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Age differences in selective memory of goal-relevant stimuli under threat

Kelly A. Durbin,¹ David Clewett,² Ringo Huang,¹ and Mara Mather¹

¹Department of Psychology, University of Southern California, Los Angeles, CA

²Department of Psychology, New York University, New York, NY

Correspondence should be addressed to Kelly A. Durbin, Department of Psychology, University of Southern California, 3620 McClintock Avenue, Los Angeles, CA 90089. E-mail:

kadurbin@usc.edu

Abstract

When faced with threat, people often selectively focus on and remember the most pertinent information while simultaneously ignoring any irrelevant information. Filtering distractors under arousal requires inhibitory mechanisms, which take time to recruit and often decline in older age. Despite the adaptive nature of this ability, relatively little research has examined how both threat and time spent preparing these inhibitory mechanisms affects selective memory for goal-relevant information across the lifespan. In this study, 32 younger and 31 older adults were asked to encode task-relevant scenes, while ignoring transparent task-irrelevant objects superimposed onto them. Threat levels were increased on some trials by threatening participants with monetary deductions if they later forgot scenes that followed threat cues. We also varied the time between threat induction and a to-be-encoded scene (i.e., 2s, 4s, 6s) to determine whether both threat and timing effects on memory selectivity differ by age. We found that age differences in memory selectivity only emerged after participants spent a long time (i.e., 6s) preparing for selective encoding. Critically, this time-dependent age difference occurred under threatening, but not neutral, conditions. Under threat, longer preparation time led to enhanced memory for task-relevant scenes and greater memory suppression of task-irrelevant objects in younger adults. In contrast, increased preparation time after threat induction had no effect on older adults' scene memory and actually worsened memory suppression of task-irrelevant objects. These findings suggest that increased time to prepare top-down encoding processes benefits younger, but not older, adults' selective memory for goal-relevant information under threat.

Keywords: selective attention, threat, memory, aging, arousal

Age differences in selective memory of goal-relevant stimuli under threat

Selectively attending to and remembering high-priority information is advantageous under threatening situations, when lapses in attention and memory can have detrimental, and potentially even fatal, consequences. Laboratory studies have shown that, in younger adults, an increase in negative arousal (e.g., via aversive sounds or emotional images) enables this selectivity by simultaneously enhancing perception and memory of high-priority stimuli (e.g., goal relevant or perceptually salient) and suppressing memory of less relevant information (e.g., Lee, Greening, & Mather, 2015; Lee, Sakaki, Cheng, Velasco, & Mather, 2014; Sakaki, Fryer, & Mather, 2014; Sutherland & Mather, 2012; for a review, see Mather & Sutherland, 2011). Although numerous studies suggest that emotional arousal has a similar effect on attention and memory in younger and older adults (e.g., Mather & Schoeke, 2011; Murphy & Isaacowitz, 2008), age differences in selectivity might emerge under arousal. Prior studies have found age-related deficits in selective attention and the ability to inhibit task-irrelevant information (Braver & West, 2008; de Fockert, Ramchurn, van Velzen, Bergstrom, & Bunce, 2009; Gazzaley et al., 2008; Gazzaley, Cooney, Rissman, & D'Esposito, 2005; Hasher & Zacks, 1988). Thus, it is possible that older adults are unable to inhibit task-irrelevant information, even under arousing or threatening circumstances.

Arousal typically enhances attention and memory for high-priority stimuli, regardless of whether it is prioritized by top-down (goal-relevant) or bottom-up (salient) processes, while simultaneously suppressing processing of any extraneous information (Lee et al., 2015; Mather & Sutherland, 2011; Sakaki et al., 2014). However, arousal does not enhance consolidation of goal-relevant information in certain cases. For instance, when stimuli are presented immediately after an emotionally arousing event, evidence suggests that arousal either impairs (e.g.,

Sutherland, McQuiggan, Ryan, & Mather, in press) or does not affect (Sakaki et al., 2014) memory of goal-relevant stimuli. Why would arousal not show the same beneficial effects when encoding subsequent goal-relevant information? If the onset of arousal occurs during encoding, then arousal will amplify memory selectivity for goal-relevant information (e.g., Anderson, Yamaguchi, Grabski, & Lacka, 2006; Lee et al., 2015; Sakaki et al., 2014). However, if arousal is induced prior to encoding, then arousal may only enhance the consolidation of subsequent goal-relevant information if the time between the arousal event and the encoding stimulus is enough to recruit top-down and inhibitory mechanisms (see Warren, Murphy, & Nieuwenhuis, 2016). Otherwise, if the delay is too brief, arousal may not be able to recruit the resources necessary to amplify selectivity of high-priority stimuli over task-irrelevant information. Given age-related deficits in selective attention and inhibitory mechanisms (de Fockert et al., 2009; Gazzaley et al., 2008; Gazzaley et al., 2005), heightened arousal and increased time to prepare top-down processes may have an additive benefit on younger adults' selectivity, whereas these factors may have no effect in older adults.

Anticipating monetary outcomes can subjectively increase arousal levels (Samanez-Larkin et al., 2007). As such, we used a monetary incentive encoding task in which we varied the amount of time participants spent preparing to encode goal-relevant stimuli (i.e., 2s, 4s, 6s) under both threatening and neutral conditions to investigate our research question. Preparation time was conceptualized as the time in which participants could prepare for selective encoding by recruiting top-down, goal-relevant processes and engaging in cognitive control. We predicted that an age-related difference in memory selectivity would emerge when an encoding stimulus followed monetary threat, and would be more pronounced after a longer preparation time (e.g., 6s) elapsed between threat induction and the to-be-encoded stimulus.

Method

Participants

Thirty-two younger adults (ages 18-25 years; $M = 19.59$; $SD = 1.54$; 26 females) and 31 older adults (ages 55-82 years; $M = 68.45$, $SD = 6.23$; 23 females) completed the study for course credit or monetary compensation.¹ Eight additional participants (five younger, three older) were excluded for not following instructions (e.g., intentionally trying to memorize the distractors they were told to ignore, as indicated by self-report at the end of the study). All participants provided written informed consent in accordance with a protocol approved by the University of Southern California's Institutional Review Board.

Materials

One-hundred and ninety-two pairs of greyscale object photographs (96 animate, 96 inanimate) and 192 greyscale scenes (96 indoor, 96 outdoor) were selected from previous datasets (Gabrieli, Brewer, Desmond, & Glover, 1997; Kensinger, Garoff-Eaton, & Schacter, 2006) and the Internet. Each pair consisted of two objects or two scenes that were semantically related (e.g., both were images of a kitchen), but differed in their perceptual features (e.g., shape, orientation). From each pair, a total of 96 objects and 96 scenes were randomly chosen to appear in the encoding task described below. To create encoding stimuli, each object was centrally and transparently superimposed onto one scene, such that the object and background scene were equally discernible (see Figure 1A). The remaining object and scene pictures were used as lures in a two-alternative forced-choice recognition test.

Procedure

Monetary Incentive Encoding Task. After providing informed consent, participants completed 96 encoding trials (for an example trial, see Figure 1A). Participants were instructed

to focus on and memorize the scenes and ignore the superimposed objects. To manipulate threat levels, participants were told that they could avoid losing money from a \$15 preset account if they remembered a particular subset of scenes. Each trial began with a 1-s abstract monetary cue (a cancel sign or a square) that cued participants as to whether forgetting the upcoming scene would result in losing \$0.50 (threat cue) or have no monetary outcome (neutral cue), respectively. Half of the participants ($n_{\text{younger}} = 16$, $n_{\text{older}} = 16$) also heard an arousing buzzer sound when the threat cue appeared onscreen.² Critically, the length of preparation time between the monetary cue and the onset of the encoding stimulus was varied (2s, 4s, or 6s). The encoding stimulus (300 x 225 pixels) was displayed for 2.5s and participants classified the scene as either indoors or outdoors.³ After the encoding image, participants viewed three unrelated, scrambled images to prevent further elaboration of the encoding stimulus. Each trial concluded with fixation cross that served as a jittered intertrial interval (ITI) of 1s, 2s, or 3s.

Recognition Memory Test. After working on a number puzzle for 10 minutes, participants were presented with a two-alternative forced-choice recognition test. The test consisted of 192 trials (96 objects and 96 scenes) in which each encoding object or scene was individually presented alongside its matched lure (see Figure 1B). Participants had up to 10 seconds to decide which image had been presented during encoding. After each response, participants had up to 5 seconds to rate their confidence by choosing “very sure,” “pretty sure,” or “just guessing.” These confidence ratings were collected on an exploratory basis to determine if threat and increased preparation time enhanced participants’ confidence in their memory of goal-relevant information (see Supplementary Table 1). Regardless of their confidence rating, participants’ memory was considered accurate if their response was correct.

Participants then completed a demographics and post-task questionnaire asking about motivation during the task and whether participants expected a memory test for objects. We have reported all data exclusions, all manipulations, and all measures in this study.

Results

Recognition memory was calculated as the proportion of correct responses within each cell of the design. To assess the contributions of age and preparation time on memory selectivity under threat, we conducted separate 2 (Age: younger, older) X 2 (Arousal: threat, neutral) X 3 (Time: 2s, 4s, 6s) mixed ANOVAs on scene and object recognition (see Table 1 for means).

Scene Recognition. We predicted that younger adults would show greater memory enhancement for high-priority scenes under threat and after a longer time had elapsed between threat induction and the encoding stimulus. For goal-relevant scenes, there were main effects of Age, $F(1, 61) = 26.62, p < .001, \eta_p^2 = .30$, and Arousal, $F(1, 61) = 6.66, p = .012, \eta_p^2 = .10$, with greater recognition among younger adults and under threatening conditions, respectively. There was also a significant Age X Arousal X Time interaction, $F(2, 122) = 3.54, p = .032, \eta_p^2 = .06$ (see Figure 1C). To examine the influence of preparation time, we conducted follow-up Age X Arousal ANOVAs at each time point. In line with our prediction, we found an Age X Arousal interaction only occurred after a 6s delay, $F(1, 61) = 6.01, p = .017, \eta_p^2 = .09$, but not after a 2s, $F(1, 61) = 1.05, p = .310, \eta_p^2 = .02$, or 4s delay, $F(1, 61) = 0.80, p = .376, \eta_p^2 = .01$.⁴ After 6s, we found an age-related difference in the memory enhancement of high-priority scenes under threat, such that younger adults had better scene memory than older adults, $t(61) = 5.03, p < .001$, mean age difference = 0.17, 95% confidence interval (CI) = [0.10, 0.23], $d = 1.27$.⁵ In contrast, this age difference was not observed under neutral conditions, $t(61) = 1.47, p = .147$, mean age difference, 0.06, 95% CI = [-0.02, 0.13], $d = 0.37$.

We predicted this three-way interaction based on the notion that younger adults' memory selectivity would benefit from having more time to recruit top-down attentional processes. Accordingly, we wanted to confirm that younger adults showed greater memory enhancements for goal-relevant scenes after a longer preparation period. To do this, we collapsed scene recognition for the two earlier time points (i.e., 2s and 4s) and compared it with scene recognition at the longest time point (i.e., 6s). Under threat, younger adults showed significantly better scene memory after a longer preparation period, $t(31) = -2.59, p = .014$, mean delay difference = -0.05, 95% CI = [-0.09, -0.01], $d_z = -0.46$. Increased preparation time did not affect younger adults' scene memory under neutral conditions, $t(31) = 0.49, p = .628$, mean delay difference = 0.01, 95% CI = [-0.04, 0.07], $d_z = 0.09$. Notably, in older adults, longer time delays did not lead to better scene memory under threatening, $t(30) = -0.26, p = .800$, mean delay difference = -0.01, 95% CI = [-.05, .04], $d_z = -0.05$, or neutral conditions, $t(30) = -2.01, p = .053$, mean delay difference = -0.05, 95% CI = [-.10, .001], $d_z = -0.36$.

Object Recognition. With respect to low-priority stimuli, we hypothesized that, relative to older adults, younger adults would show greater memory suppression for task-irrelevant objects under threat and after a longer time elapsed between threat induction and the encoding stimulus. A significant Age X Time interaction, $F(2, 122) = 4.58, p = .012, \eta_p^2 = .07$, was qualified by an Age X Arousal X Time interaction, $F(2, 122) = 4.99, p = .008, \eta_p^2 = .08$ (see Figure 1D). We again conducted follow-up Age X Arousal ANOVAs at each delay. Age X Arousal interactions emerged after a 4s, $F(1, 61) = 4.28, p = .043, \eta_p^2 = .07$, and 6s delay, $F(1, 61) = 5.06, p = .028, \eta_p^2 = .08$, but not after a 2s delay, $F(1, 61) = 0.11, p = .745, \eta_p^2 = .002$. After 4s, an interaction arose because younger adults' object recognition did not differ between threatening and neutral conditions, $t(31) = 1.10, p = .278$, mean arousal difference = 0.04, 95%

CI = [-0.04, 0.12], $d_z = 0.20$, whereas older adults had marginally better memory for objects under neutral than threatening conditions, $t(30) = -2.04$, $p = .050$, mean arousal difference = -0.06, 95% CI = [-.11, .0001], $d_z = -0.37$. Critical to our hypothesis, we found that younger adults showed better memory suppression of objects under threat than older adults after a longer preparation period (i.e., 6s), $t(61) = -2.57$, $p = .013$, mean age difference = -0.08, 95% CI = [-.15, -.02], $d = -0.65$, yet there was no age difference under neutral conditions, $t(50.71) = 0.70$, $p = .486$, mean age difference = 0.02, 95% CI = [-.04, .08], $d = 0.18$.⁶

To confirm that younger adults showed greater memory suppression of objects after a long preparation period and demonstrate that increased preparation time had no effect on older adults' ability to suppress memory of lower priority information, we collapsed object recognition for the two earlier time points (2s and 4s) and compared this to recognition after the long delay (6s). We found that, under threat, younger adults did in fact show greater memory suppression for task-irrelevant objects after a longer preparation period, $t(31) = 2.32$, $p = .027$, mean delay difference = 0.06, 95% CI = [.01, .12], $d_z = 0.41$. However, increased preparation time did not affect younger adults' ability to suppress objects memory under neutral conditions, $t(31) = -0.15$, $p = .885$, mean delay difference = -0.004, 95% CI = [-.06, .05], $d_z = -0.03$. In contrast, increased preparation time actually worsened older adults' ability to suppress object memory under threat, $t(31) = -2.33$, $p = .027$, mean delay difference = -0.07, 95% CI = [-.12, -.01], $d_z = -0.42$, and had no influence under neutral conditions, $t(30) = 0.74$, $p = .466$, mean delay difference = 0.01, 95% CI = [-.02, .05], $d_z = 0.13$.

Discussion

Using a monetary incentive encoding task, we examined how increasing both threat and the amount of time between threat induction and a to-be-encoded stimulus influenced younger

and older adults' selective memory for goal-relevant information. Age differences in memory selectivity were most apparent under a combination of threat and increased preparation time. Under threat, younger adults showed enhanced memory for task-relevant scenes and greater memory suppression of task-irrelevant objects after a long preparation period (i.e., 6s) relative to combined shorter preparation periods (i.e., 2s and 4s). In contrast, under monetary threat, increased preparation time did not enhance older adults' scene memory and actually worsened their suppression of task-irrelevant objects. Notably, older adults showed marginally better memory for scenes with increased preparation time under neutral conditions; however, this trend did not reach significance.

Why would threat and increased preparation time facilitate memory selectivity in younger, but not older, adults? Our findings among younger adults are consistent with a growing literature demonstrating that arousal amplifies selectivity (Lee et al., 2014; Sakaki et al., 2014; Sutherland & Mather, 2012). Although speculative, it is possible that our findings reflect age differences in how negative arousal affects cognitive processing in younger and older adults. Researchers have recently proposed the Glutamate Amplifies Noradrenergic Effects (GANE) model, which posits that norepinephrine release in response to arousal will interact with both excitatory and inhibitory neural mechanisms (Mather, Clewett, Sakaki, & Harley, 2016). When these neural processes are intact, as in younger adults, this model predicts that arousal amplifies selectivity by increasing excitation of high-priority stimuli while simultaneously increasing suppression of low-priority stimuli. However, it has been suggested that arousal may not amplify selectivity as effectively in older adults due to age-related changes in the norepinephrine system (Mather et al., 2016; Mather & Harley, 2016). Our results are consistent with these proposals of how arousal might affect selectivity in younger and older adults.

Our results also extend previous findings by demonstrating that younger adults' selectivity for goal-relevant information under threat was more likely to occur after a longer preparation period, supporting the idea that arousal facilitates memory selectivity when enough time has passed to recruit top-down attentional and control processes. However, we did not observe this pattern in older adults. It is possible that older adults are unable to inhibit irrelevant information regardless of preparation time due to greater deficits in selective attention and inhibition (de Fockert et al., 2009; Gazzaley et al., 2008; Gazzaley et al., 2005). Future studies would benefit from using neuroimaging techniques to establish whether older adults do in fact show a lack of activation in brain regions associated with inhibition (e.g., inferior frontal gyrus; Aron, Robbins, & Poldrack, 2014) when selectively encoding information under threat. It is noteworthy that, under neutral conditions, increased preparation time did not amplify memory selectivity in younger adults, yet older adults had a marginal enhancement of scenes. In fact, increased preparation time as a function of threat condition seemed to have an opposite effect; younger adults' scene memory was only enhanced under threat, whereas older adults only showed a marginal enhancement for scenes under neutral conditions. It is possible that threat could have beneficial effects on younger adults' selectivity, but have detrimental effects in older adults. Future research is needed to investigate whether arousal has no effect on or impedes memory selectivity in older adults and why this might be the case (e.g., increased distractibility).

Several limitations of this study should be noted. Although both younger and older adults subjectively report increased arousal when anticipating monetary outcomes (Samanez-Larkin et al., 2007), we did not include any physiological measurements of autonomic arousal. As such, we can only speculate that our findings are indicative of how negative arousal affects cognitive processing in younger and older adults. Thus, future research should include physiological

measures (e.g., pupil dilation) to determine whether arousal mechanisms contribute to age differences in memory selectivity under threat (Mather & Harley, 2016). Second, our study only threatened monetary punishment. Given that older adults typically attend to and remember a greater proportion of positive than negative information relative to younger adults (Mather & Carstensen, 2005; Reed & Carstensen, 2012), it is possible that the observed age difference may be exclusive to aversive contexts. However, given widespread inhibitory deficits in older age (Braver & West, 2008; Hasher & Zacks, 1988), we would expect older adults to show deficits in memory selectivity even when encoding is motivated by potential monetary gains.

Finally, understanding how threat and top-down control processes impact memory differently in younger and older adults has important implications for everyday life. Although evidence suggests that risky decision-making does not dramatically change across the adult lifespan or increase older adults' susceptibility to financial scams (for reviews, see Mather, 2006; Samanez-Larkin & Knutson, 2015), it is possible that an inability to inhibit processing irrelevant information could impact decision-making in other ways. For instance, older adults may be slower and less efficient than younger adults when making complex decisions, especially during distressing or time-sensitive situations (Mather, 2006). Future research should determine what effects, if any, these age differences have on decision-making across the lifespan.

Footnotes

¹ Three participants (one younger, two older) reported taking psychotropic medication; however, the pattern of results remained the same when these individuals were excluded from the analyses.

² The arousing buzzer sound ($M_{\text{arousal}} = 7.98$, $SD_{\text{arousal}} = 1.62$; $M_{\text{valence}} = 2.42$, $SD_{\text{valence}} = 1.62$) was acquired from the International Affective Digitized Sounds (Bradley & Lang, 1999). We ran the mixed ANOVAs on scene and object recognition with participants' sound condition as a factor. The main effect of Sound condition on scene recognition was marginally significant ($p = .057$), and was not significant for object recognition ($p > .10$). The four-way interaction was not significant for scene or object recognition (both $ps > .10$). Furthermore, the Age x Arousal x Time interaction in both scene and object recognition remained significant when Sound was a factor in the analysis. Thus, participants' sound condition did not influence our overall pattern of results.

³ Due to software malfunction, encoding responses from two older adult participants were not recorded.

⁴ A sensitivity analysis was conducted in G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) to determine the size of effect that could be detected with adequate power in this sample. Using our sample size ($N = 63$), an alpha level of .05, and power equal to .80, results indicated that the minimal detectable effect for the two-way interaction at a given time point was $f = 0.18$, which corresponds to $\eta_p^2 = .03$.

⁵ The reported confidence interval (CI) refers to the 95% confidence interval around the mean difference.

⁶ Levene's test for equality of variances revealed that the variance between age groups was not always equal. In those instances, the reported degrees of freedom, t statistic, and p value are those in which equal variances were not assumed.

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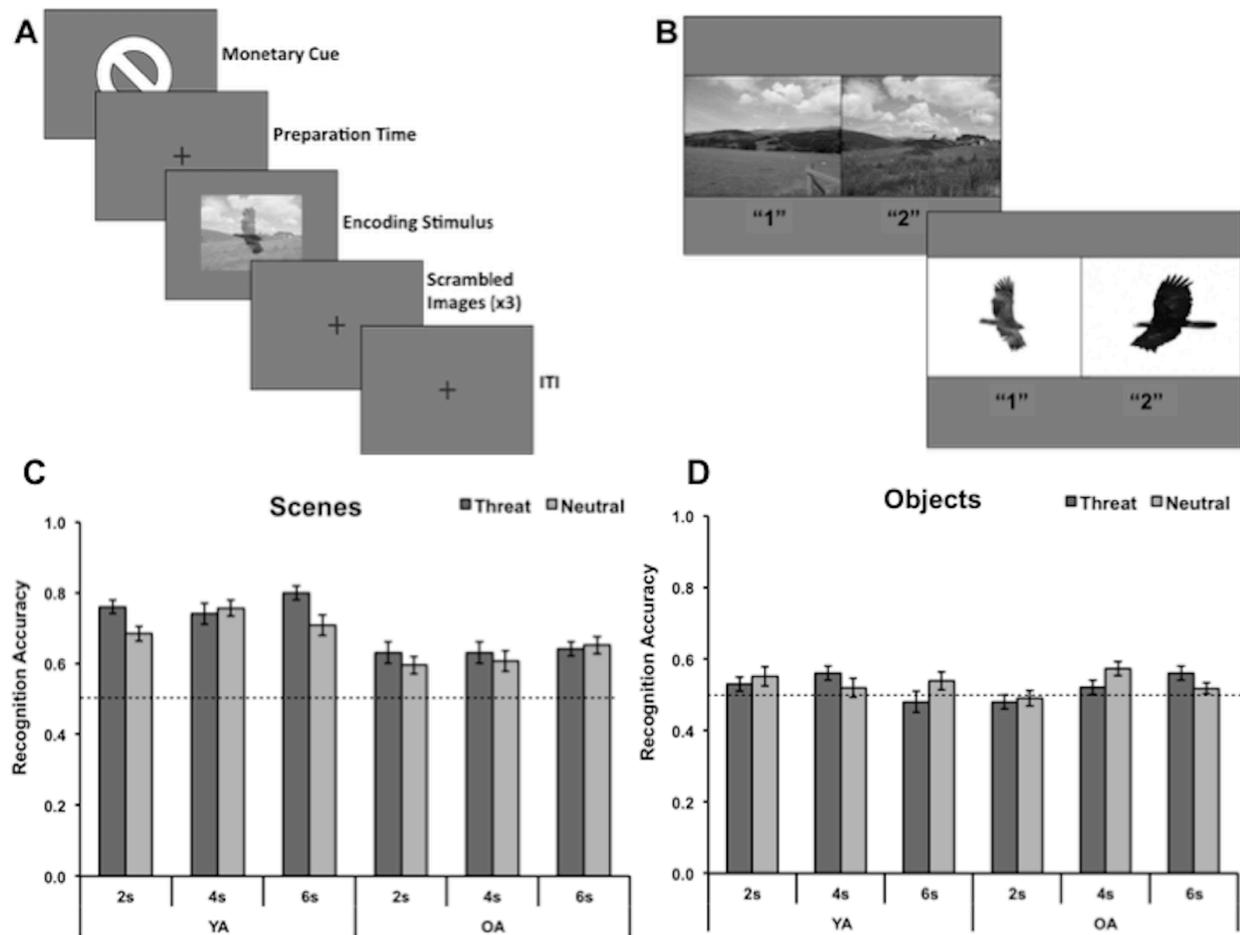


Figure 1. Example trials from (A) encoding and (B) the two-alternative forced-choice recognition test. The actual stimuli could not be shown due to copyright permissions. These pictures are exemplars of the stimuli used in the study (photos taken from public domain: scenes by Alex Liivet; Eagle 1 by Carly Lesser and Art Drauglis; Eagle 2 by Juan Lacruz). Recognition accuracy for (C) high-priority scenes (i.e., targets) and (D) low-priority objects (i.e., distractors) as a function of age, arousal, and preparation time. The dotted line represents performance at chance level. YA = younger adults; OA = older adults.

Table 1. Means for scene and object recognition as a function of age, arousal, and preparation time.

		Younger Adults			Older Adults		
		2s	4s	6s	2s	4s	6s
Threat							
	Scenes	.76 (.12)	.74 (.16)	.80 (.13)	.63 (.15)	.63 (.14)	.64 (.13)
	Objects	.53 (.11)	.56 (.12)	.48 (.14)	.48 (.13)	.52 (.10)	.56 (.12)
Neutral							
	Scenes	.68 (.12)	.76 (.13)	.71 (.16)	.59 (.14)	.61 (.16)	.65 (.14)
	Objects	.55 (.15)	.52 (.15)	.54 (.14)	.49 (.12)	.57 (.11)	.52 (.09)

Note. Standard deviations are given in parentheses.