann, 2001). These results emphasize that, at least in young adults, memory for emotional stimuli is affected by both encoding and post-encoding processes, leading to differing patterns in memory across short compared with longer delay intervals. It is not clear whether aging preserves these effects of delay on emotional memory, and it is an important issue to consider in understanding the extent to which aging impacts the mechanisms supporting emotional memory.

Present Study

The objective of this experiment was to investigate the behavioral effects of aging upon memory for central emotional items within photographic scenes relative to memory for peripheral background details. We varied the valence (positive, negative) and arousal (low, high) levels of the central emotional items placed against neutral backgrounds and compared participants' memory for these item and background scene components with their memory for neutral items placed upon neutral backgrounds. By testing memory for item components and background components separately during retrieval, we could assess the effects of valence and arousal on central item memory and on memory for peripheral non-emotional background elements across participant age groups. Note that by *central* and *peripheral*, we refer to the information's relevance to the emotional meaning of the scene, not to the spatial location of the information within the scene (i.e., central items were not necessarily presented at the center of the scene; see Reisberg & Heuer, 2004, for further discussion of this distinction).

Participants studied scenes at two time points and took one recognition memory test that probed their memories for items and backgrounds that had been studied a short time ago (approximately 10 min) or longer (approximately 24 hr). This manipulation allowed us to examine whether the trade-off magnitude varied if memory for scene information was tested after a short or long consolidation period. If the strength of the trade-off is comparable after a short compared with a long study–test delay interval, that finding would suggest that the trade-off is due primarily to encoding stage processes, perhaps resulting from attentional deployment or item elaboration. However, if the strength of the trade-off differs with delay interval, beyond an overall attenuation in memory accuracy, that pattern would suggest that consolidation processes also play an important role in shaping emotional memory content (see Payne et al., 2008, for further discussion in young adults). Thus, by using this methodology, we investigated whether

young and older adults showed similar behavioral patterns in emotional memory trade-offs over short and long delay intervals or whether the composition of emotional memories is fundamentally different between young and older adults.

Method

Participants

Participants included 24 young adults (13 men, 11 women; mean age = 19.6 years) and 24 older adults (11 men, 13 women; mean age = 72.8 years). Young adults were students at Boston College recruited through flyers on campus and the psychology department participant recruitment website. They received either class credit or \$10/hr for participating. Older adults were recruited from the Harvard University Cooperative on Aging and by flyers posted in the community, and they received \$10/hr for participating. Participants were limited to those who had not seen the stimuli used here within the context of any previous studies, and stimulus novelty was confirmed upon debriefing. No participants reported a history of psychiatric or neurological disorders, alcoholism, or present treatment with centrally acting medications. Participants were screened for the presence of depression or high anxiety. All participants had normal or corrected-to-normal vision and were not colorblind. Participant characteristics are described in Table 1. Informed consent was obtained in a manner approved by the Boston College institutional review board.

Stimuli

Stimuli consisted of scenes we created by placing images of emotional and neutral items onto neutral background scenes. One hundred fifty nameable, photographic-quality color items were included from each of three emotional valence categories of positive, negative, and neutral, for a total of 450 items. This stimulus set included images used in prior studies (Kensinger, Garoff-Eaton, & Schacter, 2006; Kensinger et al., 2007a; Kensinger, Garoff-Eaton, & Schacter, 2007b) and those that were gathered from photo clip art packages (Hemera Technologies, Quebec, Canada) and from the International Affective Picture System (Lang, Bradley, & Cuthbert, 1997). One hundred sixty-four images from prior studies had been previously rated for stimulus valence and arousal levels by young and older adults. For an additional 286 new items, we had normative information regarding stimulus valence, and so we asked an additional 10 young and 6 older adults to rate those new items for arousal level. Arousal was rated on a 5-point scale, with low numbers indicating soothing or subduing images and high numbers signifying exciting or agitating images. Valence was rated on a 7-point scale, with low numbers signifying negative valence and high numbers reflecting positive valence. Negative stimuli were rated less than 3 in valence, neutral stimuli were in the midrange for valence (rated 3–5; i.e., neither positive nor negative), and positive stimuli were those images with valence ratings greater than 5. All neutral items were judged to be low in arousal. We applied a median split to the sets of positive and negative items to create distinct high-arousal and low-arousal stimulus groups (positive median arousal = 2.39, negative median arousal = 3.86). For positive and negative stimuli, high-arousal items were rated significantly more arousing than low arousal

Table 1
Characterization of Participants

Test	Young adults		Older adults		<i>df</i>	<i>F</i>	<i>p</i>
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>			
Mini-Mental State Examination ^a			29.50	0.16			
Stroop 1 ^b	104.26	3.32	99.75	3.28	1, 46	<0.50	<i>ns</i>
Stroop 2 ^b	79.54	2.48	67.79	2.94	1, 47	9.33	.004
Stroop 3 ^b	53.54	2.49	39.38	1.98	1, 47	19.77	<.0005
Digit Symbols Substitution ^c	49.00	1.54	34.04	1.56	1, 47	46.59	<.0005
Verbal Fluency to letters ^d	47.54	2.65	47.54	1.99	1, 47	<.001	<i>ns</i>
Verbal Fluency perseverations ^d	0.63	0.18	1.50	0.22	1, 47	9.69	.003
Digits Recall, backward ^c	8.96	0.41	8.58	0.55	1, 47	0.30	<i>ns</i>
Shipley Vocabulary Test ^e	32.17	0.53	35.71	0.62	1, 47	18.80	<.0005
Dysexecutive Questionnaire ^f	21.83	1.72	15.38	1.95	1, 47	6.16	.02
Beck Anxiety Inventory ^g	13.33	2.57	5.75	1.01	1, 47	7.52	.01
Beck Depression Inventory ^h	4.33	0.65					
Geriatric Depression Scale ⁱ			1.21	0.32			

Note. Verbal Fluency to letters represent the total number of words produced in 60 s each for letter *F*, *A*, and *S*. Verbal Fluency perseverations represent the number of times words are repeated for a given letter.

^a Folstein, Folstein, & McHugh (1975). ^b Stroop (1935). ^c Wechsler (1997). ^d Spreen & Benton (1977). ^e Shipley (1986). ^f Wilson, Alderman, Burgess, Emslie, & Evans (1996). ^g Beck, Epstein, Brown, & Steer (1988). ^h Beck & Steer (1993). ⁱ Sheikh & Yesavage (1986).

items, $t(134) > 12.39, p < .001$.¹ Items with arousal ratings falling exactly on the median split value, or ranked two items above or below that value, were excluded from use. Items that had a difference greater than 0.90 between arousal ratings given by older and young adults were not included in the final stimuli selection (28 items excluded). The final stimulus set used included 68 low-arousal positive, 68 high-arousal positive, 68 low-arousal negative, 68 high-arousal negative, and 136 neutral items.

We placed images of emotional and neutral items in the context of neutral background scenes (e.g., a snake by a river; see Figure 1A) taken from Kensinger et al. (2007a) and supplemented from International Affective Picture System (Lang et al., 1997) and clip art packages (Hemera Technologies) to create composite scenes. Across emotional categories, scenes were matched for size and location of foreground object, congruency of object and background scene, and visual complexity. Across participants, items from all three of the emotional valence categories were paired with any particular background (e.g., scene of either a kitten [positive], a snake [negative], or a chipmunk [neutral] by a river; see Figure 1A), and across participants, some items were viewed in the context of multiple backgrounds (e.g., a tombstone on a grassy hill or a desert), so it was possible to isolate effects attributed to emotionality of items and not to the background within scenes. It is important to note that each participant saw only a particular type of item or background once; the valence of the item paired with each background was counterbalanced across participants.

We varied the four emotional scene type combinations of valence (positive, negative) and arousal levels (low, high) to create eight lists of 60 scenes each (15 low-arousal positive, 15 high-arousal positive, 15 low-arousal negative, 15 high-arousal negative) matched for equivalent ratings of valence type and for arousal level. We added 15 scenes with neutral items to the 60 emotional scenes in each list, for a total of 75 scenes in each stimulus set list. There was no main effect of arousal between stimuli set lists for positive or negative stimuli, $F_s(3, 119) < .50$. Study list versions and presentation order were counterbalanced between participants.

Composite scenes from the study sessions were separated into their isolated item and background components and each shown independently in a later recognition memory test (e.g., a kitten shown independently from a river background; see Figure 1C).

Procedure

Participants were allowed to choose whether they preferred to schedule morning or afternoon research appointments for two sessions. In the session on Day 1, they viewed 75 scenes presented against a white computer screen background for 3 s each (see Figure 1B). Scenes were approximately 10 × 12 in. (25.4 × 30.5 cm) and displayed directly in front of the participant. Immediately after viewing each scene, participants were presented with a screen asking whether they would prefer to approach or retreat from the scene if they encountered it in real life. Participants were given 7 s after viewing the scene to enter their response using a 7-point scale, in which 1 = *move very close*, 4 = *stay at present location*, and 7 = *move very far away*. As soon as a response was entered, the program advanced to the next image. Everyone completed a short practice version before beginning the task to ensure that the instructions were clear. Standardized cognitive testing measures were administered after the participants completed the scene-viewing task (results shown in Table 1).

Participants returned for a second session approximately 24 hr later. During this session on Day 2, they viewed an additional 75 scenes with the same procedure used on Day 1. Immediately following this portion, participants received a surprise recognition memory test in which items and backgrounds from the composite scenes they had viewed were presented independently from one

¹ Although the negative low-arousal items were rated as significantly more arousing than the neutral items ($p < .001$), the positive low-arousal items were not significantly more arousing. Thus, the absence of any memory enhancement for the positive low-arousal items could stem from the lack of arousal-related processing for those items.

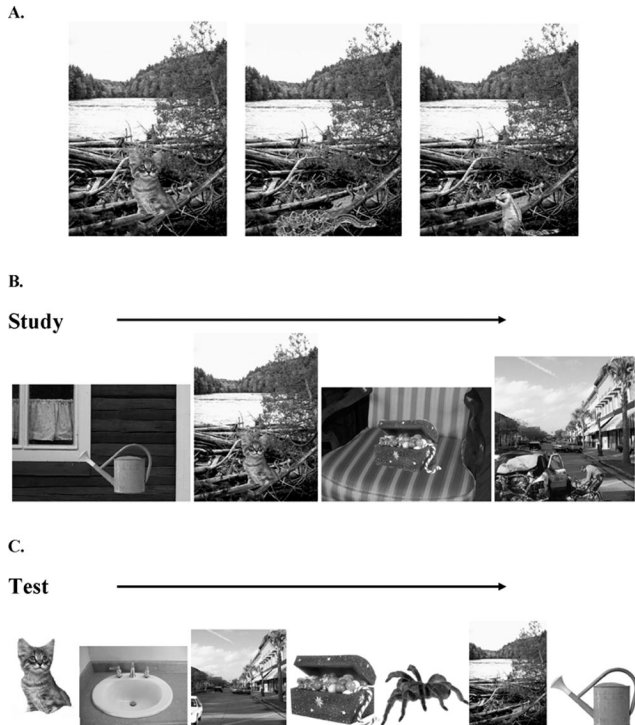


Figure 1. Example of positive (kitten), negative (snake), and neutral (chipmunk) items placed in the context of a neutral background scene (Figure 1A) and examples of studied scenes (Figure 1B) and items and backgrounds presented separately at test (Figure 1C).

another. Participants were told that items and backgrounds from scenes viewed during the same-day study session and the study session a day earlier were intermixed with novel items and novel backgrounds (test stimuli comprised 75 items from Day 1, 75 backgrounds from Day 1, 75 items from Day 2, 75 backgrounds from Day 2, 150 novel backgrounds, and 258 novel items, for a total of 708 test items). The stimuli included on the recognition task were uniform across participants and shown in a pseudo-randomized order; the study lists were counterbalanced for whether stimuli were studied or novel and for the emotionality of the item that had been studied with each background.

To prevent fatigue, we presented the test in four sections, and participants could take a short break between sections if they preferred. They viewed each item or background for 3 s, and when the image left the screen, participants had 10 s to select a key to indicate whether the item or background had been included in a scene viewed during either study session (old) or was novel (new). This was adequate time for all participants to input responses. All old items were presented in the same orientation as they had been studied initially. Participants completed a short practice version before beginning the test and were asked to describe the task in their own words to ensure that they correctly understood the meaning of old and new scene components.

Data Analysis

We conducted an analysis of variance (ANOVA) to examine effects of valence (positive, negative), arousal (low, high), and

study-to-test delay period (short, long) upon memory for scene components (items, backgrounds) between young and older adults. Although the background components were all neutral in valence, the valence and arousal levels assigned to backgrounds within analyses were defined by the type of item with which they had been paired in a composite scene during a prior study session (e.g., positive high-arousal background indicates a background, such as a kitchen table, that had been studied as part of a scene containing a positive high-arousal item, such as a birthday cake).

Response values used in analyses for each participant are corrected recognition scores of hit minus false alarm rates (reported in Table 2).² We computed these corrected recognition scores to take into consideration differences in participants' biases to indicate that an item was old. We calculated recognition scores for neutral scene components to establish baseline recognition rates for items and for backgrounds. We subtracted the baseline recognition rates for neutral items from the recognition rates for items of each emotional scene type, and subtracted the recognition rate for backgrounds from neutral scenes from the recognition rates for backgrounds from each type of emotional scene, to establish difference scores. For example, the difference score for positive high-arousal items would be equivalent to the recognition rate for positive high-arousal items minus the recognition rate for neutral items (see Leclerc & Kensinger, 2008, and Payne et al., 2008, for use of these types of difference scores). We computed this difference score to allow us to conduct analyses revealing the presence of interactions between factors of valence (positive, negative) and arousal (low, high) using a 2×2 ANOVA design, rather than measuring the difference directly between five emotional scene types (positive low-arousal, positive high-arousal, negative low-arousal, negative high-arousal, neutral).³

Results

Throughout the results section, the term *emotional enhancement in item memory* refers to occasions when emotionally salient items (positive, negative; low arousal, high arousal) are remembered more often than neutral items. The term *decrement in memory for backgrounds* refers to occasions when backgrounds that had been paired with emotional (central) items in a scene are remembered less often than backgrounds previously paired with neutral items. Finally, a *trade-off effect* is noted specifically when there is both an emotional enhancement in item memory and a decrement in mem-

² There was no significant interaction in the trade-off effect between emotional scene memory and gender, $F_s(1, 44) < 0.64$, $p_s > .10$, $\eta_p^2 < .06$, so results from men and women were collapsed for all analyses.

³ The same general conclusions were supported by ANOVAs with a five-level factor of emotion-condition (positive low, positive high, negative low, negative high, neutral) or by ANOVAs that included factors of valence and arousal but that excluded analysis of the neutral items (i.e., comparing memory for the positive low, positive high, negative low, negative high scenes), thereby eliminating the need to compute difference scores. The primary difference between these analyses and those reported in this article was that these additional analyses revealed a main effect of group (poorer memory for the older adults), whereas the use of difference scores masked this age effect and allowed us to focus upon the effects of age on the difference in memory between emotional and neutral scene components.

Table 2
Corrected Recognition and False Alarm Rates for Young and Older Adults

Study–test delay	Valence	Arousal	Young adults		Older adults		
			Corrected recognition (<i>SE</i>)	False alarms	Corrected recognition (<i>SE</i>)	False alarms	
Items							
10 min	positive	low	.63 (.03)	.19	.42 (.03)	.24	
		high	.75 (.03)	.15	.51 (.03)	.24	
	negative	low	.75 (.03)	.16	.47 (.05)	.25	
		high	.65 (.03)	.26	.50 (.03)	.32	
1 day	neutral		.60 (.03)	.17	.42 (.03)	.23	
	positive	low	.51 (.03)	.19	.22 (.02)	.24	
		high	.58 (.03)	.15	.28 (.04)	.24	
	negative	low	.59 (.03)	.16	.32 (.03)	.25	
high		.59 (.03)	.26	.35 (.03)	.32		
1 day	neutral		.41 (.03)	.17	.19 (.03)	.23	
	Backgrounds	10 min	positive			.24 (.02)	
			negative			.22 (.03)	
		1 day	positive			.26 (.03)	
negative					.19 (.03)		
1 day	positive	low	.46 (.04)	.18 ^a	.31 (.04)	.24 ^a	
		high	.31 (.03)		.14 (.03)		
	negative	low	.28 (.03)		.13 (.03)		
		high	.32 (.03)		.15 (.03)		
1 day	neutral	low	.17 (.03)		.12 (.03)		
		high	.30 (.03)	.18 ^a	.16 (.03)	.24 ^a	

^a One false alarm value is applied for all new backgrounds within each age group because backgrounds are inherently neutral when presented in isolation.

ory for backgrounds from a particular scene type. Thus, a trade-off would be present only when emotion significantly enhanced memory for items of a particular emotional type and also significantly impaired memory for the backgrounds with which they had been studied.

Enhancement in Item Memory

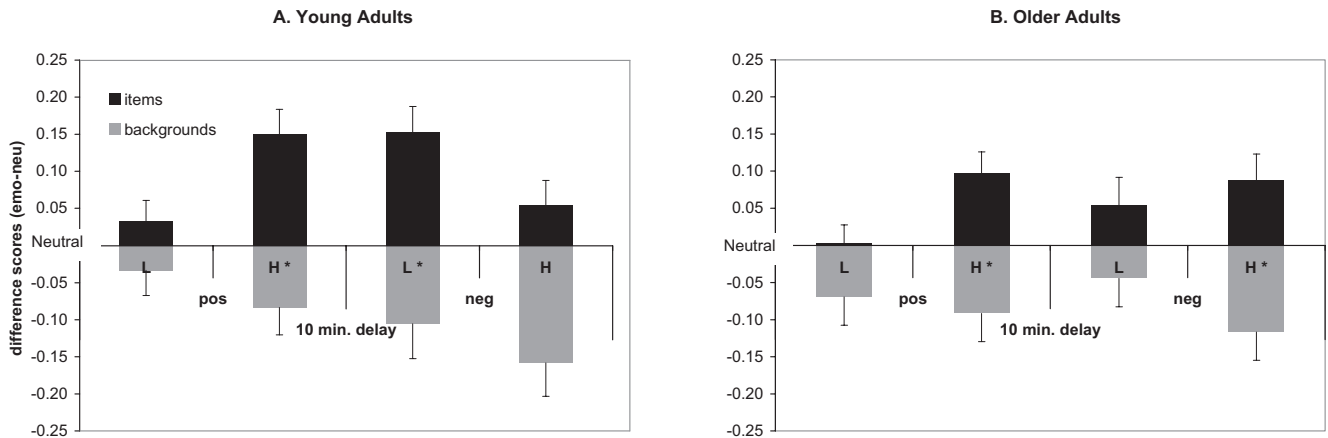
We conducted an ANOVA to understand how the emotional enhancement in item memory was affected by the within-subjects factors of valence (positive, negative), arousal (low, high), and delay (short, long) and the between-subjects factor of age group (young adults, older adults). Results investigating the emotional enhancement in item memory revealed main effects of delay, $F(1, 46) = 4.02, p = .05, \eta_p^2 = .08$; arousal, $F(1, 46) = 8.25, p < .01, \eta_p^2 = .15$; and valence, $F(1, 46) = 8.06, p < .01, \eta_p^2 = .15$. These main effects were qualified by interactions between valence and arousal, $F(1, 46) = 13.22, p < .001, \eta_p^2 = .22$; between delay and valence, $F(1, 46) = 4.81, p < .05, \eta_p^2 = .10$; and among the factors of delay, valence, and arousal, $F(1, 46) = 4.42, p < .05, \eta_p^2 = .09$. Notably, when results from both delay intervals were collapsed for the emotional enhancement in item memory, there was no main effect of age group or any significant interactions with age group, $F_s(1, 46) < 1.17, p_s > .08, \eta_p^2 < .06$.

To better understand how study–test delay period affected the emotional enhancement in item memory (i.e., the basis for the three-way interaction among delay, valence, and arousal), we ran separate ANOVAs on the data acquired after each delay interval (e.g., short-delay or long-delay test), with factors of valence, arousal, and age group. After a short delay interval, there was a main effect of arousal, $F(1, 46) = 4.46, p = .04, \eta_p^2 = .09$, but not

of valence or group, $F_s(1, 46) < 1.08, p_s > .30, \eta_p^2 < .02$. Results also showed a significant interaction between valence and arousal, $F(1, 46) = 21.30, p < .0005, \eta_p^2 = .32$, qualified by an interaction observed among the factors of valence, arousal, and group, $F(1, 46) = 6.76, p = .01, \eta_p^2 = .13$ (see Figures 2A and 2B). This three-way interaction emerged because although both groups demonstrated similar memory patterns for positive items, there were some variations in memory for high- and low-arousal negative items between groups; older adults experienced a greater enhancement in memory for high- than low-arousal negative items, yet young adults experienced a greater enhancement in memory for low- than high-arousal negative items (see Figure 2). After a long delay, there were main effects of valence, $F(1, 46) = 15.10, p < .0005, \eta_p^2 = .25$, and arousal, $F(1, 46) = 5.78, p < .02, \eta_p^2 = .11$, reflecting the significantly greater emotional enhancement in memory for negative than positive items (negative, $M = .16$; positive, $M = .10$) and for high-arousal than low-arousal items (low, $M = .11$; high, $M = .15$). There was no significant main effect of group, $F(1, 46) = 1.64, p = .21, \eta_p^2 = .03$, or any interactions among the factors of valence, arousal, and group, $F(1, 46) < 2.46, p > .12, \eta_p^2 < .05$.

In summary, analyses investigating enhancement in memory for items of each emotional valence and arousal combination showed that when recognition memory was tested after a short study–test delay, there was an emotional enhancement in item memory for scenes of all types except positive low-arousal scenes, $t(47) < 0.90$; all others, $t_s(47) > 3.02, p_s < .005$. After a long delay, an emotional enhancement in item memory was observed in response to all emotional scene types, $t(47) > 2.28, p < .03$, although the enhancement was stronger for negative than positive items (see

10-minute study-test delay interval



1-day study-test delay interval

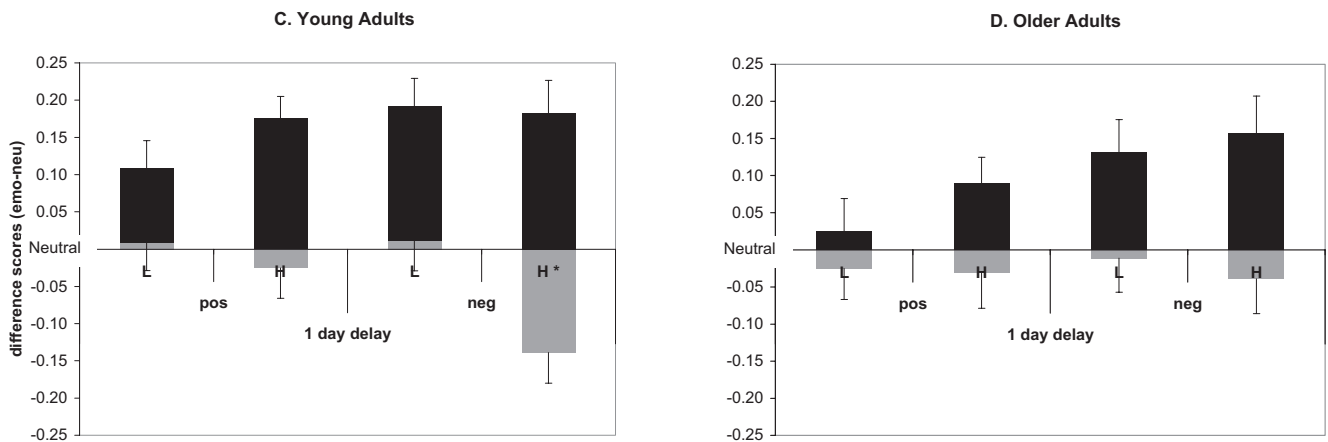


Figure 2. Responses from young and older adults across a 10-min and 1-day study-test delay interval for enhancement in item memory (black bars), decrement in memory for backgrounds (gray bars), and a trade-off in scene memory (denoted with an asterisk). Error bars indicate standard error of the mean. L = low arousal; H = high arousal; pos = positive; neg = negative; emo-neu = emotional minus neutral.

Figures 2C and 2D). The effects of emotion upon item memory enhancement were consistent in the two age groups, with the exception of differences between groups in the effects of arousal level upon memory for negative items at the short study-test delay interval.

Decrement in Memory for Backgrounds

An ANOVA examining memory for background elements revealed a main effect of delay, $F(1, 46) = 3.99, p = .05, \eta_p^2 = .08$, reflecting the fact that after a short study-test delay, there was a decrement in memory for backgrounds presented with any type of emotional item, $t(47) > 2.15, ps < .04$, whereas after a long delay, the decrement in background memory was present only for negative high-arousal scenes, $t(47) = 2.97, p < .005$. The ANOVA also revealed main effects of valence, $F(1, 46) = 7.50, p < .01, \eta_p^2 = .14$, and arousal, $F(1, 46) = 22.15, p < .0005, \eta_p^2 = .33$, although these main effects were qualified by interactions between valence and group, $F(1, 46) = 8.19, p < .01, \eta_p^2 = .15$, and between valence and

arousal, $F(1, 46) = 4.66, p < .05, \eta_p^2 = .09$. The interaction between valence and group arose because young adults demonstrated a significant main effect of valence, $F(1, 23) = 11.36, p = .003, \eta_p^2 = .33$, but older adults did not ($F < 0.02$). Young adults experienced a larger decrement in memory for backgrounds presented with negative items than for backgrounds presented with positive items (negative, $M = -.10$; positive, $M = -.03$), whereas older adults demonstrated a nearly equivalent decrement in memory for backgrounds associated with items of both valence types (positive and negative, $M = -.05$). The Valence \times Arousal interaction reflected the fact that there was a greater decrement in memory for backgrounds paired with high-arousal than low-arousal items, particularly within negative scenes (see Figure 2).

Trade-Off Effect

A trade-off effect occurs when memory for scenes reveals both a significant emotional enhancement in item memory and a sig-

nificant decrement in memory for backgrounds of scenes of a particular emotional valence and arousal type. The instances when both of these requisite circumstances arise to produce a trade-off in scene memory are reported in Table 3. On the basis of these criteria for a trade-off effect, after a short study–test delay interval, older adults showed a trade-off in memory for high-arousal positive and negative scenes, and young adults showed a trade-off in memory for positive high-arousal scenes and negative low-arousal scenes (see Figures 2A and 2B). After a long study–test delay, the incidence of a trade-off effect decreased markedly for both age groups. As observed in Figure 2C and 2D, older adults no longer demonstrated a trade-off in memory for any emotional scene type after a long delay, whereas young adults did show a trade-off, in their memory for negative high-arousal scenes.

Discussion

Results of this study emphasize the need for consideration of multiple factors to understand the influence of emotion on young and older adults' memories. The trade-offs in memory for emotional scenes demonstrated by both young and older adults confirm that emotion does not have uniform effects on memory. Within the visual domain, emotion strengthens memory for scene components differentially, depending upon the components' valence and arousal characteristics and their relations to other scene elements. Moreover, because the types of scenes that lead to a trade-off in memory differ across short and long delay intervals, these results suggest that both encoding-stage processes and post-encoding processes modulate the effects of emotion upon memory. Although many studies have explained the trade-off in terms of attentional focusing during encoding (e.g., Easterbrook, 1959; Reisberg & Heuer, 2004), these results emphasize the importance of post-encoding factors, which may include interference, rehearsal, and consolidation processes. In the sections below, we elaborate upon the importance of these findings for understanding emotion's modulation of memory in young and older adults.

Emotional Enhancement in Item Memory

Despite lower recognition accuracy rates for older adults than young adults (see Table 2), both age groups showed emotional

enhancement in item memory after short and long delays. At the short delay, the two age groups showed similar patterns of enhancement for positive items, with both groups demonstrating a robust enhancement for high-arousal positive items and no significant enhancement for low-arousal positive items. For the negative items, there was a suggestion of an age effect, with older adults' enhancement exaggerated for high-arousal items and young adults' enhancement stronger for low-arousal items. These results are in accordance with prior findings revealing less of a boost in memory for non-arousing emotional information in older adults than in young adults, particularly for negative non-arousing information (Kensinger, 2008). These findings indicate that older adults may not be subject to the short-term effects of low-arousal emotional stimuli to the same extent as young adults, consistent with evidence that emotional stimuli may need to surpass a higher threshold of arousal to evoke an emotional enhancement in item memory in older adults when given only a short study–test interval for consolidation processes (Gunning-Dixon et al., 2003; Wright, Dickerson, Feczko, Negeira, & Williams, 2007). However, the effects in the young adult group are somewhat counterintuitive, with memory enhancement greater for the negative low-arousal items than the negative high-arousal items. We cannot offer a firm explanation for these results, although it is possible that the pattern occurred because of a Yerkes–Dodson (1908) type of effect, whereby the highest levels of arousal led to impairing effects over the short term (but see Christianson, 1992, for debates about whether this type of pattern exists within emotional memory).

Importantly, despite these idiosyncrasies in the pattern of performance at the short delay, there was no evidence for a positivity effect with regard to older adults' memory for emotional items, and there was no suggestion of an age-related change in the overall magnitude of emotional enhancement in item memory. This general similarity in the pattern of performance across the two ages is consistent with prior evidence that older adults' emotion processing ability is preserved and that their attention can be drawn equally to negative and positive information, particularly when it is automatic detection or attention focusing that is being measured rather than more sustained or elaborative processing (Denburg et al., 2003; Hahn, Carlson, Singer, & Gronlund, 2006; Kensinger, 2008; Kensinger et al., 2005, 2007b;

Table 3

Trade-Offs in Emotional Scene Memory by Age Group, Study–Test Delay Interval, and Scene Type

Study–test delay	Young adults			Older adults		
	Item <i>p</i>	Background <i>p</i>	Trade-off present?	Item <i>p</i>	Background <i>p</i>	Trade-off present?
10 min						
Positive low arousal	.30	.28	no	.91	.08	no
Positive high arousal	.001	.05	yes	.003	.03	yes
Negative low arousal	<.0005	.04	yes	.17	.26	no
Negative high arousal	.10	.002	no	.02	.006	yes
1 day						
Positive low arousal	.01	.82	no	.55	.51	no
Positive high arousal	<.0005	.50	no	.02	.53	no
Negative low arousal	<.0005	.79	no	.002	.80	no
Negative high arousal	<.0005	.003	yes	.003	.35	no

Note. *P* values indicate significance level of *t* test comparing corrected recognition for emotional to neutral scene information (*df* = 23). Although the enhancement in memory for negative high-arousal items did not reach significance in young adults at a short delay interval, the uncorrected recognition value was the same as negative low-arousal items or positive high-arousal items.

Leclerc & Kensinger, 2008; Leigland et al., 2004; Mather, 2006). Because we did not detect a positivity bias in terms of the trade-off in scene memory, this result may suggest that the origin of the trade-off effect is related more to the impact of initial rather than sustained attention. Although we hesitate at drawing strong conclusions from a null result, a fruitful avenue for future research may be to increase scene-viewing time or to modify the encoding instructions to permit greater use of controlled cognitive mechanisms and a greater opportunity for sustained attention effects to influence memory. It is possible that under these conditions a positivity bias in older adults' memory would be noted (discussed by Kensinger & Leclerc, 2009; Mather, 2006).

The pattern of young and older adults' item enhancement was even more similar after a delay. Both age groups showed a greater enhancement in memory for negative than positive items and a greater enhancement for arousing items than for non-arousing ones. In general, the emotional enhancement effect also was greater after the long delay than after the short delay. Emotional arousal may necessitate slow consolidation and permit slower forgetting over a long study-test delay period than neutral information (McGaugh, 2000); thus, enhancement effects may become exaggerated after a delay, when both encoding and post-encoding processes are capable of influencing memory. Although it has been reported previously that young adults' memory enhancement for arousing words or pictures (i.e., their memory benefit for those items relative to neutral ones) can be greater after long study-test delay periods than after shorter ones (Sharot & Phelps, 2004; Sharot & Yonelinas, 2008), to our knowledge this study is the first to reveal a similar effect of delay in older adults. These results suggest that the influences of post-encoding processes, including consolidation and decay, on emotional memory enhancement may be consistent across the lifespan. Despite the general decline in baseline memory performance with aging, relative preservation of limbic structures and functioning may have permitted enhancement in memory for emotional over neutral items in the short-delay test as well as the retention of emotional information in memory after a consolidation period (Grieve, Clark, Williams, Peduto, & Gordon, 2005).

Thus, when examining the emotional enhancement in item memory, it becomes apparent that valence, arousal, and delay have generally similar effects on young and older adults' memory patterns. Although there may be some differences with regard to the effects of arousal on young and older adults' memories for negative information (see Grieve et al., 2005; Kensinger, 2008), these effects are present only after a short delay. After the opportunity for differential memory consolidation and decay processes to occur, young and older adults' patterns of emotional memory enhancement are remarkably similar.

Decrement in Memory for Backgrounds and the Memory Trade-Off Effect

Results of memory for scene backgrounds replicate prior findings that a decrement in memory for backgrounds can accompany an enhancement in item memory within emotional scenes for both young and older adults (Kensinger et al., 2005, 2007a). After a short delay, both young and older adults showed pervasive decrements in memory for backgrounds that had been studied with

emotional items, and for both age groups this decrement was weakest for backgrounds studied with positive low-arousal items. Despite the similarity in the background memory decrement after a short delay, there were age effects present when memory was tested after a longer delay. In particular, the decrement in memory for backgrounds was no longer present in older adults' memory for any scene type after a long delay, whereas young adults showed a decrement in memory for backgrounds studied with negative high-arousal items. These findings are noteworthy for two reasons. First, the fact that the decrement in emotional background memory was pervasive in both age groups after the short delay but did not occur as readily after the long delay suggests a particularly important effect of short-lasting, attentional effects on the trade-off. Participants' decrement in memory for the backgrounds appears to stem from how their attention is initially allocated during encoding, thereby yielding large trade-offs when memory is tested fairly immediately. However, once consolidation or storage processes have been implemented, those detrimental attentional effects are lessened. Thus, for all emotional scenes except for negative arousing ones, the background information appears to be more resistant to memory decay (across a delay) than the background information contained in a neutral scene. Second, the fact that age effects existed only at the long delay and not at the short delay suggests that the effects of age on emotional memory are intensified when post-encoding processes are measured, or when interactions between attention and consolidation processes can influence memory. Moreover, because the decrement in memory for backgrounds is typically attributed to the focal processing and storage of the emotional item within a scene, this age effect is broadly consistent with the suggestion that young adults may have more of a negativity focus than older adults (Charles, Mather, & Carstensen, 2003; Mikels, Larkin, Reuter-Lorenz, & Carstensen, 2005). It also is possible that older adults' failure to show a decrement in background memory after a long delay period arises because of differences in how young and older adults encode and maintain representations of items and backgrounds (e.g., Chee et al., 2006). For example, if older adults are less likely than young adults to couple together that the snake was presented in the forest, it is possible that over time their processing of the snake would not influence their processing of the forest, and their memory could strengthen or degrade at independent rates between those scene components. Although this type of uncoupling has also been shown to occur in young adults (e.g., Payne et al., 2008, have shown that memory for emotional items and their backgrounds can decay at different rates over sleep-filled delays), it is plausible that this type of uncoupling occurs more readily for older adults. The present study was not designed to investigate the issue of object-background coupling, and so further research is required to address this important issue.

Regardless of the exact processes giving rise to the decrement in memory for backgrounds, it is interesting that in the present study, older adults' trade-offs were less pervasive (i.e., less likely to be maintained over a delay) than young adults' trade-offs. This pattern contrasts with prior research revealing that older adults can show memory trade-offs after a broader range of encoding tasks than young adults. For example, young adults can successfully employ an encoding task that encourages attention to scene detail in order to distribute their attention effectively to background information, whereas older adults are not able to employ such an encoding strategy to overcome

trade-offs in memory (Kensinger et al., 2005, 2007). On the basis of the extant evidence, it seems that older adults show more pervasive trade-offs than young adults when those trade-offs reflect the way in which attention and encoding resources are allocated. By contrast, older adults may be less likely than young adults to maintain trade-offs over longer delays during which selective consolidation processes influence memory (see Payne et al., 2008, for evidence that young adults may selectively consolidate negative arousing elements of scenes).

Limitations and Directions for Further Research

We designed the scenes created for this study with the intent to minimize the impact of a host of factors, aside from emotional content, that could influence memory. For example, we carefully constructed and counterbalanced scenes across emotion types to reduce effects of scene cohesiveness, item familiarity, item size, and placement of items within a scene. The distance between high- and low-arousal scenes was matched across positive and negative scenes. Nevertheless, it is important to note that we could not match the positive and negative scenes in absolute arousal level. Because we applied a median split to divide the stimuli into high- and low-arousal groups, even though the distance between high- and low-arousal scenes was comparable for the negative and positive items, the negative stimuli were more arousing than positive stimuli overall. It is therefore possible that some of the effects of valence really are attributable to the higher arousal level of the negative items and that a positivity bias may be revealed if positive stimuli that are rated higher in arousal are included. Although it may be impossible to design scenes that are matched for arousal as well as for all the other features that we matched for here (e.g., item familiarity, size, placement in scene), it will be important for future research to examine the generality of these findings to other sets of stimuli.

It will also be important for future studies to examine whether the encoding task can influence the pattern of results over short and long delay intervals. Using an encoding task requiring participants to consider how much they preferred to approach or retreat from each scene may have evoked decision-making processes that older adults are more likely to make automatically than younger adults (Comblain et al., 2004; Mather & Carstensen, 2005). Allowing participants to direct their attention naturally or applying an encoding task that draws attention to more perceptual features of stimuli, instead of a decision guiding participants toward self-referential processing, may have produced a greater difference in the magnitude of the effect between young and older adults (Emery & Hess, 2008). It is possible that selecting a perceptual-focused encoding task or lengthening encoding times may produce a pattern of results in the trade-off effect that is consistent with a positivity bias in older adults; prior studies have found it is more often revealed under these encoding conditions (Emery & Hess, 2008). Further examination of the trade-off effect in young and older adults while manipulating encoding tasks can inform this possibility.

Conclusions

The results of the present study suggest that the composition and strength of young and older adults' memories for emotional scenes is not the same for all types of arousing information, regardless of valence. Rather, both valence and arousal may influence young and

older adults' memories, and their effects on memory may change as delay intervals increase. Although there were some age differences present, in general, the contributions of valence, arousal, and delay were similar between participant age groups. Both young and older adults evidenced a trade-off in memory for positive and negative scenes, and the magnitude of these trade-offs decreased after the opportunity for consolidation.

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