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Age Differences in Vulnerability to Distraction Under Arousal

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Abstract

Aging affects brain circuitry involved in both inhibition and arousal. In this study, we tested whether older adults are more or less prone to distraction from emotionally arousing events than young adults. To do so, we examined how arousing taboo distractor words affected concurrent 1-back task performance and subsequent memory for distractors. Our second goal was to examine how the arousal level of one item can modulate processing of preceding neutral distractors (taboo-minus-1 distractors). During the task, participants first made 1-back judgments about target pictures that were superimposed with to-be-ignored neutral or taboo distractors. Relative to young adults, older adults were more distracted by taboo than neutral words on the 1-back task and remembered more of the taboo distractors on a later incidental recognition task. Furthermore, young adults showed better suppression of taboo-minus-1 distractors than neutral distractors, whereas in older adults, arousal did not facilitate suppression of taboo-minus-1 distractors. This effect appeared to require attentional control as adding an unrelated attentional load during the 1-back task eliminated the beneficial effect of arousal for young adults' suppression of taboo-minus-1 distractors. Finally, when top-down attentional guidance was provided by increasing the goal-relevance of target pictures, both groups showed enhanced suppression of taboo-minus-1 distractors versus other neutral distractors. Together, these findings imply that the effect of arousal on distractibility in aging may arise from an interaction between top-down and bottom-up processes.

Keywords: aging, inhibition, arousal, memory

Age Differences in Vulnerability to Distraction Under Arousal

Our perception and memory tends to favor emotionally arousing events, such as witnessing a robbery or a surprise birthday celebration over mundane experiences like our daily commute (LaBar & Cabeza, 2006). This ability is invaluable to survival – it enables us to rapidly evaluate the environment and respond appropriately during high-stake moments. It has been suggested that the phasic arousal response evoked by emotionally-charged events prepares the brain to respond by triggering activity in the amygdala, which focuses attention on the event and amplifies subsequent memory for it (Vuilleumier, 2005). However, there are times when attending to emotionally arousing stimuli can be detrimental, such as when driving by the scene of a car crash on the opposite side of the freeway. In such cases, succumbing to distraction could impair performance. Consistent with this notion, prior research has shown that when emotionally arousing images are presented as distractors, immediate task performance is impaired and the arousing distractors end up being encoded and stored in long-term memory (Dolcos et al., 2013; Shafer & Dolcos, 2012).

Although the immediate and long-term effects of arousal on distractibility in young adults have been addressed (Dolcos & Denkova, 2014; Dolcos & McCarthy, 2006; Most, Chun, Widders, & Zald, 2005), this question becomes particularly critical in the context of aging. A long line of evidence suggests that inhibitory control declines in later life (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007), with older adults becoming less able to ignore distraction than young adults. As a result, older adults encode more distracting information (Campbell, Hasher, & Thomas, 2010; Gallant & Yang, 2015; Kim, Hasher, & Zacks, 2013; Titz & Verhaeghen, 2010), which can interfere with future memory performance (Biss, Campbell, & Hasher, 2013). This increase in distractibility with age is thought to arise from deficits in selective attention (Hasher & Zacks, 1988), which focuses attention on processing relevant information while simultaneously inhibiting distraction. These processes have been associated with the frontoparietal network, which controls responses to incoming stimuli and minimizes the effects of distraction on performance (Vincent et al., 2008). Relative to young adults, older adults have shown reduced connectivity within the frontoparietal network (Nashiro, Sakaki, Braskie, & Mather, 2017) and less network activation when performing tasks that involve down-regulation of task-irrelevant stimuli (Campbell, Grady, Ng, & Hasher, 2012). These age-related changes in network functioning and coherence are thought to underlie older adults' distractibility (Kennedy & Mather, 2019).

Given that older adults are at a heightened risk of succumbing to distraction, it seems likely that arousal would further exacerbate age-related impairments in distractibility. In line with this prediction, recent neuroimaging work found that arousal increased older adults' tendency to process task-irrelevant stimuli (Lee et al., 2018). During an arousal response, the brain's primary synthesizer of norepinephrine (NE), the locus coeruleus (LC), is thought to interact with the frontoparietal network to modulate selective attention (Alnaes et al., 2014; Mather, Clewett, Sakaki, & Harley, 2016; Sara & Bouret, 2012). Lee and colleagues (2018) found that arousal selectively increased brain activation associated with task-relevant images while decreasing activation associated with task-irrelevant images in young adults. Older adults, in contrast, showed greater activity in response to *both* relevant and irrelevant images under arousal. There was also increased functional connectivity between the LC and the frontoparietal network during arousing versus non-arousing trials, but this connection was stronger for young than for older adults. These findings suggest that the aging brain may be less effective at dampening responses to irrelevant stimuli under arousal, possibly due to disrupted connections between critical attention networks and the LC.

Although Lee and colleagues' (2018) neuroimaging findings show that arousal may increase the potential for distraction in older adults, behavioral evidence is required to support this notion. In the current set of experiments, we sought to tease apart age differences in how arousal influences distractibility. Specifically, our first goal was to test the immediate impact of emotionally arousing taboo distractors on young and older adults' concurrent task performance as well as whether taboo distractors were more likely to be remembered than neutral distractors.

Our second goal was to test whether the effect of taboo-related arousal modulates processing of preceding neutral distractors. Prior work has shown that arousal's influence is not just limited to enhancing memory for emotionally arousing stimuli, but that it can also influence perception and memory for nearby neutral information (Anderson, 2005; Lee, Itti, & Mather, 2012; Most et al., 2005; Sutherland & Mather, 2012). For example, emotional oddball stimuli can exert a retroactive effect, enhancing memory suppression of preceding task-irrelevant neutral stimuli (Sakaki, Fryer, & Mather, 2014). This retrograde effect can influence stimuli seen up to six seconds prior to an arousing event and seems to depend on amygdala and noradrenergic activation evoked by the emotional stimulus (Strange, Hurlemann, & Dolan, 2003). In the current study, seeing an arousing taboo word may therefore facilitate suppression of preceding neutral distractors (from here, referred to as taboo-minus-1 distractors). However, this effect may only be present in young adults, since arousal seems to indiscriminately increase older adults' brain activation for both task-relevant and task-irrelevant inputs (Lee et al., 2018).

To address these goals, we adapted a task that has been used to demonstrate age differences in the ability to ignore centrally fixated distractor words (e.g., Amer & Hasher, 2014;

Biss et al., 2013; Campbell et al., 2010; Weeks & Hasher, 2017). Participants completed a 1-back task for pictures while ignoring superimposed taboo or neutral distractor words. This picture-word overlap design was optimal for measuring inhibition as it required participants to attend to pictures while suppressing an automatic word-reading response from distractors (Kahneman & Chajczyk, 1983). A subsequent recognition task measured the degree to which distractors were encoded into memory. This design enabled us to test the immediate effect of taboo-related arousal on concurrent 1-back performance as well as the long-term effect on memory for distractors. We expected older adults to be more susceptible to distraction from taboo-related arousal than young adults, with impaired 1-back performance and greater incidental memory for taboo than neutral distractors. We further predicted that the effect of taboo-related arousal would spill over to enhance suppression of preceding neutral distractors, with reduced memory for taboo-minus-1 distractors in young but not older adults.

Experiment 1

In Experiment 1, young and older adults made 1-back judgments about whether sequentially presented pictures were the 'same' or 'different' as the previous picture, while ignoring task-irrelevant taboo or neutral words. A subsequent incidental recognition task tested memory for distractors as well as the pictures seen during the 1-back task. Using this design, we tested whether participants would remember more taboo than neutral distractors and whether seeing a taboo word would enhance young but not older adults' suppression of taboo-minus-1 distractors.

Method

Participants. The final sample after exclusions included 66 healthy young adults (ages 20-29; M = 25.21, SD = 2.17; 23 females) and 68 healthy older adults (ages 59-77; M = 65.21, *SD* = 4.67; 34 females). All participants were recruited via Turk Prime (Litman, Robinson, & Abberbock, 2016) and located in the United States. A power analysis using G*Power (Faul, Erdfelder, Lang, & Buchner, 207) indicated that this sample size would provide 80% power to detect a within-between interaction effect of $f = 0.10$ or $\eta_p^2 = 0.01$. Participants were compensated $6.25 USD for approximately 50 minutes of participation. All participants provided informed consent in accordance with procedures approved by the Institutional Review Board at the University of Southern California.

To ensure data quality, participants were required to complete three attention checks that were dispersed throughout the protocol to ensure they were reading task instructions (Oppenheimer, Meyvis, & Davidenko, 2009). This included the following multiple choice questions that required specific responses: “Please select option four” and “Please do not respond and skip to the next question”. The final attention check asked, “What was this experiment about?”, with the options “Current events”, “Judgments”, “Products”, and “Other”. The instructions above the question told participants to select “Other” and type the word “Gold” in the response box (Mather et al., 2012). If participants failed to pass these attention checks, their data were excluded from analysis. Data were also excluded if participants failed to indicate their age, indicated a diagnosis of a psychiatric and/or neurological illness, were taking psychoactive medications or beta-blockers, or if duplicate Turk Prime identification numbers were found indicating a participant took the survey multiple times. Based on these criteria, 22 participants were excluded (six older, 13 young, and three participants that did not indicate their age).

Young adults had fewer years of education ($M = 14.33$, $SD = 1.95$) than older adults ($M = 15.27$, $SD = 2.33$; $t(132) = -2.53$, $p = 0.013$, $d = 0.42$) and scored lower on the Shipley Institute of Living Vocabulary test (Shipley, 1940; $M = 30.95$, $SD = 5.62$) than older adults ($M = 35.81$, *SD* = 3.48; $t(132) = -5.99$, $p < 0.001$, $d = 1.04$). These age differences are commonly reported in the literature (e.g., Campbell et al., 2010).

Materials. The experiment was programmed and run using Qualtrics survey software (Qualtrics, Provo, UT). A total of 120 neutral pictures were selected from the Snodgrass and Vanderwart (1980) line drawings and recolored red. These pictures were separated into two lists of 60, which were counterbalanced as old and new target pictures during the 1-back and recognition task. An additional 10 filler pictures were selected, which were used for 1-back repetition trials and were not included in the recognition task.

A total of 120 words (100 neutral, 20 taboo) were selected from Janschewitz (2008). Following the experiment, words were rated on tabooness and arousal using separate 9-point scales ranging from 1 = not taboo or arousing at all to 9 = very taboo or arousing, respectively. This confirmed that taboo words were rated as higher in tabooness than neutral words by both young ($M_{taboo} = 7.01$, $SD = 1.13$, $M_{neutral} = 1.34$, $SD = .60$; $t(42) = 31.29$, $p < 0.001$, $d = 4.77$) and older adults ($M_{taboo} = 6.53$, $SD = 1.46$, $M_{neutral} = 1.18$, $SD = .57$; $t(50) = 24.62$, $p < 0.001$, $d = 3.42$).[1] Similarly, taboo words were rated as higher in arousal than neutral words by both young ($M_{taboo} = 6.28$, $SD = 1.91$, $M_{neutral} = 2.26$, $SD = 1.36$; $t(42) = 10.77$, $p < 0.001$, $d = 1.64$) and older adults ($M_{taboo} = 5.95$, $SD = 1.98$, $M_{neutral} = 2.11$, $SD = 1.33$; $t(50) = 14.39$, $p < 0.001$, $d = 3.42$). Age groups did not differ in their ratings, *ps* ≥ 0.08.

Words were separated into two sub-lists of 60 (50 neutral and 10 taboo words), which were counterbalanced as old and new lists. An additional 20 neutral words were randomly paired with the filler pictures during the 1-back task and were not included in the recognition task (selected stimuli for all experiments can be found on Open Science Framework: https://osf.io/jwpa8/). Across counterbalance conditions, pictures and words were randomly paired. On 1-back repetition trials, only the filler pictures were repeated, but not the filler words, which was why there were 20 filler words and only 10 filler pictures.

Procedure. Participants first completed the 1-back task. They were informed that the purpose of the task was to understand the effects of distraction on detection of repeated pictures, which were superimposed with task-irrelevant words that should be ignored. They were not informed of the later memory task. Participants then completed three multiple choice questions that probed their comprehension of the task instructions. If any questions were answered incorrectly, the correct instructions appeared on the screen before they could proceed. During the 1-back task, participants viewed a series of pseudo-randomized pictures superimposed with distractor words for 1500 ms each, during which they pressed the 'S' key if the picture was the same as the one presented immediately before or the 'D' key if it was different (see Figure 1). Each picture was followed by a fixation cross as an inter-trial interval (ITI) for 500 ms. Participants completed 12 practice trials, followed by 80 trials of the 1-back task. This included the 60 picture-word pairs that were used in the recognition task (50 with neutral distractors and 10 with taboo distractors) and the 20 filler picture pairs that were used for 1-back repeat trials (a total of 10 'same' responses were required). Taboo distractors never occurred on repeat trials.

A 10-minute filler period followed during which participants completed a demographic questionnaire and a non-verbal target detection task. Two separate self-paced incidental recognition tasks were then administered for target pictures and distractor words in which participants indicated their memory for each stimulus by clicking old or new response options. The order of recognition tasks was counterbalanced across participants and each task included an equal number of pseudo-randomized old and new stimuli. Participants then completed the Shipley vocabulary test and rated the word stimuli on tabooness and arousal level.

Results

1-back task. Performance on the 1-back task was first analyzed as proportional accuracy and reaction time (RT) to respond ‘same’ to repeated pictures. Prior to analyses, RTs that were +/- 2.5 SDs from the mean RT of each participant were trimmed prior to calculating the mean RT for each condition. While no age differences emerged in proportional accuracy, $t(132) = 0.50$, $p = 0.62$, $d = 0.08$, young adults ($M = 834$ ms, $SD = 122$) were faster to detect 1-back repetitions than older adults ($M = 1008$ ms, $SD = 160$), $t(132) = -7.07$, $p < .001$, $d = 1.22$, suggesting a possible speed-accuracy trade-off in older adults.

Since non-repeated trials were either neutral or taboo, we were able to examine the effect of distractor type on proportional accuracy and RTs to respond ‘different’ to non-repeated pictures in separate 2 (age group: young, older) × 2 (distractor type: taboo, neutral) mixed ANOVAs. A main effect of age group, $F(1, 132) = 6.98$, $p = 0.009$, $\eta_p^2 = 0.05$, revealed that young adults were more accurate at responding to non-repeated trials ($M = .98$, $SD = .07$) than older adults ($M = .92$, $SD = .17$). There was also a main effect of distractor type, $F(1, 132) = 4.77$, $p = .03$, $\eta_p^2 = 0.035$, qualified by an age × distractor type interaction, $F(1, 132) = 6.79$, $p = 0.01$, $\eta_p^2 = 0.049$. Older adults were less accurate at responding to non-repeated trials superimposed with a taboo ($M = .90$, $SD = .19$) than a neutral word ($M = .93$, $SD = .16$), $t(67) = 2.95$, $p = 0.004$, $d = 0.45$, whereas young adults showed no such difference ($M_{neutral} = .98$, $SD = .07$, $M_{taboo} = .98$, $SD = .08$), $t = -0.37$, $p = 0.72$, $d = < 0.001$. With regard to RTs, older adults ($M = 992$ ms, $SD = 171$) were slower to respond to non-repeated trials than young adults ($M = 821$, $SD = 118$), $F(1, 132) = 44.79$, $p < 0.001$, $\eta_p^2 = 0.25$, and both age groups’ responses were slower to respond to non-repeated trials superimposed with a taboo distractor ($M = 922$ ms, $SD = 185$) relative to a neutral distractor ($M = 893$ ms, $SD = 159$), $F(1, 132) = 22.72$, $p < 0.001$, $\eta_p^2 = 0.15$.

Memory for pictures. To determine if seeing a taboo distractor influenced memory for pictures, we compared recognition for pictures superimposed with a taboo versus neutral word. Corrected recognition rates (hit rate minus false alarm rate) were submitted to a 2 (age group: young, older) × 2 (distractor type: taboo, neutral word) mixed ANOVA; however, there were no significant effects, $Fs \leq 2.69$, $ps \geq 0.10$, $\eta_p^2 \leq 0.02$. We also examined how seeing taboo distractors influenced recognition of taboo-minus-1 pictures in a 2 (age group: young, older) × 2 (distractor type: taboo-minus-1, neutral) mixed ANOVA. A main effect of age group indicated that older adults remembered more pictures (M = .51, SD = .20) than young adults (M = .42, SD = .19), $F(1, 132) = 6.05$, $p = 0.015$, $\eta_p^2 = 0.044$, but there were no other significant effects, $Fs \leq 0.84$, $ps \geq 0.36$, $\eta_p^2 \leq 0.006$.

Memory for distractor words. Next, we compared corrected recognition of taboo and neutral distractors in a 2 (age group: young, older) × 2 (distractor type: taboo, neutral) mixed ANOVA to determine if arousal was more likely to increase memory for task-irrelevant words in older relative to young adults. A main effect of age group, $F(1, 132) = 5.34$, $p = 0.023$, $\eta_p^2 = 0.039$, showed that older adults (M = .29, SD = .16) remembered more distractors than young adults (M = .22, SD = .19), and all participants, regardless of age, remembered more taboo (M = .42, SD = .30) than neutral distractors (M = .09, SD = .13), $F(1, 132) = 175.87$, $p < 0.001$, $\eta_p^2 = 0.57$. A significant age × distractor type interaction, $F(1, 132) = 6.17$, $p = 0.014$, $\eta_p^2 = 0.045$, further revealed that older adults remembered more taboo distractors (M = .48, SD = .28) than young adults (M = .35, SD = .31), $t(133) = -2.58$, $p = 0.01$, $d = 0.46$, but there was no age difference in recognition of neutral distractors (M_{old} = .10, SD = .12, M_{young} = .09, SD = .14), $t = -0.55$, $p = 0.58$, $d = 0.063$ (Figure 2A).

We then examined how arousal influenced corrected recognition of taboo-minus-1 distractors versus all other neutral distractors in a 2 (age group: young, older) × 2 (distractor type: taboo-minus-1, neutral) mixed ANOVA. There were no significant main effects, *Fs* ≤ 3.28, *ps* ≥ 0.07, $\eta_p^2 \leq 0.024$. A significant age × distractor type interaction, $F(1, 132) = 5.24$, $p = 0.024$, $\eta_p^2 = 0.038$, revealed that taboo words influenced young and older adults' recognition of taboo-minus-1 distractors differently (Figure 2B). In line with our predictions, young adults had reduced recognition of taboo-minus-1 distractors ($M = .04$, $SD = .17$) versus other neutral distractors ($M = .09$, $SD = .13$), $t(65) = 2.49$, $p = 0.015$, $d = 0.31$, whereas older adults had no such difference ($M_{\text{taboo-minus-1}} = .11$, $SD = .17$, $M_{\text{neutral}} = .09$, $SD = .12$), $t = -0.69$, $p = 0.49$, $d = 0.10$.

Discussion

Taboo distractors exerted a greater effect than neutral distractors on older adults' concurrent performance as well as on their subsequent memory. During the 1-back task, both age groups were slower when responding to pictures superimposed with a taboo versus neutral distractor. However, only older adults' accuracy was reduced when responding to taboo distractor trials. This implies that both groups were distracted by taboo words, but this only had a detrimental effect for older adults' accuracy, with evidence for a possible speed-accuracy trade-off in young adults' responses.

The disruptive effect of arousing distraction carried over to memory, as both young and older adults incidentally remembered more taboo than neutral distractors. This effect was exacerbated in older adults: They remembered even more taboo distractors than young adults, with no age difference in recognition of neutral distractors. In contrast, picture recognition was not modulated by arousal, suggesting that the effect of taboo-related arousal was specific to distractor recognition.

The effect of taboo-related arousal also spilled over to the preceding trial. Young adults were more effective at ignoring distractors when they appeared just before a taboo trial relative to a neutral trial. Older adults, in contrast, did not show this benefit of arousal and were just as likely to remember taboo-minus-1 distractors as all other neutral distractors. This is consistent with our prediction that seeing something arousing would enhance young but not older adults' suppression of preceding neutral distractors. It also supports the notion that a surge of arousal can retroactively modulate memory representations (Sakaki et al., 2014; Strange et al., 2003).

Why does taboo-related arousal enhance suppression of preceding neutral distractors in young but not older adults? According to prior work, functional connectivity and recruitment of the frontoparietal network is reduced in older adults when performing inhibition tasks (Campbell et al., 2012). Because this network and its associated control over attention is already disrupted by aging, arousal may be less effective at dampening processing of task-irrelevant stimuli that are currently held in mind. In Experiment 2, we tested this hypothesis by examining how attentional control contributes to age differences in suppression of taboo-minus-1 distractors.

Experiment 2

In Experiment 2, we repeated the procedure of Experiment 1 but manipulated the attentional control of young and older adults to examine the role of selective attention in suppression of taboo-minus-1 distractors. Participants completed the same 1-back task as in Experiment 1, except that half of the trials were now completed with an additional information load and the remaining half under conditions of no additional load. If reduced attentional control plays a role in the effects of arousal (or lack thereof) on older adults' memory for taboo-minus-1 distractors, then age differences in recognition of taboo-minus-1 distractors should be diminished, or even eliminated, when young adults have a high attentional load.

Method

Participants. After exclusions, the final sample included 85 healthy young adults (ages 19-32; M = 25.14, SD = 2.33; 39 females) and 84 healthy older adults (ages 60-86; M = 65.33, SD = 4.53; 50 females). Participants were recruited from Turk Prime (Litman et al., 2016) and located in the United States. This sample size provided 80% power to detect a within-between interaction of $f = 0.08$ or $\eta^2_p = 0.01$. Participants were compensated $6.25 for approximately 50 minutes of participation. Using the exclusion criteria described in Experiment 1, 41 additional participants (21 young and 20 older) were excluded due to use of psychoactive drugs, diagnoses of psychiatric or neurological illnesses, or for not passing attention checks. There was a marginally significant age difference in education, with fewer years of education in young adults (M = 14.74; SD = 1.79) than older adults (M = 15.35; SD = 2.31), $t(163) = -1.88$, $p = 0.06$, d = 0.29. Young adults also scored lower on the Shipley vocabulary test (M = 30.67; SD = 6.01) than older adults (M = 35.02; SD = 5.91) $t(163) = -4.70$, $p < 0.001$, $d = 0.75$.

Materials. A total of 180 neutral line drawings were selected from Snodgrass and Vanderwart (1980) and recolored red. These pictures were separated into three sub-lists of 60, which were counterbalanced as load or no-load pictures during the 1-back task or served as new pictures during the recognition task. One hundred and fifty-three neutral words and 27 taboo words were selected from Janschewitz (2008) and similarly separated into three sub-lists (each with 51 neutral words and 9 taboo words), which were counterbalanced as load, no-load, and new words.[2] As in Experiment 1, an additional 12 neutral pictures and 24 neutral words were selected to serve as 1-back repetition trials and were not included in the recognition task.

The 1-back task was separated into six blocks of 24 trials, which each included three trials with taboo distractor words, 19 trials with neutral distractor words, and two repeat trials where the response ‘same’ was required. Information load was manipulated within subjects, such that three consecutive blocks were completed under load conditions and the remaining three were completed under no-load conditions. We counterbalanced block ordering so that half of the participants completed three load blocks first, followed by three no-load blocks, and the remaining participants had the reverse order. During load blocks, a secondary digit recall task was administered, in which participants were shown three digits at the beginning of the block and were asked to recall them in the correct order at the end of the block. To equate task structure in the no-load blocks, participants were shown three symbols (e.g., ‘&’, ‘%’, ‘\’) at the beginning, but were not required to remember them during the 1-back task block.

Procedure. After providing informed consent, participants began the 1-back task either under the load or the no-load condition. Each load block began with presentation of three to-be-remembered digits for 500 ms each. This was immediately followed by 24 pseudo-randomized trials of the 1-back task, which proceeded as in Experiment 1 (see Figure 1). At the end of each load block, participants had five seconds to recall the digits in the correct order before proceeding to the next block. At the beginning of no-load blocks, participants saw three symbols for 500 ms each, followed by 24 pseudo-randomized trials of the 1-back task. At the end of no-load blocks, a five-second break was provided before proceeding to the next block. Participants completed eight practice trials under each of the load and no-load conditions.

There was a 10-minute delay after 1-back task during which participants completed the same tasks that were administered during the filler period of Experiment 1. Participants then completed two separate self-paced recognition tasks for the pictures and distractor words seen during the load and no-load blocks. The recognition tasks proceeded as in Experiment 1, after which participants completed the Shipley vocabulary test.

Results

Secondary digit recall task. To ensure participants were engaging in the secondary digit recall task, we first examined the proportion of digits recalled in the correct order. Accuracy was high for both young (M = .88, SD = .21) and older adults (M = .91, SD = .20) and did not differ between age groups, $t(167) = -1.28$, $p = 0.20$, $d = 0.17$.

1-back task. As in Experiment 1, we separately examined proportional accuracy and RTs to respond 'same' to repeated pictures during load and no-load blocks as a function of age group.[3] Any RTs that were +/- 2.5 SDs from each participant's mean were removed before calculating mean RTs for each condition. A 2 (age group: young, older) × 2 (load: no-load, load) mixed ANOVA revealed that participants were more accurate at responding to repeated pictures during load blocks (M = .76, SD = .25) relative to no-load blocks (M = .71, SD = .24), $F(1, 167) = 7.81$, $p = 0.006$, $\eta_p^2 = 0.045$. There was no significant effect of age or interaction of age and load on proportional accuracy, $Fs \leq 0.56$, $ps \geq 0.46$, $\eta_p^2 \leq 0.003$. With regard to RTs, a main effect of age, $F(1, 167) = 5.10$, $p = 0.025$, $\eta_p^2 = 0.03$, showed that young adults (M = 942 ms, SD = 303) were faster than older adults (M = 1135 ms, SD = 653) at responding to repeated pictures, similar to the results of Experiment 1. Reaction times did not significantly vary by load nor did load interact with age, $Fs \leq .38$, $ps \geq 0.54$, $\eta_p^2 \leq 0.002$.

Since non-repeated trials were either neutral or taboo, distractor type was included as a factor in our analysis of accuracy and RTs to respond 'different' to non-repeated pictures in separate 2 (age group: young, older) × 2 (load: no-load, load) × 2 (distractor type: taboo, neutral) mixed ANOVAs. The analysis of accuracy revealed main effects of load, $F(1, 167) = 9.82$, $p =$

0.002, $\eta_p^2 = 0.05$, and distractor type, $F(1, 167) = 4.16$, $p = 0.04$, $\eta_p^2 = 0.02$, which were qualified by a Load × Distractor type interaction, $F(1, 167) = 18.87$, $p < 0.001$, $\eta_p^2 = 0.10$. Participants responded less accurately to non-repeated pictures superimposed with taboo distractors on load blocks ($M = .91$, $SD = .16$) than on no-load blocks ($M = .95$, $SD = .13$), $t(168) = -4.01$, $p < 0.001$, $d = 0.32$. Accuracy to respond to non-repeated pictures with a neutral distractor did not differ across load blocks, $t = -0.70$, $p = 0.48$, $d = 0.05$. The main effect of age on accuracy was not significant, $F = 2.90$, $p = 0.09$, $\eta_p^2 = .02$, nor were the remaining interaction terms, $Fs \leq 2.72$, $ps \geq 0.10$, $\eta_p^2 \leq 0.02$. The analysis of RTs showed that young adults ($M = 898$ ms, $SD = 297$) were faster to respond to non-repeated pictures than older adults ($M = 1072$ ms, $SD = 646$), $F(1, 167) = 5.09$, $p = 0.025$, $\eta_p^2 = 0.03$. There were no other significant effects or interactions for RTs, $Fs \leq 0.38$, $ps \geq 0.54$, $\eta_p^2 \leq 0.002$.

Memory for pictures. Next, we examined how taboo distractors influenced corrected recognition of pictures in a 2 (age group: young, older) × 2 (load: no-load, load) × 2 (distractor type: taboo, neutral) mixed ANOVA. A main effect of load, $F(1, 167) = 10.75$, $p = 0.001$, $\eta_p^2 = 0.061$, showed that picture recognition was better on no-load ($M = .38$, $SD = .22$) than on load trials ($M = .34$, $SD = .21$). The other main effects and interaction terms were not significant, $Fs \leq 2.95$, $ps \geq 0.088$, $\eta_p^2 \leq 0.017$. We also analyzed corrected recognition of pictures in the taboo-minus-1 position in a 2 (age group: young, older) × 2 (load: no-load, load) × (distractor type: taboo-minus-1, neutral) mixed ANOVA, which again revealed a main effect of load, $F(1, 167) = 16.43$, $p < 0.001$, $\eta_p^2 = 0.09$, with better recognition of pictures on no-load than load trials. There were no other significant main effects or interactions, $Fs \leq 1.34$, $ps \geq 0.25$, $\eta_p^2 \leq 0.008$.

Memory for distractor words. To determine the effect of load on age differences in memory for distractors, corrected recognition rates for neutral and taboo words were submitted to a 2 (age group: young, older) × 2 (load: no-load, load) × 2 (distractor type: taboo, neutral) mixed ANOVA. A main effect of distractor type, $F(1, 167) = 168.41$, $p < 0.001$, $\eta_p^2 = 0.50$, revealed better recognition for taboo distractors ($M = .35$, $SD = .29$) relative to neutral distractors ($M = .08$, $SD = .09$), independent of load or age (Figure 3A). No other main effects or interactions were significant, $Fs \leq 2.99$, $ps \geq 0.09$, $\eta_p^2 \leq 0.018$.

Next, we analyzed how load influenced age differences in recognition of taboo-minus-1 distractors in a 2 (age group: young, older) × 2 (load: no-load, load) × 2 (distractor type: taboo-minus-1, neutral) mixed ANOVA. The main effects of age, load, and distractor type were not significant, $Fs \leq 2.38$, $ps \geq 0.13$, $\eta_p^2 \leq 0.014$. There was a marginal Age × Distractor type interaction, $F(1, 167) = 3.70$, $p = 0.056$, $\eta_p^2 = 0.022$, which was not qualified by the three-way interaction, $F = 2.27$, $p = 0.13$, $\eta_p^2 = 0.13$. Guided by our hypotheses, we conducted a more liberal examination of the Age × Distractor type interaction within each load condition. For load trials, there were no significant main effects or interactions, Fs ≤ 1.42, $ps \geq 0.24$, $\eta_p^2 \leq 0.008$. For no-load trials, there was a significant Age × Distractor type interaction, $F(1, 167) = 5.42$, $p = 0.021$, $\eta_p^2 = 0.03$. Whereas young adults showed reduced recognition of taboo-minus-1 distractors ($M = .05$, $SD = .17$) than other neutral distractors ($M = .08$, $SD = .12$), $t(84) = 1.96$, $p = 0.05$, $d = 0.22$, older adults showed no such difference ($M_{\text{taboo-minus-1}} = .10$, $SD = .18$, $M_{\text{neutral}} = .08$, $SD = .10$), $t(83) = -1.32$, $p = 0.20$, $d = 0.14$ (Figure 3B). Thus, on no-load trials, only young adults showed better suppression of taboo-minus-1 distractors than other neutral distractors.

Discussion

On the 1-back task, participants were better able to detect repeated pictures during load trials than during no-load trials. This finding of better performance on load blocks fits with a load theory of selective attention (for a review, see Lavie, 2010), which posits that the degree to which people can focus attention in the face of distraction depends on information load. When information load is high in young adults, it leaves no capacity for distractors to be processed, whereas under low load, additional attention resources may spill over to process task-irrelevant representations (Lavie, 2010). Put differently, the ability to attend to targets and ignore distraction may be improved with the right amount of load. This benefit of load on target detection did not extend to trials with a taboo distractor, and in fact, it had a reverse effect. In Experiment 2, participants detected non-repeated pictures superimposed with a taboo distractor less accurately on load relative to no-load trials. One possible explanation for why participants were more susceptible to taboo distractors on load trials is that the benefit of information load on selective attention decreases as distractor salience increases, such as with taboo versus neutral distractors.

Although both age groups were more susceptible to taboo distractors than neutral distractors, this effect was not exacerbated in older adults during no-load blocks like it was in Experiment 1. This could be due to minor differences in the 1-back task design between the two experiments. For example, during Experiment 2, the 1-back task was broken into six blocks during which participants either encoded digits or viewed symbols at the beginning of each block. These smaller 1-back blocks of 24 trials may have made it easier for older adults to focus attention and ignore taboo distractors relative to the single block of 80 trials in Experiment 1.

Critically, our analysis of distractor recognition under each load condition supported our hypothesis that attention-based mechanisms may underlie the effects of arousal on suppression of taboo-minus-1 distractors. No age differences were observed in memory for taboo-minus-1 distractors on load trials—both young and older adults had similar recognition of taboo-minus-1 distractors and neutral distractors. It was only on no-load trials that an age-by-distractor type interaction emerged, replicating Experiment 1. Although these analyses were exploratory, results implied that the influence of taboo-related arousal spilled over to enhance young adults' suppression of taboo-minus-1 distractors during no-load trials. Older adults' performance, however, did not vary as a function of load. This suggests that the enhanced suppression of taboo-minus-1 distractors for young adults in Experiment 1 may have required attentional resources. As such, during aging, or when information load is high, arousal may be less effective at coordinating processes for suppressing nearby neutral task-irrelevant information. This pattern of results raises the question of whether attentional resources are malleable and could be improved in a manner that facilitates suppression under arousal during aging.

Experiment 3

Experiment 1 showed that, compared to young adults, older adults were more susceptible to taboo-related distraction than young adults and less likely to receive a boost in inhibition of neutral distractors that preceded taboo words. Experiment 2 suggested that reduced attentional resources could underlie this age difference in inhibition under arousal, as the benefit of arousal on suppression of taboo-minus-1 distractors was seemingly disrupted when young adults experienced increased information load from a secondary task. In Experiment 3, we examined whether we could improve older adults' attention in a manner that would enhance suppression of taboo-minus-1 distractors. Prior work has shown that when top-down attentional guidance is provided in terms of relevant knowledge about target features, older adults can improve their selective attention (e.g., Whiting, Madden, & Babcock, 2007; Whiting, Sample, & Hagan, 2014). We thus sought to improve selective attention under arousal in older adults by increasing the goal-relevance of target pictures. To do this, we had young and older adults view a series of pictures that were either colored or black-and-white line drawings with the goal of only remembering the colored pictures. Like the prior two experiments, pictures were superimposed with taboo or neutral distractor words. Half of the to-be-remembered colored pictures preceded a taboo distractor and the remaining half preceded a neutral distractor. This allowed us to compare suppression of neutral distractors superimposing goal-relevant colored pictures when they preceded taboo distractors (taboo-minus-1 distractors) versus neutral distractors (neutral-minus-1 distractors). To further increase attention to pictures during encoding, participants made 'natural' or 'manmade' judgments for each picture. We hypothesized that explicit guidance to selectively attend to goal-relevant colored pictures would enhance the effect of taboo-related arousal on suppression of taboo-minus-1 distractors in older adults.

Method

Participants. The final sample after exclusions included 58 healthy young adults (ages 19-34; M = 25.10, SD = 2.95; 28 females) and 57 healthy older adults (ages 59-82; M = 64.96, SD = 5.15; 36 females) who were recruited from Turk Prime (Litman et al., 2016) and located in the United States. A power analysis indicated that this sample size would provide 80% power to detect a within-between interaction effect of f = 0.13 or $\eta_p^2 = 0.02$. Participants were compensated $6.25 USD for 50 minutes of participation. Using the exclusion criteria described in Experiment 1, the data of 30 participants (16 young, 13 older, and one who did not report their age) were excluded due to the use of psychoactive drugs, psychiatric or neurological illnesses, or for not passing attention checks. There was no age difference in years of education (M_{young} = 14.57, SD = 1.92, M_{older} = 15.23, SD = 2.15; $t(113) = -1.74$, $p = 0.09$, $d = 0.32$). Young adults scored lower on the Shipley vocabulary test (M = 30.83, SD = 5.89) than older adults (M = 33.18, SD = 6.46; $t(113) = -2.35$, $p = 0.04$, $d = 0.38$).

Materials. A total of 40 colored pictures were selected from Rossion and Pourtois (2004), which consists of the same objects from Snodgrass and Vanderwart (1980) but colored. One hundred black-and-white line drawing pictures were also selected from Snodgrass and Vanderwart (1980). Colored pictures served as goal-relevant items that were to-be-remembered, whereas black-and-white pictures served as filler items. For distractors, the same 120 (100 neutral, 20 taboo) words from Experiment 1 were used plus an additional 20 neutral words from Janschewitz (2008). Words were rated on tabooness and arousal using the same procedure as Experiment 1. Taboo words were rated as higher in tabooness than neutral words by both young (M_{taboo} = 6.39, *SD* = 1.53, $M_{neutral}$ = 2.34, *SD* = 2.11; $t(57) = 10.55$, $p < 0.001$, $d = 1.37$) and older adults (M_{taboo} = 6.38, *SD* = 1.32, $M_{neutral}$ = 2.48, *SD* = 2.36; $t(56) = 10.29$, $p < 0.001$, $d = 1.36$). Similarly, taboo words were rated as higher in arousal than neutral words by both young (M_{taboo} = 6.17, *SD* = 1.84, $M_{neutral}$ = 1.89, *SD* = 1.71; $t(57) = 13.96$, $p < 0.001$, $d = 1.83$) and older adults (M_{taboo} = 5.43, *SD* = 2.06, $M_{neutral}$ = 2.47, *SD* = 2.19; $t(56) = 9.47$, $p < 0.001$, $d = 1.25$). Age groups were similar in their ratings ($ps \geq 0.12$) with the exception of older adults showing lower arousal ratings for taboo words than young adults, $t(113) = 2.04$, $p = 0.04$, $d = 0.38$.

Using these stimuli, picture-word pairs were created. Colored pictures were only paired with neutral words while black-and-white pictures were paired with either neutral or taboo words. Sub-lists of words and pictures were created to counterbalance the pairing of words across participants so that words were not always paired with the same picture. These sub-lists were also used to counterbalance stimuli as old during the encoding phase or new during recognition. An additional 12 pictures and 12 neutral words were selected for practice trials, which included three colored pictures and nine black-and-white pictures.

Procedure. Participants first completed the encoding task. Instructions indicated that the purpose of the task was to understand how people remember information in the face of distraction. Participants were asked to focus on remembering the colored pictures for a later memory task and to ignore distractor words. To focus attention on pictures, participants were instructed to indicate whether each picture was of a natural or manmade object. Participants then completed three multiple choice questions, which checked their comprehension of instructions. During encoding, participants viewed each picture-word pair for 1500 ms and pressed the 'N' key if the picture was of something natural or the 'M' key if the picture was of something manmade (see Figure 4). Afterwards, a fixation cross as an ITI appeared for 500 ms. Participants completed 12 practice trials, followed by 80 pseudo-randomized encoding trials. Of those trials, there were a total of 20 to-be-remembered colored pictures, 10 of which preceded a trial with a taboo distractor and 10 of which preceded a trial with a neutral distractor. The remaining 60 filler trials consisted of black-and-white pictures paired with neutral distractors.

A 10-minute delay followed during which participants completed the same tasks as the filler period in Experiment 1. Participants then completed two self-paced recognition tasks for pictures and words that were seen during the encoding task. Participants saw an equal number of pseudo-randomized old and new stimuli and indicated whether each stimulus was old or new via mouse click. After the recognition tasks, the Shipley vocabulary test was completed and participants were debriefed about the purpose of the experiment.

Results

Memory for pictures. As a manipulation check, we first examined memory for colored versus black-and-white pictures. This allowed us to gauge whether colored images were intentionally encoded to a greater degree than black-and-white pictures. Corrected recognition rates were submitted to a 2 (age group: young, older) × 2 (picture type: colored, black-and-white) mixed ANOVA, which revealed a main effect of picture type, $F(1, 113) = 114.62$, $p < 0.001$, $\eta_p^2 = 0.51$. Corrected recognition was higher for colored pictures ($M = .70$, $SD = .29$) than for black-and-white pictures ($M = .50$, $SD = .26$). There was no significant age difference nor an interaction with age, $Fs \leq 0.24$, $ps \geq 0.62$, $\eta_p^2 \leq 0.002$.

We then compared memory for pictures that were superimposed with a taboo or a neutral distractor word in a 2 (age group: young, older) × 2 (distractor type: taboo, neutral) mixed ANOVA. The main effects and interaction were not significant, $Fs \leq 1.39$, $ps \geq 0.24$, $\eta_p^2 \leq 0.012$. This was also the case when we analyzed how arousal influenced corrected recognition for the preceding picture in a 2 (age group: young, older) × 2 (distractor type: taboo-minus-1, neutral-minus-1) mixed ANOVA, $Fs \leq 0.27$, $ps \geq 0.60$, $\eta_p^2 \leq 0.002$.

Memory for distractor words. Corrected recognition rates for taboo and neutral distractors were submitted to a 2 (age group: young, older) × 2 (distractor type: taboo, neutral) mixed ANOVA to determine how arousal modulated memory for task-irrelevant words. Recognition of taboo distractors ($M = .37$, $SD = .32$) was greater than neutral distractors ($M = .09$, $SD = .14$), $F(1, 113) = 92.03$, $p < .001$, $\eta_p^2 = .45$ (Figure 5A). The main effect of age and interaction were not significant, $Fs \leq 0.48$, $p \geq 0.49$, $\eta_p^2 \leq 0.004$.

We then examined memory for taboo-minus-1 distractors versus neutral-minus-1 distractors in a 2 (age group: young, older) × 2 (distractor type: taboo-minus-1, neutral-minus-1) mixed ANOVA. As shown in Figure 5B, there was a main effect of distractor type, $F(1, 113) = 6.11$, $p = 0.015$, $\eta_p^2 = 0.051$, with lower recognition of taboo-minus-1 distractors ($M = .05$, $SD = .29$) than neutral-minus-1 distractors ($M = .12$, $SD = .17$). There were no other significant effects, $Fs \leq 0.13$, $ps \geq 0.72$, $\eta_p^2 \leq 0.001$.

Discussion

There were no age differences in performance during Experiment 3—both young and older adults showed similar distractibility from taboo versus neutral words and better suppression (i.e., reduced recognition) of taboo-minus-1 relative to neutral-minus-1 words. Providing top-down guidance to selectively focus attention on target pictures thus seemed to improve the efficiency with which arousal modulated selective processing in older adults.

General Discussion

The inability to focus attention amid distraction can be a frustrating and dangerous experience. When faced with an emotionally arousing but distracting event (e.g., a car accident on the opposite side of the highway), adaptive behavior relies on our ability to focus on the task at hand (concentrating on driving) while ignoring salient but irrelevant distractions (looking at the scene of the car crash). Prior work has shown that exposure to emotionally arousing distraction can disrupt both immediate task performance and increase memory for irrelevant information (Dolcos et al., 2013; Shafer & Dolcos, 2012). Emotionally arousing distraction may thus increase the potential for impaired performance. In the current study, we examined age differences in susceptibility to distraction from taboo-related arousal on immediate performance as well as on subsequent memory. Due to reduced inhibitory control in later life (Hasher & Zacks, 1988; Lustig et al., 2007) and changes in arousal system circuitry (Lee et al., 2018), we predicted that older adults would be more vulnerable to the effects of arousing distraction on performance than their young counterparts.

Our findings indicated a double impact of impaired suppression under arousal in older adults' 1-back performance as well as their subsequent memory for distractors. Relative to young adults, older adults were more distracted by task-irrelevant taboo words during the 1-back task and subsequently remembered those distractors better than neutral distractors. This implies that older adults were more likely than their young counterparts to succumb to distraction from arousing task-irrelevant stimuli. Moreover, whereas young adults showed better suppression of taboo-minus-1 distractors than of neutral-minus-1 distractors, older adults showed no such benefit. This supports prior evidence that arousal is less effective at evoking inhibitory processing in the aging brain (Lee et al., 2018). For young adults in Lee and colleagues' study, arousal increased activation for task-relevant inputs and decreased activation for task-irrelevant inputs. For older adults, arousal increased activation indiscriminately without diminishing brain activity associated with task-irrelevant stimuli. Findings of Experiment 1 extend these results, providing the first behavioral evidence that older adults' inhibition of distracting information is less sensitive to the effects of arousal.

It seems likely that the reason arousal failed to modulate older adults' suppression of taboo-minus-1 distractors is because of age-related changes in attentional control. When these processes work efficiently, they limit attention to task-relevant information, minimizing the tendency for distracting information to be encoded (for a review, see Amer, Campbell, & Hasher, 2016). When we simulated poor attentional control by increasing information load during the 1-back task of Experiment 2, the age difference in suppression of taboo-minus-1 distractors was no longer observed. Our exploratory analyses revealed similar performance between young and older adults, with no evidence for enhanced suppression of taboo-minus-1 distractors in young adults' memory performance. Yet when information load was low, the age-by-distractor type interaction emerged such that only young adults showed better suppression of taboo-minus-1 distractors versus other neutral distractors. These findings align with prior work highlighting deficits in attentional with age (e.g., Campbell et al., 2012) and imply that arousal may be less able to coordinate inhibition of task-irrelevant stimuli in older adults or under conditions of high information load.

Furthermore, when we provided top-down attentional guidance in Experiment 3, we observed enhanced suppression of taboo-minus-1 distractors in both age groups. Specifically, when increasing the goal-relevance of target pictures, both young and older adults showed reduced memory for taboo-minus-1 distractors relative to neutral-minus-1 distractors. These findings imply that when provided with guidance or cues about where to focus attention, a brief surge of arousal may benefit older adults' inhibitory processing in a similar manner to young adults. Thus, age differences in regulating distraction under arousal may arise from an interaction of bottom-up (i.e., stimulus-driven) and top-down (i.e., goal-oriented) processes.

Why would arousal enhance older adults' inhibition when top-down attentional guidance is provided but not when it is absent? Top-down attention helps amplify processing of goal-relevant stimuli while suppressing processing of goal-irrelevant stimuli (Katsuki & Constantinidis, 2014). As previously described, this selective control of attention has been associated with the frontoparietal network (Vincent et al., 2008). One hypothesis we propose is that top-down cues may facilitate connectivity between the LC-NE system and the frontoparietal network, thereby increasing selective processing under arousal. For example, the top-down goal to remember colored pictures in Experiment 3 may have evoked frontoparietal activity during the task to focus attention on goal-relevant pictures. Increases in LC-NE system activity from seeing a taboo distractor would then trigger excitatory and inhibitory responses across the cortex. This, would, in turn, amplify selective processing and connectivity within the frontoparietal network (Lee et al., 2018). With this network already engaged by goal-relevant pictures, the LC-NE system may be better able to coordinate frontoparietal activity and promote selective attention.

Of course, our investigation was entirely behavioral and so future neuroimaging work is required to test this hypothesis that top-down cues can increase frontoparietal network activity and enhance functional connectivity with the LC during arousal.

While the frontoparietal network and the LC-NE system are likely important for understanding age differences observed in the current studies, age-related alterations within the default network may also play a role. Reduced coherence within the default network has been identified as a hallmark of aging and has been associated with poorer executive control (Damoiseaux et al., 2008). The frontoparietal network has also shown to coactivate with the default network during goal-oriented tasks (Spreng, Stevens, Chamberlain, Gilmore, & Schacter, 2010). Reduced connectivity within and between each of these networks in later life could thus contribute to inefficient reallocation of attentional resources, particularly during challenging or emotionally arousing instances. Future work should investigate the degree to which these two networks contribute to the interaction of arousal and distractibility in aging.

Limitations and Future Directions

There are some limitations of this study's design. Although we demonstrated the taboo-minus-1 suppression effect in older adults when attentional guidance was provided (Experiment 3) relative to when there was no attentional guidance (Experiments 1 and 2), a cleaner approach would have been to include a control group in Experiment 3 given that the task design differed from the other two experiments. Our findings would have also been strengthened by inclusion of objective arousal measures, such as pupil dilation, in addition to subjective ratings. Pupil dilation has been associated with phasic LC responses (Alnaes et al., 2014; Murphy, O'Connell, O'Sullivan, Robertson, & Balsters, 2014) as well as modulation of the frontoparietal network under arousal (Lee et al., 2018). Including such physiological measures would thus have be useful for inferring the role of the LC-NE system in responses to taboo words as well as age differences observed in distractibility across experiments.

Additionally, other stimulus features – beyond emotional arousal – could have influenced 1-back performance and memory for distractors. In particular, our results may be valence-specific as taboo words tend to be rated negatively (Janschewitz, 2008). However, arousing positive and negative stimuli often have similar effects on perception and memory. Prior work has found that arousing stimuli, such as erotic positive and aversive negative images or words, disrupt attention and detection of visual targets in a similar manner (Anderson, 2005; Lee et al., 2012; Most, Smith, Cooter, Levy, & Zald, 2007; Sutherland & Mather, 2017; Sutherland, Mcquiggan, Ryan, & Mather, 2017) and elicit similar selectivity effects on memory (Sakaki et al., 2014). Nevertheless, future work should test if positive and negative arousal have a similar effect on age-related distractibility.

Our results could also be attributed to an oddball effect since taboo distractors occurred infrequently relative to neutral distractors, making their appearance a novel event. However, like emotional stimuli, novel oddball stimuli have shown to increase activity in the LC (Murphy et al., 2014), yet this increase tends to be larger for emotional oddballs than for neutral oddballs (Krebs, Park, Bombeke, & Boehler, 2018). This implies that emotional salience and novelty may have an additive effect on LC activity. In other words, had we used novel but non-emotional stimuli, we may have observed similar effects although probably to a lesser extent.

The current study focused on how the arousal level of task-related stimuli modulates attention and memory. Future work should also determine how increases in autonomic arousal from external/physical sources (e.g., electric shock, isometric handgrip exercise) would influence distractibility in aging. This would help to unconfound arousal state and stimulus property.

Conclusion

In closing, reduced inhibitory processing during aging increases older adults' susceptibility to distraction (Hasher & Zacks, 1988) and recent work suggests that these processes may be further compromised under arousal (Lee et al., 2018). Our findings add to this research by showing that older adults' attention and memory is more vulnerable to arousing distraction than young adults'. Moreover, young adults experienced a benefit from arousing distraction, with a better ability to regulate suppression of nearby distractors, implying an increase in selective attention under arousal. Older adults showed no such benefit from arousal. However, the effects of arousal on inhibition appear to be malleable. In the context of top-down attentional guidance, arousal dampened memory for taboo-minus-1 distractors in both age groups. Thus, arousal may not always increase distractibility in older adults and may depend on the availability of top-down cues in the environment.

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Footnotes

[1] Only a sub-set of participants (43 young adults, 51 older adults) opted to complete the taboo ratings at the end of Experiment 1. As such, the degrees of freedom for these *t*-tests are slightly reduced relative to other analyses.

[2] We did not conduct a word ratings task for Experiment 2 due to time constraints. However, based on the ratings collected in Experiments 1 and 3, we found that both young and older adults rated taboo words as higher in arousal and overall tabooness than neutral words.

[3] Two participants in Experiment 2 did not make any responses during the 1-back task and so their data were removed from all analyses.

Figures

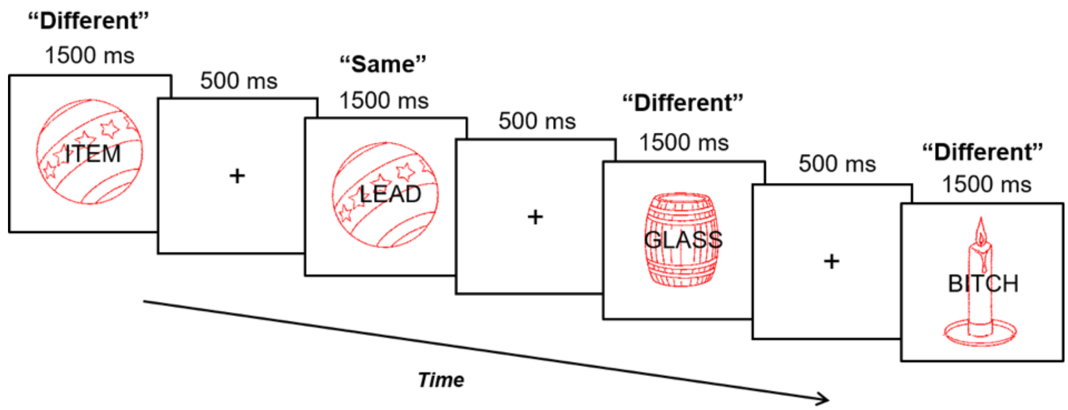

Figure 1. Example of a trial series from the 1-back task used in Experiments 1 and 2, with correct responses indicated above each picture. In this example, 'GLASS' would be a taboo-minus-1 distractor.

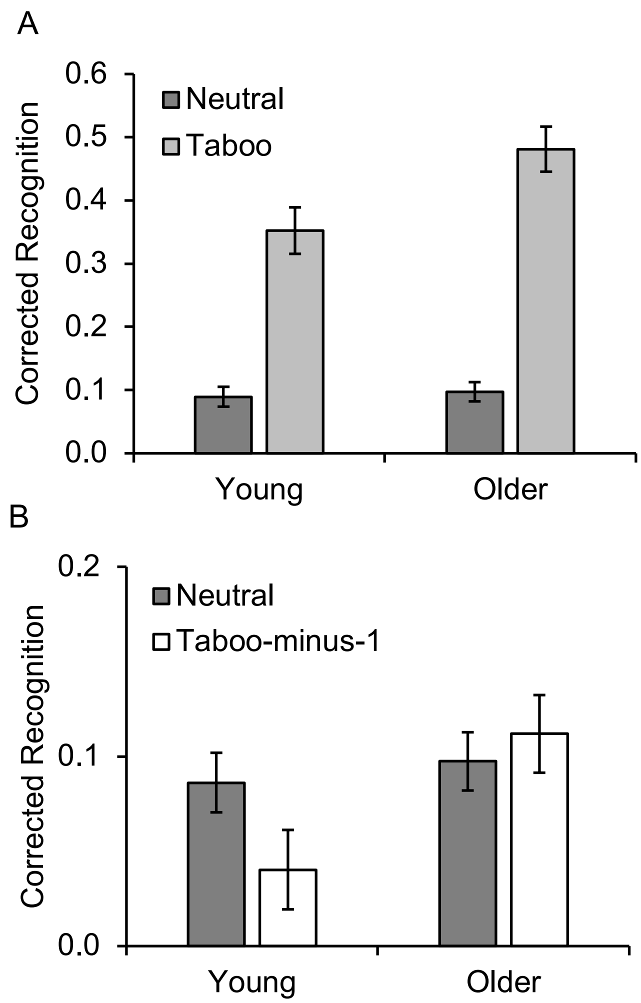

Figure 2. (A) Mean corrected recognition rates for taboo versus neutral distractors as a function of age group in Experiment 1. (B) Mean corrected recognition rates for taboo-minus-1 versus neutral distractors as a function of age group. Error bars represent standard error of the means.

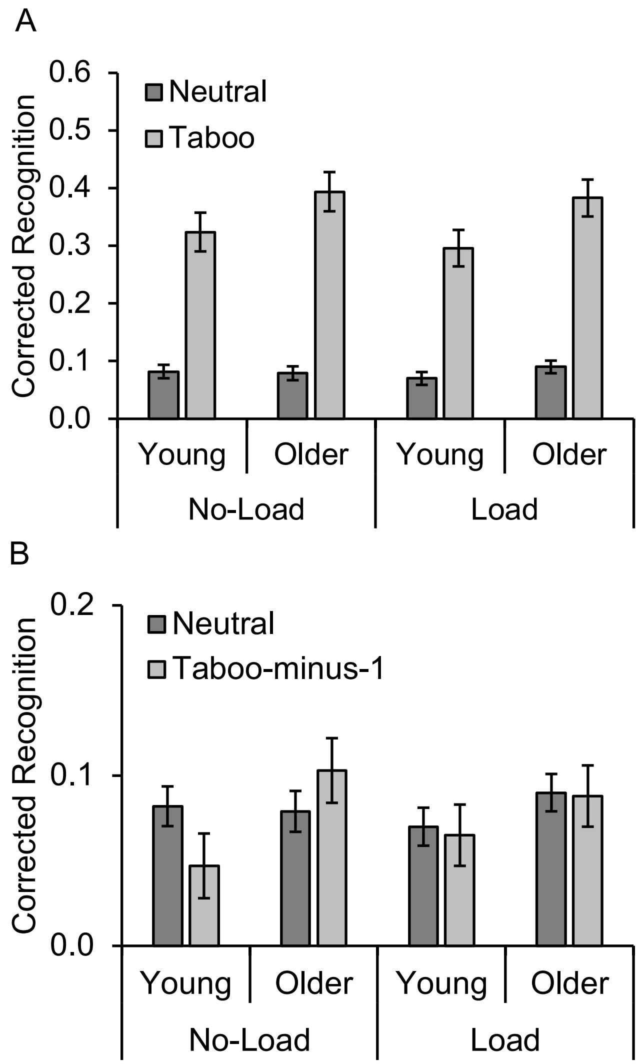

Figure 3. (A) Mean corrected recognition rates for taboo versus neutral distractors as a function of age group and load condition in Experiment 2. (B) Mean corrected recognition rates for taboo-minus-1 versus neutral distractors as a function of age group and load condition in Experiment 2. Error bars represent standard error of the means.

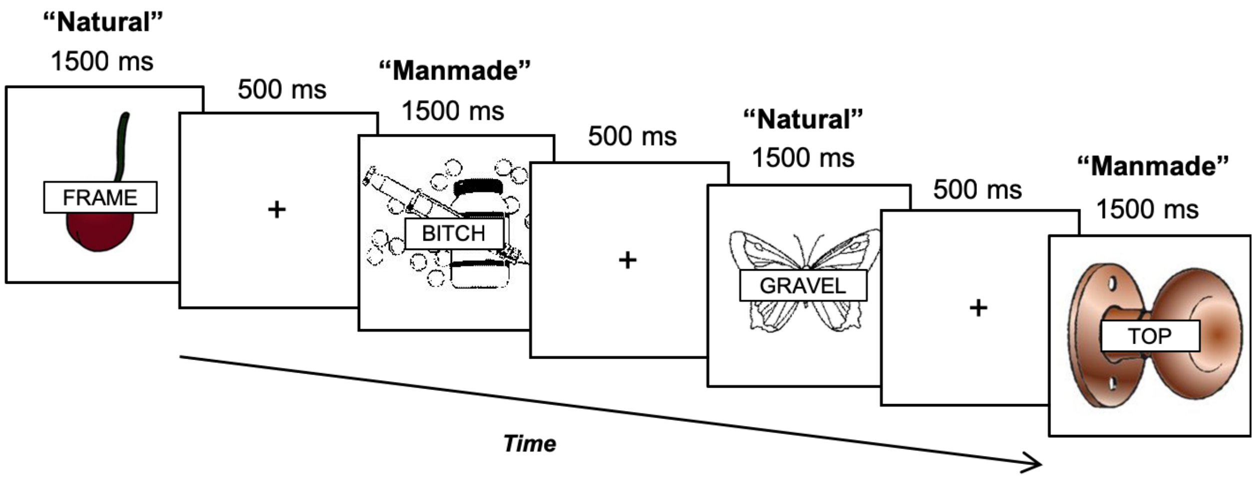

Figure 4. Example of a trial series from the encoding task used in Experiment 3, with correct responses indicated above the pictures. In this example, 'FRAME' would be a taboo-minus-1 distractor.

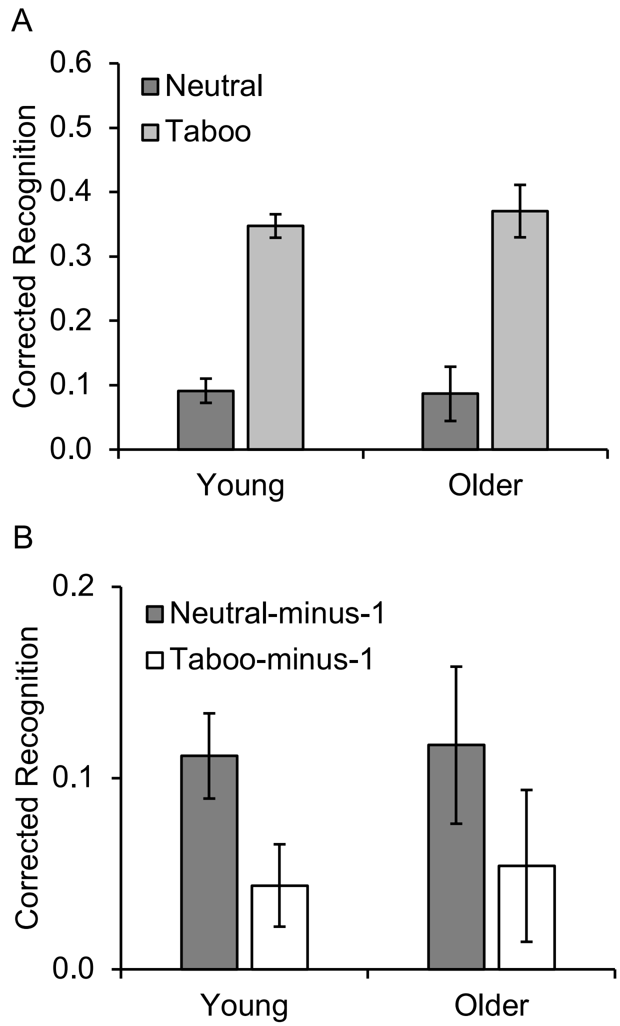

Figure 5. (A) Mean corrected recognition rates for taboo versus neutral distractors as a function of age group in Experiment 3. (B) Mean corrected recognition rates for taboo-minus-1 versus neutral-minus-1 distractors as a function of age group in Experiment 3. Error bars represent standard error of the means.