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Research Report

The impact of visual distraction on episodic retrieval in older adults

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ABSTRACT

Impairment in long-term memory is one of the most salient alterations in cognitive aging. Findings of age-related deficits in source monitoring and recollection have revealed a selective decline in memory for detailed information. The underlying mechanism of this phenomenon is not well understood. We hypothesized that the influence of task-irrelevant visual stimuli present in our environment interferes with retrieval of detailed memories more for older than younger adults. We compared memory performance on a recall test for visual details when older adult participants' eyes were closed versus performance when their eyes were open and irrelevant visual stimuli were presented. The results showed that the presence of irrelevant visual information diminished long-term memory performance based on an objective measure of recollection for visual details. Comparison of the current results to findings from our earlier study using the same experimental paradigm with younger adults revealed that visual distraction disrupted recollection of relevant details to a greater degree in older than younger adults. This result suggests that visual distraction overwhelms older adults' declining cognitive control resources that are instrumental in the retrieval and selection of mnemonic details. More generally, these findings explicate a mechanistic basis for selective impairment of recollection in normal aging.

1. Introduction

Cognitive aging takes a toll on both the encoding (Ferguson et al., 1992) and retrieval (Hashtroudi et al., 1990) of information that forms our awareness of prior experiences–memories. Impairment in long-term memory (LTM) is one of the most disruptive alterations in cognitive function to occur over the course of normal aging (Zacks and Hasher, 2006). Research directed at characterizing the specific nature of retrieval impairment has highlighted age-related deficits in recollection (Li et al., 2004) and suggests that older adults do not retrieve vivid, detailed information about prior episodes as effectively as younger adults (Craik, 2002). Recollection is the effortful retrieval of perceptual and contextual details for prior episodes (Atkinson and Juola, 1973) and is more specific than simple recognition that yields a general sense of knowing about an item when relevant details from past experience are not available (Mandler, 1980). Recent findings from younger adults show that the accuracy of episodic retrieval is diminished in the presence of irrelevant visual information, despite goals to direct full attention at the retrieval task (Wais et al., in press; Wais et al., 2010). The influence of

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external distraction on LTM in older adults has not yet been evaluated in conditions when the singular goal is to recollect visual details about prior experiences.

Recent research on working memory (WM) has distinguished between the impact of interference from interruption (i.e., divided attention to relevant information in a secondary task, or multitasking) and distraction (entirely irrelevant information) (Berry et al., 2009; Clapp et al., 2010). Neural evidence suggests that distinct mechanisms underlie these two types of interference, as well as their aging effects (Clapp and Gazzaley, in press; Clapp et al., 2010, 2011). The critical difference between these two effects of interference is whether top-down processes that support higher cognitive faculties are directed toward dual tasks (i.e., divided attention) or a singular task. In terms of LTM, behavioral studies have examined interference from interruption (i.e., engagement in a concurrent cognitive task during memory retrieval) that diminishes free recall (Fernandes and Moscovitch, 2000) and the accuracy of source memory (Troyer et al., 1999) in younger adults. Results from studies with older adults show that divided attention during a memory test increases response latencies (Verhaeghen et al., 2003), but it is not clear that age-related deficits in episodic retrieval are exacerbated by interference from concurrent tasks (Fernandes et al., 2006; Park et al., 1989).

In terms of distraction, cognitive aging has been associated with greater susceptibility to interference by irrelevant, external information (Hasher et al., 1999), and this type of distraction has been associated with impairment in WM performance (Gazzaley et al., 2005, 2008). Based on the convergence of findings that (i) older adults are more susceptible to interference by distracting information and (ii) visual distraction has a negative impact on the accuracy of episodic retrieval of visual details in younger adults, we hypothesized that the impact of visual distraction on episodic retrieval would be greater in older than younger adults.

To explore the impact of visual distraction on LTM in older adults, we utilized the same experimental paradigm used previously with younger adults (Wais et al., 2010) to test the objective recollection of relevant details under different visual test conditions (Fig. 1). Participants were instructed to direct their undivided attention to recall the number of objects from previously studied images while test conditions manipulated whether their eyes were closed, open looking at a gray screen, or open looking at irrelevant visual stimuli. Because the incidental encoding period was the same for all target images (i.e., the study session), the details and quantity of information was equivalent for all test stimuli. Therefore, any impairment that existed in the older adults' ability to encode the details of studied stimuli (Chalfonte and Johnson, 1996) would impact each test condition equally. Diminished recollection performance during conditions when eyes were open and irrelevant visual stimuli were presented, relative to the eyes shut condition, would thus be evidence of a negative impact of visual distraction on episodic retrieval of visual details. Furthermore, because the incidental encoding procedure and retention interval were the same as used previously with younger adults, the analysis could distinguish between a generalized age-related decline in LTM performance and a differential impact of visual distraction on episodic retrieval in older adults.

2. Results

The impact of visual distraction on retrieval of LTM was analyzed through comparisons of the following categories of responses to the auditory cues (i.e., memory sub-types). Correct: responses that gave the correct object count corresponding with the number of objects in a previously studied image (i.e., targets) were interpreted as being based on an objective measure of recollection. Incorrect: responses

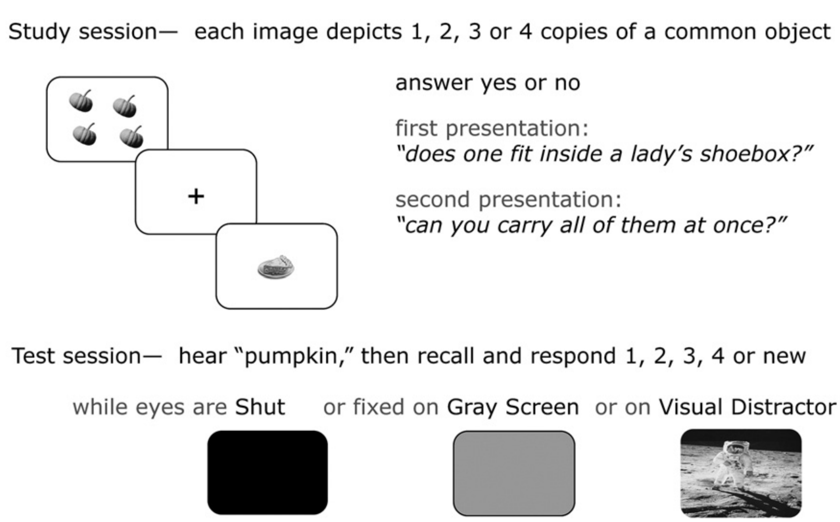

Fig. 1 – Experimental paradigm. A schematic of the procedure shows the study session, when participants encoded and answered two incidental questions about each of 168 images (3 s per presentation), and the test session, when auditory probes described 168 targets and 36 lures in singular form (2.5 s per presentation, 10.0 s inter-trial interval) to cue recall of the count of objects on the related studied image. Auditory probes cued participants' recall during trials presented in three visual conditions.

Table 1 – Neuropsychological test results.

Neuropsychological test	Mean score
Mini-mental state examination	29.5 (1.0)
Geriatic depression scale	1.7 (1.3)
CVLT: Trial 5 recall	13.4 (2.7)
CVLT: short delay free recall	11.7 (3.1)
CVLT: short delay cued recall	12.9 (2.1)
CVLT: long delay free recall	12.4 (2.8)
CVLT: long delay cued recall	12.8 (2.5)
Memory for modified Rey	12.7 (2.6)
Calculation ability (out of 5)	4.8 (0.5)
WAIS-R: backward digit span	5.9 (1.4)
WAIS-R: digit symbol	53.9 (10.2)
Trail making test: A	32.2 (11.2)
Trail making test: B	69.8 (25.9)
Stroop: color naming	89.3 (15.2)
Stroop: color–word naming	53.1 (11.8)
Semantic fluency	22.8 (6.5)
Phonemic fluency	14.9 (5.5)

Mean scores for the older adults are shown for the standardized neuropsychological tests (standard deviation). Each participant scored within two standard deviations of their age-matched normative value.

that gave an incorrect object count for a target were interpreted as being based on item recognition, such that the participant indicated recognition of the target having been studied, but recollection of details relevant to the current task was weak or unavailable (Mandler, 1980). False Alarms: cues for unstudied objects (i.e., lures) that were erroneously given an object count were classified as false alarms. The trials in which the cue for a target was given a “new” response were classified as forgotten, and cues for lures that were given a “new” response were classified as correct rejections.

We used mixed-design ANOVA to compare results across conditions for overall recognition performance and for recollection of visual details between older adults in the current study and younger adults in a previous study that used the same paradigm (Wais et al., 2010, behavioral study).

2.1. Overall recognition performance

Overall recognition was estimated between conditions as d’ (Macmillan and Creelman, 2005), which compared hit rates (i.e., the proportion of targets in each condition that were given a count, whether the count was correct or incorrect) to false alarm rates (Table 2). A mixed-design ANOVA (younger/older X SHUT/GRAY/VD) for estimates of d’ revealed a main effect of age ($F_{1,51}=11.01$, $p<0.005$), no effect of condition ($F_{2,102}=1.87$, $p=0.16$) and an interaction of age and condition ($F_{2,102}=3.20$, $p<0.05$). The interaction of age and condition on d’ reflected the specifics of when recognition performance by younger adults was superior to that by older adults: SHUT, young>older ($p<0.001$); GRAY, younger>older ($p<0.02$); and a trend in VD, young>older ($p=0.07$). Within-group comparisons showed no effect of condition on d’ for older adults ($F_{2,50}=0.53$) and an effect of condition for younger adults ($F_{2,52}=8.16$, $p<0.001$). For the younger adults, d’ was greater for SHUT than GRAY ($p<0.03$) and VD ($p<0.001$), and there was no difference between GRAY and VD.

In order to better understand the interaction between groups, we next compared the underlying hit and false alarm rates. The mixed-design ANOVA for hits revealed no effect of age ($F_{1,51}=2.76$, $p=0.10$), no effect of condition ($F_{2,102}=2.35$, $p=0.10$), and an interaction of age and condition ($F_{2,102}=4.07$, $p<0.03$). To interrogate this interaction, both within-group and between-group tests were performed. Pair-wise comparisons for older adults showed that hits did not differ by condition. Younger adults had fewer hits in VD than SHUT or GRAY (both comparisons, $p<0.01$), and there was no difference between SHUT and GRAY. Comparisons between groups showed that hits were greater for younger adults in SHUT and GRAY (both comparisons, $p<0.03$) and did not differ between age groups in the VD condition. The mixed-design ANOVA for false alarms revealed an effect of age ($F_{1,51}=7.20$, $p<0.01$), no effect of condition, a trend for an interaction of age and condition ($F_{2,102}=2.51$, $p=0.09$). Pair-wise comparisons for older adults showed that false alarms did not differ by condition. Younger adults had fewer

Table 2 – Behavioral results.

	Targets			Lures	d’
	Correct	Incorrect	Forgotten	False alarms	
a. Older					
Total	44.9% (2.1)	34.5% (1.9)	20.6% (1.6)	24.9% (2.2)	1.63 (0.12)
SHUT	48.0% (2.0)	32.1% (2.1)	19.9% (1.7)	27.8% (3.7)	1.56 (0.15)
GRAY	46.3% (2.5)	32.0% (2.1)	21.7% (2.3)	24.5% (3.3)	1.63 (0.13)
VD	40.3% (2.3)	39.5% (2.1)	20.2% (1.7)	22.5% (2.5)	1.70 (0.14)
b. Younger					
Total	56.1% (2.6)	27.8% (1.7)	16.0% (1.8)	16.6% (2.7)	2.10 (0.14)
SHUT	58.2% (2.9)	27.0% (2.3)	14.5% (1.8)	12.4% (2.0)	2.46 (0.15)
GRAY	57.1% (2.9)	28.3% (2.0)	14.5% (1.8)	20.1% (3.2)	2.11 (0.14)
VD	53.1% (2.6)	27.6% (1.7)	19.1% (2.0)	17.3% (2.9)	1.97 (0.14)

A summary shows statistics for the responses to 168 targets and 36 lures that were presented during the test session in experiments with (a.) a group of 26 older adults and (b.) a group of 27 younger adults (published previously, Wais et al., 2010). For each group of participants, mean performance on the memory test (standard error of the mean) is shown in each of the three conditions for responses to the targets categorized as Correct count recalled, Incorrect count recalled and Forgotten, and for False alarms to the lures. Overall recognition performance is estimated as d’, which compared the hit rate for targets (correct+incorrect responses) to the false alarm rate for lures.

false alarms in SHUT than GRAY or VD (both comparisons, $p<0.05$), and there was no difference between GRAY and VD. Comparisons between groups showed that false alarms increased for older adults in SHUT ($p<0.001$) and did not differ from younger adults in GRAY or VD. Therefore, the results for overall recognition performance showed a significant age-related impairment in the SHUT condition and no difference between older and younger adults in the visual distraction condition (VD).

2.2. Recollection of visual details

An objective measure of recollection of relevant details was assessed using conditional correct scores, which computed the proportion of responses for a correct count given that an item was not forgotten (i.e., p(Correct) / (1- p(Forgotten)). A mixed-design ANOVA (younger/older X SHUT/GRAY/VD) compared the conditional correct scores, which revealed a main effect of age ($F_{1,51}=6.34$, $p<0.02$), a main effect of condition ($F_{2,102}=15.71$, $p<0.001$), and an interaction of age and condition ($F_{2,102}=5.74$, $p<0.005$). To interrogate this interaction, both within-group and between-group tests were performed (Fig. 2). The comparison for older adults showed a main effect of condition ($F_{2,50}=17.59$, $p<0.001$), such that retrieval of relevant visual details declined significantly in VD relative to SHUT and GRAY (both pair-wise comparisons, $p<0.001$). There was no difference between conditional correct scores for SHUT and GRAY. The results showed that the presence of visual distraction diminished objective recollection for older adults. In the comparison for younger adults, there was no main effect of condition on conditional correct scores ($F_{2,52}=1.78$, $p=0.18$). These results suggest a more subtle impact of visual distraction on objective recollection for the younger adults, relative to the older adults. Pair-wise tests showed that VD declined relative to SHUT ($p<0.05$), but not GRAY, and there was no difference between SHUT and GRAY.

Between-group comparisons, which directly compared conditions for older and younger adults, revealed that objective recollection declined significantly for older adults in VD (relative to younger adults, $p<0.001$), while there were only trends for age-related declines in SHUT and GRAY (relative to younger adults, $p=0.07$ for SHUT and $p=0.08$ for GRAY). This finding that older adults exhibited diminished recollection in the setting of visual distraction is in contrast to the absence of an age-related change in overall recognition under those circumstances, thus establishing the selectivity of distractibility on recollection.

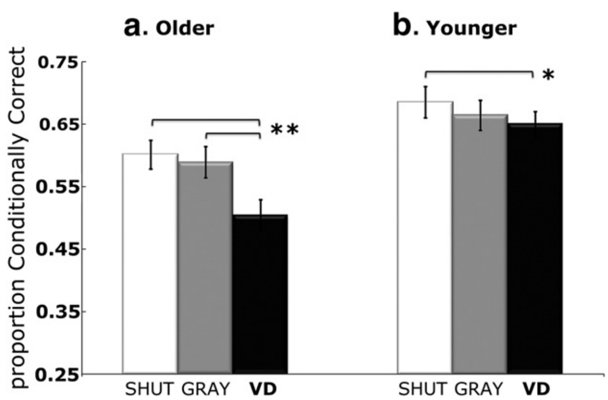

Fig. 2 – Impact of visual distraction on episodic retrieval. The mean conditionally correct score is shown for each of the three visual conditions for (a.) Older and (b.) Younger participants. Conditionally correct scores were computed as the proportion of responses giving the correct count of objects for a studied image given that an image was not forgotten (i.e., p(Correct) / (1- p(Forgotten). The level of chance for recollecting the correct count was one in four. Visual distraction disrupted episodic retrieval of visual details for both older and younger adults. Error bars represent the standard error of the mean, * indicates p<0.05, and ** indicates p<0.001.

2.3. Distractibility index

Further analyses used a distraction index to account for overall differences in recollection performance between individuals and directly explore differences between age groups induced by distraction. For each older and younger participant, a distraction index was calculated for conditional correct scores (i.e., SHUT correct–VD correct). A greater index corresponds to greater disruption by distraction during episodic retrieval, that is to say greater distractibility. An independent samples test of the distraction index, assuming unequal variances, revealed greater distractibility in the older adults than the younger adults (Fig. 3; $t_{51}=3.03$, $p<0.005$). The result of the comparison of distractibility indices provides strong evidence that visual distraction disrupted recollection of relevant details to a greater degree in older than younger adults.

3. Discussion

A broad literature has proposed that cognitive decline in older adults is based on a combination of underlying factors (Zacks

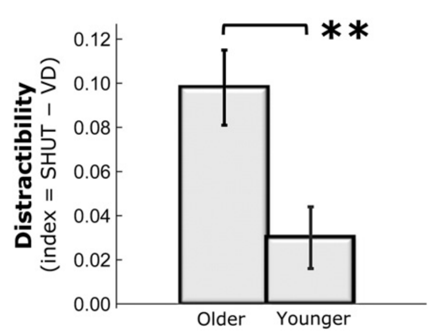

Fig. 3 – Comparison of distractibility between older and younger adults. For each older and younger participant, a distraction index was calculated for conditional correct scores (i.e., SHUT correct–VD correct). A greater index corresponds to greater distractibility. Comparison of the group means revealed a greater impact of distractibility during LTM retrieval on the older adults, relative to younger adults. Error bars represent the standard error of the mean, and ** indicates $p<0.005$.

and Hasher, 2006), including deficits in the ability to suppress irrelevant information (Gazzaley et al., 2005, 2008; Hasher et al., 1999). However, diminished ability to suppress irrelevant, external information has not yet been shown to account for selective deficits in retrieval of detailed memory that occurs in aging (i.e., episodic retrieval deficits). To evaluate if the negative influence of irrelevant external information is a factor in age-related memory decline, we tested retrieval when older participants were undisturbed by external visual distraction (i.e., eyes closed) or exposed to irrelevant visual stimuli (i.e., eyes open).

The results of the current study revealed that visual distraction substantially disrupted recollection of relevant visual details in older adults, yet had no significant effect on overall recognition. False alarms did not differ across conditions, indicating that false memories were not influenced by visual distraction. Therefore, the results showed an impact on retrieval of mnemonic details, but not on overall discrimination in recognition memory. Moreover, when the negative impact of visual distraction on episodic retrieval was indexed as a measure of distractibility for each participant, older adults suffered greater disruption in the accuracy of their memory of detailed information than younger adults. These data support our hypothesis that increased susceptibility to distraction is a factor in the impairment of recollection of relevant visual details in normal aging. Of note, there was a trend for an age-related recollection deficit when older participants' eyes were closed, and thus the impact of distraction seems to be an exacerbating factor on memory deficits rather than the sole cause.

Interestingly, the results for overall recognition showed that younger adults' performance was superior to older adults, but the effects of visual distraction were different between the groups. Older adults showed equivalent recognition performance across all three conditions. Younger adults showed a decline in d' in the VD condition, relative to the SHUT condition, which was the result of both fewer hits and increased false alarms during visual distraction. Notably, this pattern for the younger adults in the VD condition does not indicate a shift in their recognition criterion (i.e., their memory threshold for responding “old”) and, therefore, does not provide clear evidence of substantive trade-offs in memory retrieval processes between the groups. If the younger adults had adopted a more liberal recognition criterion in VD (which they did not), then both hits and false alarms would have increased (Macmillan and Creelman, 2005). In summary, the results for overall recognition show that younger adults' superiority was reduced by the influence of visual distraction, but not in a way that complicates the critical finding that visual distraction disrupted recollection of relevant details to a substantially greater degree in older than younger adults.

3.1. *Basis of the impact of visual distraction*

Our results showing that recollection for visual details in older adults, relative to younger adults, is more susceptible to disruption by irrelevant, external information suggest the decline in performance was caused by interference on control processes mediating the selection of specific mnemonic details.

One explanation of the distraction effect is that visual processing of irrelevant external information may have resulted in bottom-up interference and diminished fidelity of internal representations of memoranda generated via visual imagery. This may be due to the fact that both perceptual and imagery representations of visual stimuli rely on overlapping regions of the visual association cortex (Kahn et al., 2004; Mechelli et al., 2004; Ranganath et al., 2004), which have limited representational capacity (Lavie, 2005). Interference between the enhancement of relevant mnemonic information and suppression of irrelevant visual information has been proposed as a reason for the ubiquitous act of looking away, or closing ones eyes, when trying to remember — actions that have been found to improve cognitive performance (Glenberg et al., 1998). Notably, evidence from neuroimaging has revealed an age-related deficit in top-down suppression of cortical activity associated with task-irrelevant representations (Clapp et al., 2010, 2011; Gazzaley et al., 2005, 2008).

An alternative, non-mutually exclusive, explanation is that because attentional resources are limited (Pashler and Shiu, 1999), top-down control mechanisms required to retrieve detailed memories may have been diverted by incidental attention to irrelevant visual information. Although this diversion would have been driven by bottom-up factors because there were no top-down goals to attend to visual stimuli (i.e., there was no division of directed attention to multiple goals or tasks), excessive demands on cognitive networks in common across these control processes may have resulted in recollection impairment. Support for this top-down basis of the distraction effect in older adults was obtained in a recent fMRI study with younger adults engaged in the same paradigm. The results revealed that the presence of irrelevant visual information interfered with recollection abilities and was associated with an alteration in functional connectivity within a neural network involving the prefrontal cortex (PFC), hippocampus and visual association cortex, which supported recollection via visual imagery when eyes were shut (Wais et al., 2010).

3.2. *Diminished accessibility to specific details*

Several explanations have been proposed for the selective decline in recollection in normal aging, including deficits in retrieving multiple features (Chalfonte and Johnson, 1996), in the vividness and complexity of visual imagery for prior experiences (Henkel et al., 1998), and in the ability to merge associations that form episodes (Naveh-Benjamin et al., 2003). These deficits all reflect diminished accessibility to specific details about prior experiences. A common feature influencing all of these deficits, including the results from the current study, may be an impact of interference on selection processes that support detailed retrieval.

Cognitive control processes that guide the selection of contextual details during recollection are mediated by regions of the left inferior frontal gyrus (Badre and Wagner, 2007), which was a node in the network disrupted by visual distraction in younger adults (Wais et al., 2010). Although the neural correlates of the impact of distraction during recollection have yet to be examined in older adults, a growing literature has implicated impairment of PFC function, including processes mediated by the inferior frontal gyrus, in LTM deficits in aging (Buckner, 2004). Thus, increased susceptibility to interference during recollection in older adults may be related to diminished function in, and associated compensatory shifts across, regions of the PFC (Velanova et al., 2007). It is also reasonable that age-related decline in function of the other nodes of the recollection network identified by Wais et al. (2010), such as the hippocampus and visual cortex, may contribute to increased vulnerability of this network to interference by distraction in older adults.

The current findings may reflect a more fragile top-down control network in older adults, even when the older participant's eyes were shut, which explains the trend of weaker recollection performance in this condition compared to younger adults. Top-down control guiding the selection of contextual details during episodic retrieval would then be further compromised by interference from visual distraction, resulting in a larger cumulative impact on recollection in older adults when irrelevant, external information was present. Further research using neuroimaging will be required to elucidate the impacted neural networks that develop increased susceptibility to interference in the presence of visual distraction, which in turn underlies greater recollection impairment in normal aging.

4. Experimental procedure

4.1. Participants

Thirty-three healthy older adults (11 males; mean age = 69.7 ± 7.2 years), who were native speakers of English, gave their informed consent to perform the experimental tasks and were compensated for their time. All participants were screened at least two weeks in advance of completing the experiment to ensure that they had no history of neurological, psychiatric, or vascular disease, were not taking any psychotropic or thyroid medications, and had normal or corrected-to-normal vision. All participants had completed a minimum of 12 years of education. Seven participants were excluded from analysis because their overall recall score was at the level of chance, and thus it was not possible to assess the impact of irrelevant information on their recollection performance. The final analysis included 26 participants (9 males; mean age = 68.0 ± 6.2 years).

4.2. Participants from prior study with younger adults

In a prior study, 29 university students (13 males), who were native speakers of English, met the above criteria applied for the older adults and gave their informed consent, performed the same experimental tasks in return for course credit or a small fee (behavioral experiment from Wais et al., 2010). Two participants did not comply with the instructions, and their data was excluded from analysis. The final analysis included 27 participants (11 males; mean education 12.9 ± 1.0 years)

4.3. Neuropsychological testing

All older participants were administered 11 standardized neuropsychological tests of executive and memory function in a session at least two weeks in advance of their experiment appointment, and they were found to be cognitively intact (within two standard deviations) relative to normative values for age-matched controls (Table 1).

4.4. Auditory normalization

Before the memory test session, all older participants completed an auditory test on the experimental computer with a set of Sennheiser eH 150 sound-canceling headphones to ensure that the volume level during the test phase was adequate for speech perception and was approximately normalized across the group. Ten images were presented in a block with each image displaying four phonetically similar words numbered 1–4 (e.g. 1. rang, 2. ring, 3. rink, 4. wing). For each image, participants studied the four words on screen for 2500 ms and then heard one of the words spoken in a recorded, female voice. The spoken word was a cue to identify one the four words on screen (e.g. "ring") within 2500 ms, after which the trial advanced. If participants scored 90% or better on the first series, the volume was raised slightly and the test phase began. If participants scored less than 90% correct, then the headphone volume was raised to a higher standardized level, and a new block was displayed. If participants scored lower than 90% correct in this second block, then the headphone volume was raised to a higher standardized level, and a third block was presented. All of the participants passed within three blocks.

4.5. Summary of experimental procedure

The experiment was separated into two sessions: study and test. Written instructions were read out loud to each participant by the experimenter before each session, and the participant then completed a brief practice run for each session with the experimenter. The older adults in the present study completed the same procedure with the same stimuli as used with younger adults in the prior study, as described below (Fig. 1).

4.6. Stimuli

168 object images (i.e., targets), one image of a 25% gray screen, 68 color images of natural scenes, and 204 voice recordings of singular nouns (i.e., auditory cues) were used in the experiment. The images were displayed on a computer screen at 1024 × 768 pixel resolution. Each target image displayed one to four copies of the same object from a three-dimensional perspective, in color, on a plain white background. The objects were selected from a stimulus set of common items developed by Bakker et al. (2008) that were controlled for concreteness and ease in namability. The displacement in the viewable area from the objects was held as constant as possible, whereas the actual objects varied in size (i.e., wishbones versus sofas). The number of target images with each count of objects (1, 2, 3 or 4) was equated.

Stimuli were presented using E-prime 2.0 (Psychology Software Tools, Inc.; Pittsburgh, PA). The recordings of auditory cues were equated and normalized for power spectral density (PSD) in Audacity® 1.3.5 d digital audio editor.

4.7. Procedure

During the study session, each of the 168 target images was presented for 3000 ms, in random order, twice in separate runs. During the first run, participants encoded each image and entered a yes or no answer to indicate their judgment about whether one of the objects from the image could fit inside a lady's shoebox. During the second run, participants encoded each image again and indicated whether they believed they could carry all of the objects from the image across the room using only their hands and arms. The incidental encoding tasks promoted in-depth visualization of the targets without specifically referencing numerosity. Each of the 336 trials were preceded by a 2000 ms fixation cross, and 12-second rest periods occurred after each block of 56 trials.

When their study session was complete, participants visited a nearby coffee shop for approximately 45 minutes and were urged to avoid any reading materials. After the break, participants returned to the experiment room and were instructed about a surprise memory test. During the entire test session, participants wore a set of Sennheiser eH 150 sound-canceling headphones. Six test blocks (34 trials in each block, 28 targets presented in a random order with 6 lures) were presented in one of three pseudo-random orders. Each trial included an auditory cue that described an object encoded in the previous session, or a novel (i.e., unstudied) object, in singular form. The singular nouns recorded to describe each object (i.e., auditory cues) were developed by agreement across three independent raters. Participants were instructed to recall the count for the object described by the cue from the respective image viewed during their encoding session and to give their answer by pressing 1, 2, 3, 4 or "new" (pressing all four buttons simultaneously) on a response pad, as rapidly as possible without sacrificing accuracy. Because some older adults had difficulty pressing all four buttons simultaneously, we interpreted responses of "1, 2, 3" and "2, 3, 4" as also indicating "new." The 2500 ms test period was followed by a 5500 ms second inter-trial interval (ITI), the last second of which included a visual (enlarged fixation cross) or auditory prompt (two beeps) to alert the participant that the next trial was about to begin.

The critical manipulation was that participants gave recall responses for visual details under three different conditions (i.e., two blocks in each condition and the order of the six test blocks was counter-balanced): when visual stimulation was nil (eyes closed: SHUT), when bottom-up processing was minimal (looking at a gray screen: GRAY), and when neutral, visual environmental stimuli were presented (looking at pictures of natural scenes: Visual Distraction, or VD). The visual stimuli appeared simultaneously with the presentation of the auditory probe and remained on screen for 2500 ms. During the SHUT blocks, participants were instructed to keep their eyes closed for the entire block, which the experimenter monitored. During the GRAY and VD blocks, participants were instructed to hold their gaze constant on the center of the viewing screen throughout each trial and not blink or look away when the screen changed from the fixation cross. Before each test block began, participants were informed about the condition for that block and reminded of the recall instructions referring back to the encoded object images. The sequence of test conditions (GRAY, VD and SHUT) was pseudo-randomized after the first test block, which was always Gray in an effort to optimize orientation to the task across participants.

At the conclusion of the two sessions, participants completed a verbal exit interview.

4.8. Eye tracking during the memory test

In order to assess compliance of the older adults with the instructions to fix their gaze at the center of the computer screen during stimulus presentation in GRAY and VD trials, eye movement was recorded using an infrared eye-tracking system (EyeTrac6 Long Range Optics System, Applied Science Laboratories, Bedford, Massachusetts). An initial sample of six participants surveyed with the eye tracker showed compliance with task instructions. Therefore, in order to avoid delays associated with individual calibration of the eye-tracker, this equipment was not employed during the remaining test sessions. As expected from previous experience with groups of younger adults tested with and without eye-tracking in the same experimental paradigm, a post-hoc comparison of results in the current study showed that the subset of participants who completed the test session with eye-tracking were not different from the remainder of the experiment population.

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