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Goal-Directed Memory: The Role of Cognitive Control in Older Adults' Emotional Memory

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The present study revealed that older adults recruit cognitive control processes to strengthen positive and diminish negative information in memory. In Experiment 1, older adults engaged in more elaborative processing when retrieving positive memories than they did when retrieving negative memories. In Experiment 2, older adults who did well on tasks involving cognitive control were more likely than those doing poorly to favor positive pictures in memory. In Experiment 3, older adults who were distracted during memory encoding no longer favored positive over negative pictures in their later recall, revealing that older adults use cognitive resources to implement emotional goals during encoding. In contrast, younger adults showed no signs of using cognitive control to make their memories more positive, indicating that, for them, emotion regulation goals are not chronically activated.

Keywords: aging, emotion, memory, motivation, executive function

Recent studies have revealed some intriguing age differences in the valence of emotional memory (for a review, see Mather & Carstensen, 2005). Compared with younger adults, more of what older adults recall is positive information than negative information, resulting in age by valence interactions in recall and recognition memory (Charles, Mather, & Carstensen, 2003; Leigland, Schulz, & Janowsky, 2004; Mather & Carstensen, 2003; Mather, Knight, & McCaffrey, 2005). For example, Charles et al. (2003) found a decrease across the adult life span in the proportion of recalled images that were negative, along with an increase in the proportion that were positive. This age by valence interaction was not influenced by gender, socioeconomic status, or ethnicity. Similar effects are seen in memory for choices, as older adults are more likely than younger adults to make memory errors in support of their choices (Mather & Johnson, 2000). Older adults' memories also tend to distort past health and behaviors in ways that make them seem more favorable (Kennedy, Mather, & Carstensen, 2004).

Socioemotional selectivity theory offers one explanation for these shifts in emotional valence in its tenet that regulating emotion is a more central goal for older adults than for younger adults (Carstensen, Isaacowitz, & Charles, 1999). According to the theory, as one's time left in life moves from seeming expansive to seeming more limited, goals focusing on information acquisition become less preeminent, and goals focusing on emotional well-being and emotionally meaningful aspects of life gain priority. Thus, older adults might attempt to avoid negative information that could detract from current emotional experience. Consistent with socioemotional selectivity theory, both cross-sectional and longitudinal studies have found that older adults report experiencing negative affect less frequently than do younger adults (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000; Charles, Reynolds, & Gatz, 2001; Labouvie-Vief & Medler, 2002; Mroczek & Almeida, 2004; Mroczek & Kolarz, 1998). Older adults also report using emotion regulation strategies more than do younger adults (Gross et al., 1997; Labouvie-Vief & Medler, 2002; Lawton, Kleban, Rajagopal, & Dean, 1992). They also are more likely than younger adults to prefer emotion-focused strategies to deal with social conflict (Blanchard-Fields, Camp, & Casper Jahnke, 1995) and to favor nonconfrontational strategies that help avoid conflict and negative affect (Birditt & Fingerman, 2005; Blanchard-Fields et al., 1995; Blanchard-Fields, Stein, & Watson, 2004; Winkeler, Filipp, & Boll, 2000).

From research with younger adults, we know that there are a number of strategies for regulating negative emotion, including reappraising a situation to decrease its emotional impact (Gross, 2001), retrieving positive memories (Josephson, Singer, & Salovey, 1996; McFarland & Buehler, 1997, 1998), suppressing the outward signs of emotion (Gross, 2001), and not attending to negative stimuli or thoughts (Parkinson & Totterdell, 1999). Each of these strategies is likely to recruit cognitive control processes such as selection among competing stimuli in attention, inhibition of goal-irrelevant information, and self-initiated encoding and retrieval. Supporting this link between emotion regulation and resource-demanding cognitive control processes, dividing attention, or otherwise limiting cognitive resources reduces younger adults' ability to regulate emotion (Muraven, Tice, & Baumeister, 1998; Wegner, Erber, & Zanakos, 1993). In addition, recent neuroimaging studies have revealed that prefrontal regions associated with cognitive control are activated when people engage in emotion regulation (for a review, see Ochsner & Gross, 2005).

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The idea that older adults' positivity effects in memory are the result of cognitive control processes may seem counterintuitive. After all, many studies have shown that older adults are worse than younger adults at tasks requiring cognitive control, such as inhibiting irrelevant information (Hedden & Gabrieli, 2004; M. K. Johnson & Raye, 2000; Prull, Gabrieli, & Bunge, 2000; Salthouse, Atkinson, & Berish, 2003; Zacks, Hasher, & Li, 2000). Nevertheless, even if their strategic processing is less effective, older adults may be more successful in regulating emotion if they devote a larger proportion of their resources to such goals. For instance, some studies have found that older adults who perform as well as younger adults on memory tasks show bilateral activation whereas younger adults show more unilateral activation patterns (Cabeza, 2002; Cabeza, Anderson, Locantore, & McIntosh, 2002; Reuter-Lorenz et al., 2000; Reuter-Lorenz, Stanczak, & Miller, 1999; Rosen et al., 2002). Thus, older adults may sometimes recruit additional resources to accomplish their goals.

We suggest that emotion regulation goals are chronically available at an unconscious level for older adults, whereas emotion regulation goals are activated only in certain contexts for younger adults (for discussions of chronic accessibility and unconscious goals, see Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trotschel, 2001; Fitzsimons & Bargh, 2004; Higgins, 1996). Thus, inducing younger adults to focus on their emotions can make their memories as positively biased as those of older adults, but in control conditions in which there are no external reminders about regulating emotion, younger adults' memories are less positively biased than are those of older adults (Kennedy et al., 2004; Mather & Johnson, 2000). As outlined in Figure 1, we further hypothesized that these chronic emotional goals recruit cognitive control processes to diminish negative information and enhance positive information as older adults navigate their everyday environment.

In the present study, we examined whether our model can account for older adults' positivity effects in memory. Like Charles et al. (2003), in each of our three experiments we showed participants a slide show of positive, negative, and neutral images selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999). In Experiment 1, we gave half the participants an additional memory test before the final memory test. If older adults use cognitive control to enhance memories for positive information relative to negative information, then repeated retrieval should increase the positivity effect. At the time of retrieval, they should allocate more attention to (and elaborate more on) positive information than to negative information. In Experiment 2, we examined whether older adults who do better on cognitive control tasks are better able to execute their emotional goals and therefore show a larger positivity effect. In Experiment 3, we reduced participants' access to cognitive control processes during memory encoding by having them do an unrelated task while watching the picture show. If our model is correct, dividing younger adults' attention should not influence the valence of their memories, because they do not have chronically available emotional goals. In contrast, the older adults should show more of a positivity effect in the full-attention condition, where they can engage cognitive control processes to implement their chronic emotion regulation goals, than they do in the divided-attention condition, where cognitive control processes are less available.

Experiment 1

In Experiment 1, we examined the impact of repeated retrieval on older adults' positivity effects in memory. Participants watched a picture slide show and were asked to recall the pictures 2 days later. Half of the participants also completed an intervening memory test 20 min after viewing the pictures. We hypothesized that if older adults spend more time and effort thinking about each positive memory that comes to mind than they do thinking about each negative memory, the additional retrieval attempt should strengthen memory more for the retrieved positive pictures than for the retrieved negative pictures. In particular, any positive picture retrieved on the first test should be less likely to be forgotten than any negative picture retrieved at the same time.

Recent work has highlighted the importance of considering the time of day when comparing younger and older adults' performance (for a review, see Yoon, May, & Hasher, 1999). Although not all tasks follow a circadian rhythm, older adults tend to prefer the morning as a time to carry out most daily activities, whereas younger adults prefer to carry out most daily activities in the afternoon (Hasher, Zacks, & May, 1999; May, Hasher, & Stoltzfus, 1993; Zacks et al., 2000). Cognitive tasks that have been shown to follow circadian patterns include those that require the acquisition of new information and those that require the implicit or explicit use of newly acquired information and inhibitory control over irrelevant and distracting material (Zacks et al., 2000). Because our research interests center on older adults' ability to carry out goal-directed processes and the influence of these processes on memory for emotional information, in all three experiments we controlled for time-of-day effects by randomly assigning half of the participants from each age group to morning testing sessions and half to afternoon testing sessions.

To rule out the possibility that any age differences in memory were due to age differences in the subjective interpretation of the images, we had all participants rate each image on the valence dimension. This allowed us to analyze recall based on participants' individual ratings to control for individual differences in the subjective interpretation of the images.

Insofar as older adults are in more positive or less negative moods than are younger adults (e.g., Carstensen et al., 2000), age

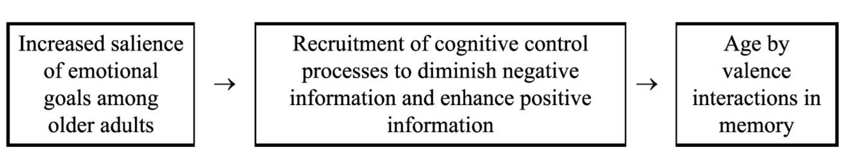

Figure 1. Proposed mechanisms of the age-related shift to favor positive over negative information in memory.

by valence interactions in memory may result from mood-congruent memory effects (Bower, 1981). To examine this possibility, we measured participants' moods at the beginning of the experiment session.

Method

Participants. The research participants consisted of older (65–83 years; $M = 72.72$, $SD = 4.68$; $N = 48$; 19 males) and younger (18–29 years; $M = 19.73$, $SD = 2.52$; $N = 48$; 12 males) adults. Older adults were recruited through flyers posted throughout Santa Cruz county. All older individuals successfully passed a phone version of the Mini-Mental State Examination that screens for dementia (Folstein, Folstein, & McHugh, 1975).[1] Younger participants were either students at University of California, Santa Cruz who received course credit or members of the community who received payment. Participants driving from off campus received $50, and those from on campus received $40.

Apparatus. In this experiment and in the following two experiments, the pictures were presented on the screen of a Power Macintosh G4 with PsyScope experimental software (Cohen, MacWhinney, Flatt, & Provost, 1993).

Stimuli. Participants viewed 48 digitized photographs (16 negative, 16 neutral, and 16 positive). Within each valence set, half of the images contained people, and half contained animals, natural scenery, or inanimate objects. Forty-one images were selected from the IAPS (Lang et al., 1999). The IAPS includes standardized ratings of the emotionality of each picture based on a scale ranging from 1 (*most unpleasant*) to 9 (*most pleasant*). In addition, the IAPS includes standardized ratings for arousal level on a scale ranging from 1 (*least arousing*) to 9 (*most arousing*). Because the IAPS had an insufficient number of pictures containing both people and a neutral rating, seven additional images were selected that conformed to the neutral/people category criteria: a shop selling sundries, people seated at a bar, people with scuba gear, people waiting in a lunch line, an outdoor clothes market, people on a boardwalk, and a crowded street fair. Only images with content that was distinguishable from the others in the set were selected to allow the coders to identify each one. The average IAPS valence of our images was 7.83 ($SD = .38$) for positive, 4.99 ($SD = .41$) for neutral, and 2.43 ($SD = .21$) for negative.

Procedure. The study involved two sessions. To control for the time of day, participants were randomly assigned to a morning (8 a.m.–11 a.m.) or an afternoon (12 p.m.–5 p.m.) testing time. Participants within each time-of-day group were also randomly assigned to one of two test conditions. In the repeated-test condition, participants were given a surprise recall test both 20 min after viewing the images and 48 hr after the images were presented. In the single-test condition, participants were given a recall test at the 48-hr delay only.

After giving informed consent and completing the Positive and Negative Affect Scale (PANAS), a brief questionnaire consisting of 10 positive and 10 negative emotion words (Watson, Clark, & Tellegen, 1988), participants were seated in front of a computer screen and were told that they would be viewing a series of pictures and that their task was simply to look at the pictures. The presentation consisted of 48 pictures shown for 2 s each. The order of the images was randomized for each participant. At the conclusion of the presentation, participants filled out a short demographics questionnaire and completed an unrelated filler task. Twenty minutes after the end of the picture presentation, participants in the repeated-test condition were given their first recall test. Participants were instructed to give, in as much detail as possible, a written description of all of the pictures they remembered seeing. Participants were also told that they could list the pictures in any order and that they could use as much time as needed.

The Horne-Ostberg Morningness-Eveningness Questionnaire (MEQ; Horne & Ostberg, 1976) was administered following the recall test (for participants in the repeated-test condition) or following the demographics questionnaire (for participants in the single-test condition). The MEQ consists of 19 questions and is scored on a scale ranging from 16 to 86, with scores indicating one of three categories: morning types, neutral types and evening types. Replicating previous findings of a shift toward morningness with age, older adults scored higher on the scale ($M = 65.02$) than did younger adults ($M = 43.83$), $t(89) = 12.23$, $p < .001$. Next, participants filled out the Nelson-Denny vocabulary test (Brown, Fishco, & Hanna, 1993) and the 20-item Center for Epidemiologic Studies Depression (CES-D) Scale (Radloff, 1977).

All participants returned after a 2-day delay (48 hr after their first session began) and completed the recall test. Thus, half the participants completed the recall test twice, and the other half of the participants completed it only once. The instructions on the single-test recall test were identical to those given for the repeated-test condition recall test. After completing the recall test in the second session, all participants viewed the same pictures once again, in a random order, and rated them on a scale ranging from 1 (*highly negative*) to 7 (*highly positive*).

Results

For all of the analyses in this article, we used a .05 alpha level, included 95% confidence intervals, and used partial Eta squared (η_p^2) to measure effect sizes.

Mood scores. On the PANAS, older adults reported more positive affect ($M = 36.08 \pm 1.80$) than did younger adults ($M = 27.15 \pm 1.80$), $t(93) = 7.04$, $p < .01$. Negative affect scores did not differ significantly between older adults ($M = 11.50 \pm .72$) and younger adults ($M = 12.94 \pm 1.40$), $t(93) = 1.83$, $p = .07$. In addition, older adults' scores on the depression scale ($M = 12.21 \pm 1.20$) did not differ significantly from those of younger adults ($M = 11.45 \pm 1.58$), $t(93) = .75$, *ns*.

Ratings. We analyzed participants' ratings of the pictures with a 3 × 2 mixed factorial analysis of variance (ANOVA) with our predetermined IAPS valence category (negative, positive, neutral) as a within-subjects factor and age (older, younger) and time of day (a.m., p.m.) as between-subjects factors. There was a main effect of valence rating, $F(2, 182) = 1688.93$, $p < .001$, $\eta_p^2 = .95$. Corroborating the IAPS valence categorizations, across both age groups, negative pictures were given lower valence ratings ($M = 1.67 \pm .10$) than were neutral ($M = 4.27 \pm .10$) and positive pictures ($M = 6.12 \pm .12$).

Older adults' average ratings were more positive ($M = 4.18 \pm .08$) than were younger adults' ratings ($M = 3.87 \pm .08$), $F(1, 91) = 27.10$, $p < .001$, $\eta_p^2 = .23$. In addition, there was a significant valence rating by age interaction, $F(2, 182) = 5.06$, $p < .01$, $\eta_p^2 = .05$. Older adults rated neutral pictures more positively ($M = 4.54 \pm .14$) than did younger adults ($M = 4.00 \pm .14$) and rated positive pictures more positively ($M = 6.29 \pm .18$) than did younger adults ($M = 5.96 \pm .17$) but rated negative pictures ($M = 1.70 \pm .15$) about the same as did younger adults ($M = 1.65 \pm .15$).

[1] Answering the questions involved reporting today's date, naming the current and previous presidents, counting backward by threes, repeating and later recalling and then recognizing three words the interviewer said, and describing how a dog and a lion are alike and how sugar and vinegar are different. In all three of our experiments, most participants answered all questions correctly. The one question some participants missed was the delayed recall for the three words (the most missed was two words). However, perfect performance on the recognition test that followed was required for the participant to be invited to come in for the session.

Table 1
Number of Positive, Negative, and Neutral Pictures Recalled in Experiments 1–3

Group	Positive	Negative	Neutral
	Experiment 1		
20-min delay (first test)			
Younger	6.75 (.42)	7.96 (.59)	4.96 (.46)
Older	5.54 (.48)	4.96 (.51)	3.52 (.42)
Total pictures	16	16	16
2-day delay (repeated test)			
Younger	5.92 (.47)	7.21 (.59)	4.58 (.36)
Older	5.08 (.53)	4.00 (.55)	3.08 (.40)
Total pictures	16	16	16
2-day delay (first test)			
Younger	2.79 (.32)	3.06 (.34)	2.46 (.38)
Older	3.44 (.36)	2.96 (.29)	2.04 (.38)
Total pictures	16	16	16
	Experiment 2		
Low cognitive control			
Younger	6.75 (.93)	9.08 (.60)	4.25 (.55)
Older	7.53 (1.06)	9.20 (.78)	4.13 (.57)
Total pictures	27	27	26
High cognitive control			
Younger	6.54 (.74)	10.31 (1.11)	4.77 (.96)
Older	8.44 (.87)	7.44 (.66)	3.31 (.57)
Total pictures	27	27	26
	Experiment 3		
Divided attention			
Younger	4.44 (.56)	6.13 (.69)	2.25 (.42)
Older	1.75 (.48)	4.88 (.74)	1.25 (.28)
Total pictures	27	27	26
Full attention			
Younger	6.88 (.93)	8.13 (.66)	4.94 (.94)
Older	8.69 (.62)	8.00 (.80)	5.25 (.86)
Total pictures	27	27	26

Note. Valence categories are based on individual ratings. Values enclosed in parentheses represent standard errors.

Recall. Two coders matched recall responses to the images. They agreed on 95.70% of the items. Discrepancies were resolved after the coders met and reached consensus. In total, 54 responses were uncodeable (1.1% of younger adults' recall and 4.8% of older adults' recall). Most of the uncodeable items were descriptions that were too general to be matched to a picture (e.g., "3 figures," "animals"). As shown in the Appendix, the pictures that younger adults recalled more often than did older adults were negative, whereas those that older adults recalled more often tended to be positive. (See Table 1 for number of items recalled.)

Images recalled were categorized according to each participant's valence rating for that image.[2] Participants' ratings for the images were sorted and divided into high, medium, and low valence categories, each comprising 16 items. This yielded subjective positive, neutral, and negative categories that had the same number of items for the younger and older adult groups. When multiple items at the boundaries of valence categories were given the same rating, the normative IAPS ratings were used to break the ties and determine category membership. To see how much participants favored negative or positive information in their recall, we then computed the proportion of total recall that consisted of positive and negative items (if valence does not affect recall levels, these values should each be about .33, on average).

Recall proportions after 48 hr. We examined the proportion of recall that consisted of positive images versus negative images with a repeated-measures ANOVA, with age (younger, older) and time of day (a.m., p.m.) as between-subjects factors and proportion of recalled items that were of each valence (negative, positive) as a within-subjects factor. Replicating previous findings (Charles et al., 2003), there was a significant age by valence interaction, $F(1, 92) = 6.00$, $p < .05$, $\eta_p^2 = .06$. Older adults recalled a larger proportion of positive images ($M = .42 \pm .04$) than did younger adults ($M = .34 \pm .04$).

[2] When we analyzed the results with the proportions of total recall that were positive, negative, or neutral on the basis of the normative valence categories, we found the same effects, but the effect sizes were typically smaller, which makes sense as participants' subjective ratings should be a better indicator of whether they found the picture positive or negative than should the ratings based on the population of younger adults used by the IAPS.

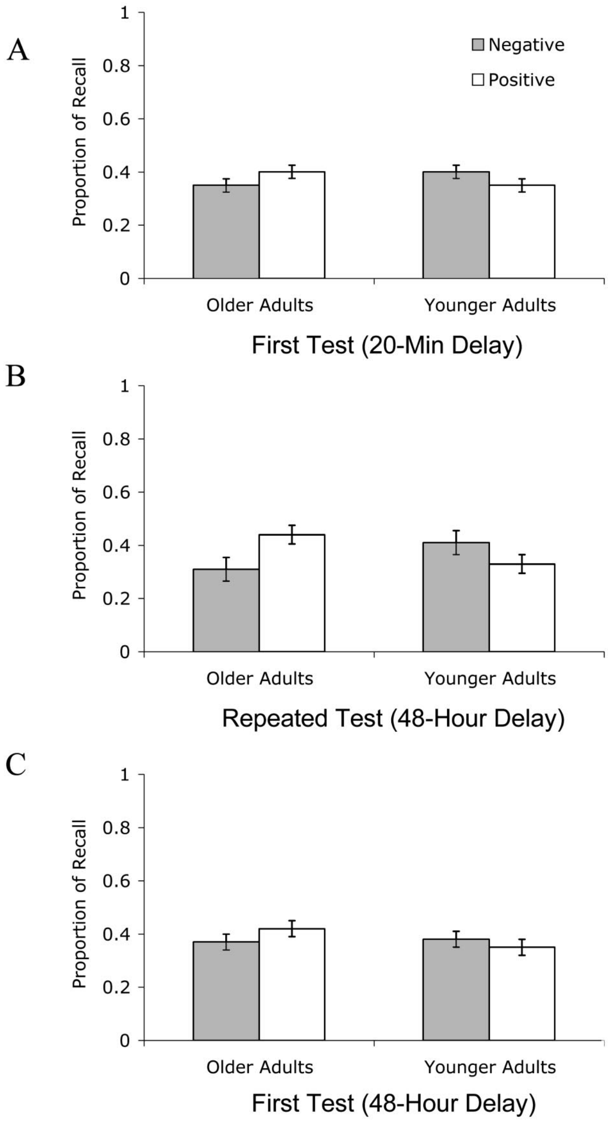

Figure 2. Experiment 1 proportions of recalled items that were positive or negative 20 min after encoding (A), for the same group on their second test 48 hr after encoding (B), and for the other group on their first test 48 hr after encoding (C). Error bars denote the standard error.

Younger adults recalled a larger proportion of negative images (M = .39 ± .04) than did older adults (M = .34 ± .04).[3,4]

Does the passage of time increase age differences in valence? We compared 20-min recall data for the repeated-test group (Figure 2a) with 48-hr recall data for the single-test group (Figure 2c) to examine the effects of the passage of time on an initial recall test. A repeated-measures ANOVA, with test delay (20 min, 48 hr), age (younger, older), and time of day (a.m., p.m.) as between-subjects factors and valence (negative, positive) as a within-subjects factor, revealed no significant interaction of age, valence, and test delay, $F(1, 88) = .12$, $p > .7$, $\eta_p^2 = .00$. Thus, the passage of time in itself has little impact on the positivity effect.

Do age differences in valence increase with repeated testing? We examined the impact of repeated retrieval attempts on the positivity effect for participants in the repeated-test condition (comparing data presented in Figures 2a and 2b) with a repeated-measures ANOVA. Valence (positive, negative) and test type (repeated test, single test) were within-subjects factors. Age (younger, older) was a between-subjects factor. There was a significant age by valence by test type interaction, $F(1, 46) = 5.78$, $p < .05$, $\eta_p^2 = .11$. At the 20-min delay, older adults recalled a larger proportion of positive images (M = .40 ± .05) than did younger adults (M = .35, CI ± .05) and a smaller proportion of negative images (M = .35 ± .05) than did younger adults (M = .40 ± .05). On the second test, older adults once again recalled a larger proportion of positive images (M = .44 ± .05) than did younger adults (M = .33 ± .05) and a smaller proportion of negative images (M = .31 ± .05) than did younger adults (M = .41 ± .05); however, the age differences in emotional recall were larger for the second retrieval than for the first retrieval.

Hypermnesia and forgetting rates. The strengthening of the age by valence interaction across repeated tests could be a result of additional pictures being recalled on the second test that were not recalled on the first. Examining age differences in the proportion of positive and negative images recalled on Test 2 but not on Test 1 with a 2 (age: older, younger) × 2 (valence: positive, negative) factor ANOVA revealed no significant interaction of age and valence, $F(1, 46) = .56$, *ns*, indicating that hypermnesia could not account for the increase in the age by valence interaction with repeated testing.

Alternatively, the increase in the age by valence interaction over the delay could be a result of differential forgetting rates. Indeed, examining the proportion of images recalled on Test 1 that were not recalled on Test 2 revealed a significant age by valence interaction, $F(1, 46) = 10.80$, $p < .01$, $\eta_p^2 = .19$ (see Table 2 for means). Older adults were about twice as likely to forget previously retrieved negative images than to forget previously retrieved positive images. In contrast, younger adults showed less of a

[3] The age by valence interaction remained significant when including the PANAS positive and negative scores as well as the CES-D scores as covariates, $F(1, 84) = 7.35$, $p < .01$, $\eta_p^2 = .08$. In addition, none of the covariates was significant (all *p*s > .2). (One younger participant's data could not be included in this analysis because of incomplete mood data.)

[4] Including whether the pictures had people in them or not as a factor yielded a significant age by valence by people interaction. Follow-up tests, separately for the people and the nonpeople pictures, revealed that there was a significant age by valence interaction for the people pictures but not for the nonpeople pictures. Experiments 2 and 3 were designed to equate stimuli on arousal. The low arousal positive and negative sets each had half people and half nonpeople pictures, but because of difficulties in finding enough nonpeople pictures in the high arousal categories, we had 11/16 people pictures in the positive high arousal category and 13/16 people pictures in the negative high arousal category. Adding whether the pictures had people or not as a factor led to different results in Experiment 2 and the control condition of Experiment 3, despite the fact that the experiments used the same stimuli and method. In Experiment 2, there was an age by valence by people interaction indicating a greater age by valence interaction for the people pictures, whereas in Experiment 3, there were no age by valence by people or age by valence by condition by people interactions in the overall data and no age by valence by people interactions when the data were analyzed separately in the control and divided attention conditions (all *p*s > .5). These conflicting results about whether the positivity effect is greater for pictures of people suggest that further investigation is needed to see if the increase is reliable.

Table 2
Proportions of Positive, Negative, and Neutral Pictures Forgotten in Experiment 1 Between the First (20-Min) and Second (2-Day) Recall Test

Experiment 1: Repeated-test group	Positive	Negative	Neutral
Younger	.20 (.05)	.14 (.04)	.17 (.05)
Older	.15 (.03)	.32 (.06)	.26 (.06)

Note. Valence categories are based on individual ratings. Values enclosed in parentheses represent standard errors.

difference in forgetting rates for negative and positive images. These results confirm our hypothesis that repeated retrieval increases the positivity effect for older adults and that it does so because, for older adults, retrieval is more beneficial for positive items than for negative items.

Time of day effect. Although time of day did not yield a significant interaction with the proportion of positive versus negative pictures recalled, a univariate ANOVA, with total number of pictures recalled as the dependent measure and age (younger, older) and time of day (a.m., p.m.) as between-subjects factors, revealed that older adults recalled more pictures at their peak time (morning $M = 11.91 \pm 2.48$) than at their off-peak time (afternoon $M = 8.96 \pm 2.38$). Younger adults recalled more pictures at their peak time (afternoon $M = 13.83 \pm 2.48$) than at their off-peak time (morning $M = 11.76 \pm 2.38$), $F(1, 92) = 4.25$, $p < .05$, $\eta_p^2 = .04$. There was also a marginally significant main effect of age, $F(1, 92) = 3.75$, $p = .056$, $\eta_p^2 = .04$. Younger adults recalled more images overall ($M = 12.79 \pm 1.72$) than did older adults ($M = 10.44 \pm 1.72$).

Discussion

Experiment 1 replicated the age by valence interaction (Charles et al., 2003); compared with younger adults' recall, a larger proportion of older adults' recall consisted of positive images, and a smaller proportion consisted of negative images. In addition, repeated retrieval increased the extent to which older adults' memories were positive rather than negative, as retrieval strengthened older adults' memories for positive pictures more than their memories for negative pictures. Thus, older adults seem to do more elaborative processing when retrieving positive information than when retrieving negative information. This selective enhancement for positive information suggests that, for older adults, repeated retrieval of information may increase the positivity effect in memory.

Experiment 2

As outlined in Figure 1, our model is that the positivity effect in older adults' memories originates from goal-directed processes. If true, then older adults who are best able to implement their emotion-regulation goals should be those most likely to remember positive pictures rather than negative pictures. There are a number of ways that cognitive control mechanisms associated with prefrontal brain regions could help regulate emotion and simultaneously lead to positivity effects in memory. Ignoring negative information but attending to positive information, maintaining positive information but inhibiting retrieval of negative information, and making associations to positive cues but not to negative cues are all strategies requiring cognitive control that should both help regulate emotion and increase the positivity effect in memory.

To investigate how individual differences in cognitive control processes affect emotional memory, we included in Experiment 2 several tasks measuring cognitive control: the executive component of the Attentional Network Test (Fan, McCandliss, Sommer, Raz, & Posner, 2002), the refresh task (M. K. Johnson, Reeder, Raye, & Mitchell, 2002), and a modified version (Baddeley, Logie, Nimmosmith, & Brereton, 1985) of the sentence span task (Daneman & Carpenter, 1980). We chose these tasks because they each measure self-initiated processes that could help participants control their encoding and rehearsal processes within the context of our experiment. Thus, participants performing highly on all these tests should be better able to exert internal control over what information gains access to working memory and long-term memory. We used a composite score from these three tasks to divide participants into low and high groups on cognitive control.

The Attentional Network Test was developed to measure the processing efficiency of three attentional networks defined in anatomical and functional terms (Fan et al., 2002). These networks include alerting, orienting, and executive attention. Because of our interest in the ability to implement goals, we focused our analyses on the executive attention network, which is responsible for resolving conflict among competing responses and is associated with activation in midline frontal and lateral prefrontal brain regions (Fan et al., 2002).

The refresh task measures the efficiency of bringing recently presented information to mind (M. K. Johnson, Raye, Mitchell, Greene, & Anderson, 2003). According to Johnson's multiple entry modular memory model, refreshing a representation that has just been activated is a reflective component process that contributes to working memory, long-term memory, and higher order executive processes (M. K. Johnson, 1992). Refreshing a word or an object is associated with activity in the left prefrontal areas of the brain (M. K. Johnson et al., 2003). Older adults tend to refresh just-activated information more slowly, derive less long-term memory benefit from doing so, and show reduced left prefrontal brain activity during refresh tasks than do younger adults (M. K. Johnson, Mitchell, Raye, & Greene, 2004; M. K. Johnson et al., 2002).

The sentence span task requires the simultaneous storage and processing of information (Baddeley et al., 1985). The storage and processing demands gradually increase as participants master each level, and the test terminates when participants are unable to master a particular level on two consecutive occasions. The simultaneous demands placed on working memory require keeping relevant information accessible in the face of distraction. Together, these cognitive control tasks should be related to older adults' ability to selectively attend to goal-relevant information and ignore goal-irrelevant information as well as to selectively refresh and rehearse positive images rather than negative images.

In this experiment, we also manipulated picture arousal independently from picture valence, to see whether age differences in the impact of arousing stimuli could account for positivity effects. Age-related cardiovascular changes (i.e., decreased cardiac muscle mass and decreased stroke volume) can impair physiological reactions to emotionally arousing events (Cacioppo, Berntsen, Klein, & Poehlmann, 1998). For example, older adults show reduced cardiovascular reactivity in emotional responding compared with younger adults when viewing of film clips or retrieving memories (Labouvie-Vief, Lumley, Jain, & Heinze, 2003; Tsai, Levenson, & Carstensen, 2000). Older adults' decreased cardiovascular reactivity may lead them to show fewer memory advantages for arousing events than do younger adults (but for a discussion of why this might not be the case, see Mather, in press). If the negative pictures tend to be more highly arousing than the positive pictures, this could give younger adults (but not older adults) an advantage in memory for negative pictures. To control for this possible confound, we equated the arousal level of the positive and negative emotional images used in this experiment.

Method

Participants. Older adults (65–85 years; $N = 31$, $M = 73.6$ years, $SD = 6.0$, 8 males) were recruited through local radio and newspaper announcements and flyers. All older participants successfully completed the dementia phone screen that was used in Experiment 1. The younger participants were either students at University of California, Santa Cruz or members of the community who received payment for their participation (18–28 years; $N = 25$, $M = 21.7$ years, $SD = 3.3$, 12 males).[5] Participants who traveled to campus for the study received $40, and those who were already on campus received $30. Older adults reported having had more years of education ($M = 16.42$, $SD = 2.11$) than did younger adults ($M = 13.96$, $SD = 1.17$), $t(54) = 5.21$, $p < .001$.

Stimuli. Participants viewed 80 pictures (32 negative, 32 positive, and 16 neutral). Seventy-eight were from the IAPS, and two were from outside sources (pictures of a crowd of people on the street and an empty train station). Across the positive and negative categories, we equated the arousal level of the images by including an equal number of low and high arousal images. This resulted in four picture categories: low arousal positive, high arousal positive, low arousal negative, and high arousal negative images. The average IAPS arousal rating for the high arousal positive images ($M = 6.38 \pm .24$) and high arousal negative images ($M = 6.37 \pm .32$) did not differ significantly from each other, $t(30) = -.015$, *ns*. Likewise, the average IAPS arousal rating of the low arousal positive images ($M = 4.53 \pm .18$) and low arousal negative images ($M = 4.55 \pm .20$) did not differ significantly from each other, $t(30) = .86$, *ns*. The positive images ($M = 7.39 \pm .10$) and negative images ($M = 2.71 \pm .28$) differed from each other in terms of their normative valence ratings, $t(62) = 30.37$, $p < .001$. The additional 16 neutral pictures had the lowest average arousal rating ($M = 3.24 \pm .68$) and fell around the midpoint of the valence scale ($M = 5.00 \pm .10$). As in Experiment 1, to allow coders to identify each picture, we selected images that were distinguishable from the other images based on verbal descriptions.

Procedure. Participants were randomly assigned to a morning (8 a.m.–10 a.m.) or an afternoon (2 p.m.–5 p.m.) testing time. After giving informed consent, participants were seated in front of a computer screen and asked to complete the PANAS, as in Experiment 1. Following the mood scale, participants were told that they would be viewing a series of pictures (with the same instructions, 2-s presentation time, and randomized presentation format as in Experiment 1).

After the picture show, participants completed a demographics questionnaire. Then they completed the Attentional Network Test (Fan et al., 2002). On each trial, a centrally located fixation cross was followed by a variable 400–1600-ms delay during which a spatial cue appeared (for 100 ms) or did not appear. At the end of the delay, a row of stimuli (arrows or lines) appeared. Participants had 1700 ms to press a key to indicate which direction a central arrow pointed (right or left) before the trial timed out. On congruent trials, all of the arrows pointed in the same direction. On incongruent trials, the centrally located arrow pointed in a different direction than did the flanker arrows. To quantify executive attention efficiency, we followed Fan et al.'s (2002) procedure and subtracted the average congruent trial reaction time from the average incongruent trial reaction time after removing data from trials with incorrect responses or response times that exceeded 1700 ms (4.31% of the data).

Twenty minutes after the end of the picture show, participants completed a surprise recall test (with the same instructions as in Experiment 1). After the recall test, participants completed the remaining cognitive control tasks. During the sentence span task (Baddeley et al., 1985), participants saw several series of sentences. They were asked to evaluate the plausibility of each sentence as quickly and accurately as possible. In addition, after each sentence series, participants were asked to recall the last word of each sentence in the order of presentation. If participants failed two sentence series in a row, the task terminated. Otherwise, they were given a new series comprised of one or more sentences, increasing the memory load.

The refresh task had 360 trials. During each trial, a word was presented on the computer screen (for a description of the stimuli used, see M. K. Johnson et al., 2004). There were three types of trials. On read trials, a novel word appeared. On repeat trials, the word was the same as on the previous trial. Finally, on refresh trials, a small dot cued the participant to respond with the word seen on the previous trial. Participants had 1450 ms to say the target word before the trial timed out. A headset with a microphone detected the voice onset times. After each response, there was a 550-ms intertrial interval before the next trial.

In the final phase of the session, participants made valence and arousal ratings (on scales ranging from 1 to 9) for all the pictures presented in a new random order. Valence and arousal were defined in the instructions, and participants were encouraged to ask questions if any portion of the task was unclear. Each image remained on the screen until ratings were selected for valence and arousal.

Results

Mood. On the PANAS, older adults had higher positive affect ($M = 32.97 \pm 2.32$) than did younger adults ($M = 27.12 \pm 2.62$), $t(53) = 3.35$, $p < .01$, and lower negative affect ($M = 11.10 \pm .78$) than did younger adults ($M = 14.12 \pm 2.48$), $t(53) = -2.51$, $p < .05$.

Ratings. We used an ANOVA, with age (older, younger) and time of day (a.m., p.m.) as between-subjects factors and valence based on IAPS normative ratings (positive, negative, and neutral) as a within-subjects factor, to examine age differences in subjective ratings. As expected, there was a significant main effect of valence, $F(2, 102) = 412.38.17$, $p < .001$, $\eta_p^2 = .89$. For all participants, positive images received the highest valence ratings ($M = 7.00 \pm .36$), followed by neutral images ($M = 5.45 \pm .16$). Negative images received the lowest valence ratings ($M = 2.36 \pm .17$). There were no other significant effects.

Arousal ratings were analyzed with a repeated-measures ANOVA, with IAPS arousal categorization (low arousal images, high arousal images) and IAPS valence categorization (positive, negative) as within-subjects factors and age (younger, older) as a between-subjects factor. As expected, there was a significant main effect of arousal, $F(1, 50) = 186.73$, $p < .001$, $\eta_p^2 = .79$. High arousal images ($M = 6.42 \pm .36$) were given higher subjective

[5] An additional older adult and 6 younger adults participated but were not included in the data analyses because of missing cognitive control data from either the refresh task (because of microphone failures) or the sentence span task (because of experimenter error).

arousal ratings than were low arousal images ($M = 5.10 \pm .36$). There were no significant effects of age.[6]

Overall number of items recalled. An age by time of day univariate ANOVA with total number of items recalled revealed no significant effects (all $ps > .2$).

Attentional Network Test. There was no significant difference in the executive attention scores of older adults ($M = 130.12 \pm 25.72$) and those of younger adults ($M = 113.24, \pm 56.80$), $t(54) = .57$, *ns*. In terms of accuracy, there was no significant difference between the average number of errors committed by older adults ($M = 8.29 \pm 4.08$) and younger adults ($M = 16.44 \pm 12.72$), $t(54) = 1.33$, $p = .19$, *ns*.

Refresh task. We discarded trials on which errors were made or for which the response time exceeded the 1450-ms limit or fell above or below 2 *SD* from its trial type mean (7.2% of the data). Consistent with findings from previous research (M. K. Johnson et al., 2002), older adults were slower on dot-present trials ($M = 716.27 \pm 39.28$) than were younger adults ($M = 664.96 \pm 30.46$), $t(54) = -1.99$, $p = .05$. In addition, older adults were slower to repeat a word ($M = 604.17 \pm 38.08$) than were younger adults ($M = 547.91 \pm 35.78$), $t(54) = -2.11$, $p < .05$.

To compute refresh scores that controlled for the overall slower response times for older adults, we divided the average refresh time by the average read time for each participant, as was done by M. K. Johnson et al. (2002). Older and younger adults had the same refresh scores (older $M = 1.16 \pm .04$; younger $M = 1.16 \pm .14$), $t(54) = .94$, *ns*. However, one younger adult's refresh score was over 6 *SD* higher than the overall average. Excluding this participant's data indicated that older adults were disproportionately slower than were younger adults at refreshing (older $M = 1.16 \pm .04$; younger $M = 1.09 \pm .04$), $t(53) = 2.34$, $p < .05$.

Sentence span task. The total score for each participant was determined by adding the total number of sentences seen during the task after incorrect trials and trials lasting an excessive amount of time (9 s or more) were removed. Older adults had lower sentence span scores ($M = 9.65 \pm 2.76$) than did younger adults ($M = 15.52 \pm 5.20$), $t(58) = -2.47$, $p < .05$.

Correlations among cognitive control measures. Overall, none of the measures were significantly correlated when correlations were calculated for all participants together (see Table 3) or for participants split by age group.

Composite cognitive control measure. We used a composite score because, although the tests tap different types of cognitive control (as indicated by the lack of correlations among the tests), participants who score highly on all three types should be those best equipped to remember goal-consistent information. For instance, those people scoring highly on executive attention but poorly on refreshing just-activated information might be good at selectively attending to goal-relevant information in their initial attention but not good at refreshing goal-relevant information after it is no longer visible, in which case the benefits in attention for goal-relevant information might not be carried through to later recall.

To examine the relationship between cognitive control task performance and emotional memory, we converted scores on each task to *Z* scores. Refresh and executive attention scores were

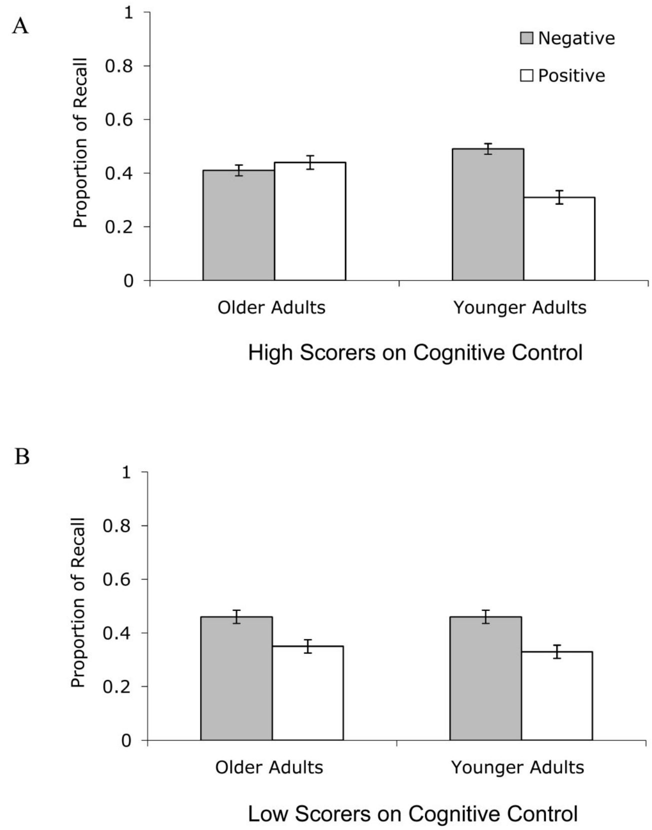

Figure 3. Experiment 2 proportions of recalled items that were positive or negative for high scoring (A) and low scoring (B) participants on the composite cognitive control measure. Error bars denote the standard error.

Table 3
Correlations Among Cognitive Control Tasks In Experiment 2

Score	Executive attention	Refresh	Sentence span
Executive attention	—		
Refresh	.05	—	
Sentence span	.09	.01	—

Note. The executive attention and refresh scores were multiplied by −1 so that positive *r* values indicate that better performance on one test is associated with better performance on another test.

[6] There were a couple of other significant effects. Participants gave the negative images higher arousal ratings ($M = 6.02 \pm .36$) than they did the positive images ($M = 5.50 \pm .46$), $F(1, 50) = 5.04$, $p < .05$, $\eta_p^2 = .09$. There was also a significant valence by arousal interaction, $F(1, 50) = 14.14$, $p < .001$, $\eta_p^2 = .36$. Negative high arousal images ($M = 6.93 \pm .42$) were given higher subjective arousal ratings than were negative low arousal images ($M = 5.11 \pm .36$). Likewise, positive high arousal images were given higher subjective arousal ratings ($M = 5.90 \pm .46$) than were low arousal positive images ($M = 5.10 \pm .50$), but the discrepancy between the subjective arousal ratings for the high and low arousal negative images was larger than that for positive images.

multiplied by −1 so that high scores would indicate good performance, and then each participant's three Z scores were averaged. Then, within each subgroup of the experiment (e.g., older adults tested in the morning), participants were categorized as either above or below the median in that subgroup on this composite cognitive control measure.[7]

Valence of recall. Two coders matched the recall responses to images, with 96.88% agreement. Discrepancies were resolved by means of discussion among the coders. (See Table 1 for number of items recalled within each valence category.) Thirty-two items could not be matched to a picture (0.6% of younger adults' recall and 4.2% of older adults' recall). To make the subjective valence proportions comparable across experiments, we again used participants' valence ratings to divide the pictures into positive, neutral, and negative sets with about the same number of items (27 positive, 27 negative, and 26 neutral). As before, IAPS ratings were used to break any ties in subjective valence. The proportion of each participant's total recall that consisted of pictures from their own positive or negative picture set was analyzed with an ANOVA. Age (younger, older), time of day (a.m., p.m.), and cognitive control performance (high, low) were between-subjects factors. Valence (negative, positive) was a within-subjects factor.

Replicating Experiment 1 and Charles et al.'s (2003) findings, there was a significant age by valence interaction, $F(1, 48) = 6.37$, $p < .05$, $\eta_p^2 = .12$.[8] The proportion of recall that was positive was higher for older adults ($M = .39 \pm .04$) than for younger adults ($M = .32 \pm .04$). The proportion of recall that was negative was lower for older adults ($M = .43 \pm .04$) than for younger adults ($M = .47 \pm .04$).

In addition, there was a significant age by valence by time of day interaction, $F(1, 48) = 6.13$, $p < .05$, $\eta_p^2 = .11$. In the morning, at older adults' peak time of day, the age differences were most extreme, with older adults' recall consisting of relatively more positive pictures ($M = .42 \pm .05$) than did younger adults' recall ($M = .30 \pm .05$) and relatively fewer negative pictures ($M = .42 \pm .05$) than did younger adults' recall ($M = .52 \pm .05$). In the afternoon, the age differences were attenuated, with older adults recalling only slightly higher proportions of positive pictures ($M = .36 \pm .05$) than did younger adults ($M = .34 \pm .05$) and about the same proportion of negative pictures ($M = .44 \pm .04$) as did younger adults ($M = .42 \pm .05$).

There was a significant age by valence by cognitive control interaction, $F(1, 48) = 4.72$, $p < .05$, $\eta_p^2 = .09$ (see Figures 3a and 3b). Among participants with high cognitive control scores, the proportion of recall that was positive was higher for older adults (older $M = .43 \pm .05$; younger $M = .31 \pm .05$), and the proportion that was negative was higher for younger adults (older $M = .40 \pm .04$; younger $M = .48 \pm .05$). Among participants with low cognitive control scores, the age differences were attenuated, with older adults and younger adults recalling similar proportions of positive pictures (older $M = .35 \pm .05$; younger $M = .33 \pm .05$) and similar proportions of negative pictures (older $M = .46 \pm .05$; younger $M = .46 \pm .05$).

Discussion

As expected, we replicated the age by valence interaction in this experiment. Compared with younger adults, older adults were more likely to recall positive pictures and less likely to recall negative pictures. Furthermore, this experiment demonstrates that these age-related differences in emotional memory are not associated with cognitive decline. Instead, it was those older adults who did best on tests of cognitive control who were most likely to show a positivity effect in memory. Being good at ignoring goal-irrelevant information (as required by the Attention Network Test) may help older adults attend less to negative pictures. In addition, being good at refreshing just-activated information (as required by the refresh task) and keeping selected information in working memory despite the presence of new potentially distracting information (as required by the sentence span task) should enable them to selectively maintain the activation of goal-relevant information.

Experiment 3

In this experiment, we examined whether reducing participants' ability to use cognitive control processes would have a different effect on younger and older adults. Studies with younger adults have shown that negative emotional words (especially highly arousing negative words) are more memorable than are neutral words even when they are learned while distracted (Kensinger & Corkin, 2003, 2004); however, to our knowledge, previous studies have not examined whether divided-attention affects negative and positive memories differently. Our prediction was that dividing attention would make older adults' memories less positive because it would reduce their ability to implement their emotional goals. In contrast, we predicted that dividing attention would not affect the valence of younger adults' memories because they do not have chronic emotion regulation goals.

Method

Participants. The research participants consisted of a group of older adults (64–84 years; $N = 32$, $M = 73.8$ years, $SD = 5.8$) and a group of younger adults (18–39 years; $N = 32$, $M = 22.8$ years, $SD = 5.5$). Older adults were recruited through the Lifelong Learners, a senior citizen organization affiliated with University of California, Santa Cruz and with flyers posted throughout Santa Cruz county. All older participants successfully completed the phone screen used in the previous experiments and received $20. The younger participants were students at a local community college who received credit for fulfilling a college course research participation requirement.

Older adults reported having more years of education ($M = 16.9$, $SD = 2.03$) than did younger adults ($M = 14.64$, $SD = 2.57$), $t(62) = 3.86$, $p < .001$. In addition, older adults had higher vocabulary scores ($M = 21.22$, $SD = 1.70$) than did younger adults ($M = 13.22$, $SD = 4.73$).

Stimuli. We used the same picture stimuli as those in Experiment 2. For the divided-attention task, we used repeating rhythmic sound patterns that differed in the number of times they changed from trial to trial (an adaptation of the task used by Kensinger & Corkin, 2003).

[7] As mentioned in the section above on the refresh task, there was one extreme outlier on this task (with a Z score of 6.51, indicating very slow refresh relative to read trials). Substituting this score with the next most extreme younger adult Z score on this task (.54) and recomputing the composite score for this participant did not change their categorization as low on cognitive control.

[8] Including the PANAS positive and negative affect scores as covariates actually strengthened the age by valence interaction, $F(1, 45) = 8.19$, $p < .01$, $\eta_p^2 = .15$. Neither of the covariates was significant (both ps $> .12$).

Procedure. Participants were randomly assigned to a morning (8 a.m.–10 a.m.) or an afternoon (2 p.m.–5 p.m.) testing session and to the divided-attention condition or the full-attention condition. After giving informed consent, participants completed the PANAS and a brief demographics questionnaire. Next, participants were told that they would be viewing a series of pictures. During the presentation of each image in the divided-attention condition, participants heard a series of sound patterns. When the picture disappeared, they pressed a key to indicate whether the patterns had changed once or twice (e.g., Kensinger & Corkin, 2003).

Each sound sequence consisted of two different sounds spliced together with Sound Studio (Felt Tip Software, 2002). The sound patterns were equal in duration to the presentation time for each picture (3 s) and randomly alternated between trials in which the sound pattern changed once or twice. In half of the trials, the sound pattern changed one time. In the remainder of the trials, the sound pattern changed two times. For sounds that changed once, there were two different onset times for the change (early vs. late). For sounds that changed twice, the initial sound heard could be either of the two sounds used to create the sequence. The no-distraction control group was given the same instructions as in the previous experiments. In both the control condition and the divided-attention condition, the order of picture presentation was randomized.

Following the picture show, participants completed the Nelson-Denny vocabulary test, the CES-D, and a crossword puzzle (used as a filler task). Twenty minutes after the end of the picture show, participants completed a surprise recall test (with the same instructions as in the previous experiments). Finally, participants rated the valence and arousal of the pictures.

Results

Mood measures. We analyzed PANAS positive and negative affect scores with a repeated-measures ANOVA, with affect score (positive, negative) as a within-subjects factor and age (younger, older) as the between-subjects factor. Older adults reported experiencing less negative affect ($M = 11.38 \pm 1.36$) than did younger adults ($M = 13.84 \pm 1.36$) and more positive affect ($M = 33.97 \pm 2.44$) than did younger adults ($M = 28.81 \pm 2.44$), $F(1, 62) = 16.38$, $p < .01$, $\eta_p^2 = .21$. In addition, the CES-D indicated that older adults were less likely to be depressed ($M = 7.09 \pm 2.34$) than were younger adults ($M = 16.58 \pm 3.52$), $t(62) = 4.48$, $p < .01$.

Ratings. Participants' ratings of the photographs were analyzed with a repeated-measures ANOVA, with the IAPS valence rating (negative, positive, neutral) as the within-subjects factor and age (older, younger) and condition (control, divided attention) as between-subjects factors. Across both age groups, negative pictures were rated as having the lowest valence ($M = 2.52 \pm .12$), followed by neutral pictures ($M = 5.35 \pm .16$) and positive pictures ($M = 7.07 \pm .20$), $F(2, 120) = 959.40$, $p < .001$, $\eta_p^2 = .94$.

Arousal ratings were analyzed with a separate repeated-measures general linear model, with the IAPS arousal category (low arousal images, high arousal images) and IAPS valence category (positive, negative) as the within-subjects factors and age (older, younger), time of day (a.m., p.m.) and condition (control, divided attention) as between-subjects factors. As expected, high arousal images ($M = 5.94 \pm .42$) were given higher subjective arousal ratings than were low arousal images ($M = 4.57 \pm .36$), $F(1, 56) = 15.20$, $p < .001$, $\eta_p^2 = .21$. There was also a marginally significant main effect of age, $F(1, 56) = 3.77$, $p = .057$, $\eta_p^2 = .06$. Older adults ($M = 5.61 \pm .52$) tended to give higher subjective arousal ratings than did younger adults ($M = 4.90 \pm .52$). However, there were no significant interactions of age and valence (all $ps > .25$), indicating that valence had a similar impact on arousal ratings for the two groups.[9]

Distraction task performance. Accuracy on the sound change discrimination task was high for both older adults (93.36%) and younger adults (96.71%), although older adults made more errors ($M = 5.31 \pm 2.20$) than did younger adults ($M = 2.63 \pm 1.16$), $t(30) = 2.17$, $p < .05$.

Overall number of items recalled. Recall scores were analyzed with a univariate ANOVA, with total number of images recalled as the dependent factor and age (younger, older), time of day (a.m., p.m.), and condition (control, divided attention) as between-subjects factors. Participants in the control condition recalled a larger number of images ($M = 20.94 \pm 2.38$) than did participants in the divided-attention condition ($M = 10.34 \pm 2.38$), $F(1, 56) = 39.38$, $p < .001$, $\eta_p^2 = .41$. In the control condition, older adults' ($M = 19.94 \pm 2.36$) and younger adults' ($M = 21.94 \pm 2.36$) total recall output was more similar than in the divided-attention condition (older $M = 7.88 \pm 2.36$; younger $M = 12.81 \pm 2.36$), yielding an interaction of age and condition, $F(1, 56) = 4.22$, $p < .05$, $\eta_p^2 = .07$. In addition, there was a condition by time of day interaction, $F(1, 56) = 4.52$, $p < .05$, $\eta_p^2 = .08$. In the control condition, participants recalled a greater number of images at the afternoon test time ($M = 23.13 \pm 2.36$) compared with the morning test time ($M = 18.75 \pm 2.36$). In the divided-attention condition, this pattern was reversed. Participants recalled a greater number of images in the morning ($M = 11.88 \pm 2.36$) than in the afternoon ($M = 8.81 \pm 2.36$). The age by condition by time of day interaction was not significant, $F(1, 56) = .09$, *ns*.

Valence of recall. Two coders matched the recall responses to the images. The coders agreed on 98% of the images and resolved the remaining discrepancies by means of discussion. Only four pictures (.4% of younger adults' recall and .4% of older adults' recall) could not be coded. (See Table 1 for the number of items recalled.) The Appendix shows that, as in the previous experiments, in the control condition, the pictures that younger adults were more likely than older adults to recall tended to be negative, whereas those that the older adults were more likely than younger younger adults to recall tended to be positive. This pattern did not occur in the divided-attention condition, as indicated in the analyses below. The control group in this experiment had the same pictures and retention interval as participants in Experiment 2. Thus, it is interesting to note that the pictures that yielded the largest age differences in recall differed across the two experiments (see the Appendix), although in both cases, the pictures more likely to be recalled by younger adults than by older adults tended to be negative, and those more likely to be recalled by older adults tended to be positive. Thus, the age differences seem to depend more on the valence of the pictures than on their specific content.

[9] There was also a significant valence by arousal interaction, $F(1, 56) = 15.20$, $p < .001$, $\eta_p^2 = .21$. Negative high arousal images ($M = 6.11 \pm .52$) were given higher subjective arousal ratings than were negative low arousal images ($M = 4.37 \pm .38$). Likewise, positive high arousal images were given higher subjective arousal ratings ($M = 5.78 \pm .40$) than were low arousal positive images ($M = 4.77 \pm .38$). However, the discrepancy between the subjective arousal ratings for the high and low arousal negative images was larger than that for positive images.

Age differences in recall for emotional images were examined with a repeated-measures ANOVA. Subjective valence, coded in the same manner as in Experiment 2 (negative, positive) and normative ratings of arousal (low, high) were within-subjects factors. Age (younger, older) and condition (control, distraction) were between-subjects factors. A main effect of condition, $F(1, 56) = 7.83$, $p < .01$, $\eta_p^2 = .12$, revealed that if attention was divided during encoding, later recall was more likely to consist of emotional pictures ($M = .83 \pm .02$) than if attention was not divided ($M = .74 \pm .04$). (The expected proportion for emotional pictures if positive, negative, and neutral pictures were equally likely to be recalled is .675.)

On average, across all participants, recall was more likely to consist of negative images ($M = .50 \pm .04$) than of positive images ($M = .32 \pm .04$), $F(1, 56) = 30.72$, $p < .001$, $\eta_p^2 = .35$. Also, recall was more likely to consist of high arousal images ($M = .50 \pm .04$) than of low arousal images ($M = .29 \pm .03$), $F(1, 56) = 37.73$, $p < .001$, $\eta_p^2 = .40$. These advantages for both negative arousal pictures and for high arousal pictures were driven by the divided-attention condition. For participants in the control condition, the proportion of negative images recalled ($M = .41 \pm .06$) did not differ much from the proportion of positive images recalled ($M = .38 \pm .05$). However, for participants in the divided-attention condition, negative images ($M = .59 \pm .06$) had a large recall advantage over positive images ($M = .25 \pm .05$), $F(1, 56) = 19.14$, $p < .001$, $\eta_p^2 = .26$. Likewise, the advantage for high arousal pictures was less pronounced in the control condition (high arousal $M = .42 \pm .06$; low arousal $M = .33 \pm .04$) than in the divided-attention condition (high arousal $M = .60 \pm .06$; low arousal $M = .25 \pm .04$), $F(1, 56) = 12.63$, $p = .001$, $\eta_p^2 = .18$.

The only significant effect of age was a condition by age by valence interaction, $F(1, 60) = 16.04$, $p < .001$, $\eta_p^2 = .21$[10], which is consistent with our predictions. In the control condition (see Figure 4a), the proportion of recall that was positive was higher for older adults ($M = .43 \pm .07$) than for younger adults ($M = .33 \pm .07$), and the proportion of recall that was negative was lower for older adults ($M = .36 \pm .09$) than for younger adults ($M = .46 \pm .09$), which replicates our previous two experiments. In contrast, in the divided-attention condition (see Figure 4b), the recall proportions of positive and negative pictures for older adults showed a dramatic reversal. Under divided attention, older adults' recall was more likely to consist of negative images ($M = .70 \pm .09$) than was younger adults' recall ($M = .48 \pm .09$) and less likely to consist of positive images ($M = .16 \pm .07$) than was younger adults' recall ($M = .35 \pm .07$).[11]

Discussion

Older adults' positivity bias in memory disappeared (in fact, it reversed entirely) when their attention was distracted by a concurrent task during encoding. In contrast, dividing attention had little impact on the emotional valence of younger adults' memories. This indicates that, in the control condition, the older adult participants were using their attentional resources in ways that helped them remember more positive than negative pictures, whereas younger adults did not use their attentional resources for emotion regulation purposes during the picture presentation.

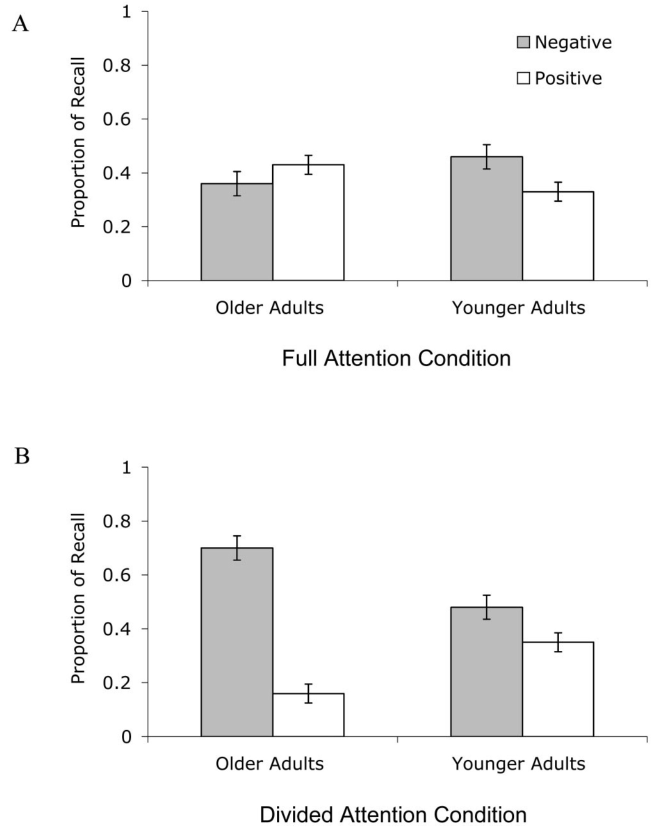

Figure 4. Experiment 3 proportions of recalled items that were positive or negative in the control (A) and divided attention (B) conditions. Error bars denote the standard error.

General Discussion

Emotion and cognition have different trajectories across the life span (Carstensen, Mikels, & Mather, in press; Knight & Mather, in press; Mather, 2004). In particular, cognitive control processes decline (Buckner, 2004; Hedden & Gabrieli, 2004; M. K. Johnson & Raye, 2000), whereas affect regulation improves, with age

[10] After entering CES-D score, PANAS positive mood score, and PANAS negative mood score as covariates, the age by valence by condition interaction remained significant, $F(1, 53) = 14.39$, $p < .001$, $\eta_p^2 = .21$. None of the covariates was a significant predictor of recall (all ps > .2).

[11] In our analyses, we used the proportions of total recall that were positive and negative because this removed the variance attributable to the different total number of items recalled by individual participants. However, analyses of the raw recall scores (shown in Table 1) yielded mostly the same findings. Consistent with the results from the analyses examining recall proportions, the age by valence interactions were significant for the raw counts in Experiment 1, $F(1, 92) = 12.40$, $p < .005$, $\eta_p^2 = .12$, and in Experiment 2, $F(1, 54) = 11.35$, $p < .005$, $\eta_p^2 = .17$. In Experiment 1, the interaction between age, valence, and retrieval attempt was not significant for the raw counts. In Experiment 2, the age by valence by cognitive control interaction was significant in the analysis with raw scores, $F(1, 52) = 7.03$, $p < .05$, $\eta_p^2 = .17$. In Experiment 3, the age by valence by condition interaction was marginally significant with the raw counts, $F(1, 60) = 3.73$, $p = .058$, $\eta_p^2 = .058$.

(Carstensen et al., 1999; Gross et al., 1997; Labouvie-Vief & Medler, 2002). Our study demonstrates that emotional memory is an interaction between these two systems; older adults' positivity effect cannot be explained entirely by either emotion or cognition accounts. Emotional goals grow more chronically accessible with age, but in order for those goals to guide attention and memory, cognitive control processes are required (Mather, in press; Mather & Carstensen, 2005).

Role of Cognitive Control in Age Differences in Emotional Memory

This study replicated the age by valence interaction in memory seen in previous studies in a variety of contexts (Charles et al., 2003; Kennedy et al., 2004; Mather, 2004; Mather & Carstensen, 2003; Mather et al., 2005). In each of three experiments, older adults recalled a smaller proportion of negative images and a larger proportion of positive images than did younger adults. In addition, each experiment provided evidence that this positivity effect results from strategic processing rather than from age-related cognitive decline.

In the first experiment, we examined the effects of repeated testing on the positivity effect. Older adults' positivity effect increased with repeated testing but not simply with the passage of time. Comparison of the pictures recalled during the first and second test revealed that this effect was due to different forgetting rates for positive and negative pictures recalled during the first test rather than to different rates of new recall during the second test. For older adults, retrieving a positive picture increased long-term memory strength for that item more than did retrieving a negative picture, suggesting enhanced elaborative processing for positive pictures at the time of retrieval.

Like the other strategic processes that enhance memory, elaborative processing typically occurs in prefrontal brain regions (Buckner, Kelley, & Petersen, 1999). There are large individual differences in how much prefrontal regions and associated cognitive control processes decline with age (e.g., Buckner, 2004; Glisky, Polster, & Routhieaux, 1995). In Experiment 2, we tested participants on several tasks involving cognitive control and found that older adults with above-average cognitive control abilities show the most dramatic differences compared with younger adults in terms of the emotional quality of their memories. In contrast, being better at cognitive control did not make younger adults' memories more positive.

We found similar age differences in how cognitive control resources are implemented in another recent study (Mather et al., 2005) that assessed participants' executive function with three different tasks and examined their decision search strategies. On each of the three executive tasks, younger adults who performed highly relied more on a decision search strategy that emphasizes information seeking (examining all the features of one option before moving on to the next option). In contrast, older adults who performed highly on the executive tasks relied more on a decision search strategy that can help avoid regret (comparing all the options on one dimension before moving on to the next dimension). Previously, findings of age differences in decision search strategies (M. M. S. Johnson, 1990) were interpreted as resulting from older adults' poorer executive processes (Peters, Finucane, MacGregor, & Slovic, 2000; Sanfey & Hastie, 2000; Yates & Patalano, 1999). Mather et al. (2005), and the present study provides two examples in which the obvious assumption that age differences are due to age-related cognitive decline is wrong; in fact, it is the high-functioning older adults who perform the most differently from the younger adults. This interaction of cognitive ability and age supports our model that older and younger adults differ in their goals and that these goals influence attention and memory by recruiting cognitive control mechanisms (see Figure 1).

Experiment 3 provided further support for our model. Half the participants were given an effortful but unrelated task to accomplish while watching the picture show. As predicted, this manipulation was irrelevant for the valence of younger adults' memories but eliminated the older adults' positivity bias. It is possible that, instead of interfering with goal implementation, reducing cognitive resources prevents goal formation or maintenance. However, the surprising finding that the positivity effect was not only eliminated but also was reversed, such that about 70% of older adults' memories in the distracting condition consisted of negative pictures, suggests that older adults might be suffering from an ironic effect of their goals (Wegner, 1994).

According to Wegner (1994), attempting to control the contents of one's thoughts involves both an effortful operating process that attempts to create the desired mental state and an automatic ironic process that searches the contents of thought for evidence of failure of mental control. To be successful, the effortful operating process requires cognitive resources. The automatic ironic process does not require cognitive resources, and thus, when attention is divided, the automatic process continues to search for the undesired thoughts. This can lead to the rebound of suppressed thoughts when people are distracted (see also Hester & Garavan, 2005). Older adults may rely on automatic processes that detect negative information and signal the need to initiate more effortful cognitive control processes to diminish its impact. Thus, during divided attention, when effortful cognitive control processes are ineffective, negative information might be particularly salient for older adults.

Role of Arousal Versus Valence

Arousing stimuli can automatically capture attention without any effortful processing (Dolan, 2002). We have found that when asked to find one emotional face among an array of neutral faces, older adults show just as much of an advantage in detecting threatening faces as do younger adults (Mather & Knight, in press). Thus, the automatic detection of negative high arousal stimuli in the environment does not seem to decline with age.

Under conditions of full attention, however, valence becomes a factor in age differences, as older adults focus less on negative information than do younger adults (Mather & Carstensen, 2003; Mather et al., 2005; Rosler et al., 2005). In one study, participants were asked to indicate as quickly as they could whether a dot appeared on either the right or left side of the screen (Mather & Carstensen, 2003). Immediately before each dot appeared, two photographs of a person's face appeared for 1 s, one on each side of the screen. One photograph in each pair was of an emotional expression, and the other was of a neutral expression. Older adults were slower to respond to dots that appeared after sad or angry faces than to those that appeared after neutral faces, whereas younger adults showed no bias. In a functional MRI study of younger and older adults viewing emotional pictures, older adults showed more amygdala activation in response to positive pictures than in response to negative pictures, whereas younger adults showed greater amygdala activation for either type of emotional pictures compared with neutral pictures (Mather et al., 2004). There also are age differences in the type of information people focus on when making choices. When given information about several cars for purchase, older adults spend more time examining positive features and less time examining negative features than do younger adults (Mather et al., 2005).

In Experiments 2 and 3, we included equal numbers of high and low arousal pictures among the positive and negative pictures. We found that younger and older adults showed similar arousal-based memory enhancements (see also Denburg, Buchanan, Tranel, & Adolphs, 2003), and controlling for the arousal levels of the positive and negative pictures did not eliminate or reduce the strength of the age by valence interaction.

Broader Implications and Questions for Future Research

Experiment 3 provides a counterexample of the idea that age differences in memory are due to older adults' reduced attentional resources (for a review, see Balota, Dolan, & Duchek, 2000). Although older adults may not have as many processing resources as do younger adults, Experiment 3 indicates that they sometimes use them for different purposes than do younger adults. Thus, unlike in some other memory paradigms (Anderson, Craik, & Naveh-Benjamin, 1998; Jennings & Jacoby, 1993), in emotional memory tasks, dividing younger adults' attention does not make their performance more like that of older adults.

The cognitive control processes used for complex cognitive processing and for emotion regulation are part of a limited resource that can be depleted, at least for younger adults (Baumeister, Muraven, & Tice, 2000; Richeson et al., 2003; Richeson & Shelton, 2003; Schmeichel, Vohs, & Baumeister, 2003; Vohs & Heatherton, 2000; Vohs & Schmeichel, 2003). Participants who suppress their emotions while watching a film are impaired in subsequent self-regulation tasks such as a task to avoid eating snack foods if they are dieting (Vohs & Heatherton, 2000). An interesting question for future research is whether older adults' emotion regulation strategies also lead to resource depletion, where they might be less effective at other tasks involving self-regulation after being in a situation that called for effortful emotion regulation.

Another important question for future research is how much older adults' emotional goals have an influence at the time of retrieval. Experiment 3 indicates that the increased positivity of older adults' memories results, at least in part, from processes occurring at encoding. The effects of repeated retrieval in Experiment 1 suggest that positivity effects can also be amplified at retrieval, but it is possible that the subsequent increase in the positivity effect among older adults is due to reencoding processes during retrieval. In future experiments, it would be interesting to directly compare the effects of divided attention during encoding and retrieval.

Our study indicates that emotion regulation goals are more likely to influence older adults' memories than younger adults' memories and that cognitive control plays an important role. However, our data do not address the question of why older adults are more likely to have activated emotion regulation goals. Learning throughout the lifetime may play a role in these age differences (e.g., Carstensen, Fung, & Charles, 2003; Labouvie-Vief, 2003). However, socioemotional selectivity theory (Carstensen et al., 1999, in press) posits that time perspective, rather than age per se, is the important factor. The theory argues that because older adults perceive time as more limited than do younger adults, they focus more on emotional goals than on information-seeking goals. Previous studies that manipulated time perspective by asking participants to imagine various scenarios (such as an impending move or a new medical advance lengthening life) found that when participants perceive time as limited, they prefer spending time with emotionally meaningful social partners, whereas when they perceive time as expansive, they prefer meeting people who provide opportunities to learn new information (Fredrickson & Carstensen, 1990; Fung & Carstensen, 2004; Fung, Carstensen, & Lutz, 1999; Fung, Lai, & Ng, 2001). Future studies may be able to use similar methods to determine whether experience or time perspective better account for older adults' positivity effect. Along these lines, a recent study found that 1st-year college students spent more time viewing sad faces than did seniors approaching graduation (a salient ending) (Prunzan & Isaacowitz, in press).

Our central finding is an age by valence interaction. As with most interactions, there are at least a couple of ways to think about the effect. We have focused on how older adults' recall is more likely than younger adults' recall to consist of positive information than. Calling it a positivity effect emphasizes this aspect of the interaction. However, another way to describe the effect is as a negativity effect among younger adults, as younger adults' recall is more likely than older adults' recall to consist of negative information. Many studies show that negative information is more salient than positive information for younger adults (Baumeister, Bratslavsky, Fickenauer, & Vohs, 2001; Rozin & Royzman, 2001). Some of older adults' positivity effect may be due to goal-directed ignoring or suppression of negative information that helps avoid a negativity effect rather than just enhancement of positive information. The raw recall counts presented in Table 1 suggest that the age differences in the processing of both positive and negative information contribute to the positivity effect. For instance, among participants with high cognitive control scores in Experiment 2, older adults recalled more positive pictures but fewer negative and neutral pictures than did younger adults. Thus, these participants seemed to focus especially on the positive pictures. It is especially interesting that these high cognitive control older adults recalled fewer negative pictures than did the low cognitive control older adults, suggesting that they might have been using their cognitive resources to avoid the negative pictures. Future research is needed to see whether older adults' enhancement of positive memories and impairment of negative memories are separable processes.

In Experiments 2 and 3, older adults did not recall significantly fewer total pictures than did younger adults, unlike the impairments usually seen among older adults in free recall. Older and younger adults' memory accuracy may have been closer overall in our study than in others either because we controlled the time of day of testing or because we may have recruited a particularly high functioning group of older adults. However, we are not sure why the age differences in overall recall output are more pronounced in Experiment 1 than in Experiments 2 or 3. In any case, it is worth noting that older adults showed a positivity effect compared with younger adults both when they had overall lower recall than did younger adults (in Experiment 1) and when they were equated.

Boundary Conditions for Older Adults' Positivity Effect

Although we replicated the finding that older adults' memories favor positive information more, and negative information less, than do younger adults' memories in each of our three experiments, this study also makes it clear that older adults will not always show a positivity effect in memory. Older adults with poor cognitive control abilities will be unlikely to do so, as will those distracted during encoding. It is also possible that older adults at their off-peak time of day are less likely to show positivity effects, although this time-of-day effect was only significant in Experiment 2 and thus may be due to random chance. Future research may reveal that older adults who have recently engaged in a taxing executive task are less likely to show positivity effects. In addition, the unconstrained picture-viewing session in our experiments may be more likely than a structured encoding task, such as rating the valence of the pictures, to permit the influence of emotional goals. Some combination of these factors may explain findings of weak or no positivity effects among older adults in some studies (Comblain, D'Argembeau, Van der Linden, & Aldenhoff, 2004; Denburg et al., 2003; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002).

Overview

In summary, we found that older adults use cognitive control mechanisms to help them remember relatively more positive than negative information. At different phases in the remembering process, older adults may engage in different forms of cognitive control such as selective attention, inhibition of goal-irrelevant information, making associations to the information, and thinking about its personal meaning. Experiment 1 reveals that such processes that selectively benefit positive and impair negative information operate at the time of retrieval; Experiment 3 indicates that they also operate at the time of encoding. It seems likely that positivity effects in memory often are a by-product of emotion regulation strategies (e.g., thinking more about positive information than about negative information should help regulate emotion and will also lead to positivity effects in memory) rather than the primary goal. But positivity effects in memory may also serve as an emotion regulation mechanism in their own right, as remembering the past can be a powerful way to influence mood (e.g., Kennedy et al., 2004; Pasupathi & Carstensen, 2003).

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(*Appendix follows*)

Appendix

The following table lists descriptions of pictures that differed most in their likelihood of being recalled by younger and older adults in Experiments 1–3. The pictures with the highest value for the percentage of younger adults recalling the picture minus the percentage of older adults recalling that picture are listed in the first column and the pictures with the highest value for the older minus younger percent difference are displayed in the second column.

Experimental group	Younger-older % difference	Older-younger % difference
Experiment 1: Day 2 recall	1. NG: Man with knife (38%) 2. NG: Man pointing gun in woman's face (33%) 2. NG: Crashed plane (33%)	1. NT: Crowded street fair (17%) 2. PS: Three little girls (15%) 2. PS: Flowers and lake vista (15%)
Experiment 2	1. NG-H: Baby with eye tumor (23%) 2. NG-L: Drug addict with syringe (21%) 3. NG-H: Burn victim (20%)	1. PS-L: Fluffy clouds (30%) 2. NT: Glowing volcano (27%) 3. PS-L: Two girls with kittens (25%)
Experiment 3: Controls	1. NG-L: Dirty homeless drunk (44%) 2. NG-L: Snake in grass (38%) 2. PS-H: Sexy woman running along water (38%)	1. PS-L: Garden and bridge (38%) 2. PS-H: Couple embracing, kissing (31%) 2. PS-H: Sailing on ocean (31%)
Experiment 3: Divided attention	1. PS-H: Sexy woman running along water (56%) 2. NG-H: Skeletal child lying on tarp (50%) 3. NG-H: Burn victim (38%) 3. PS-L: Interracial couple kissing (38%)	1. PS-H: Hiker on mountain (13%) 1. NG-L: Two women at table (13%) 1. NT: Construction worker (13%)

Note. The top three pictures in each category are listed (except where there was a tie for third place). International Affective Picture System categorization is indicated by the following abbreviations: NT = neutral; NG = negative; PS = positive; H = high arousal; L = low arousal.

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