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Aging, Neuropsychology, and Cognition

A Journal on Normal and Dysfunctional Development

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/nanc20

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AGING, NEUROPSYCHOLOGY, AND COGNITION
https://doi.org/10.1080/13825585.2023.2282223

Goal-directed remembering in older adults

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ABSTRACT

Compared to younger adults, older adults show a reduced difference in memory between items they are directed to remember and items they are directed to forget. This effect may result from increased processing of goal-irrelevant information in aging. In contrast, healthy older adults are often able to selectively remember valuable information, suggesting preservation of goal-directed encoding in aging. Here, we examined how value may differentially affect directed-forgetting and memory for irrelevant details for younger and older adults in a value-directed remembering task. In Experiment 1, participants studied words paired with a directed-forgetting cue and a point-value they earned for later recognition. Participants' memory was then tested, either after an 8-min or 24-hr retention interval. In Experiment 2 words were presented in two colors and the recognition test assessed whether the participant could retrieve the incidentally-presented point value and the color of each recognized words. In both experiments, older and younger adults displayed a comparable ability to selectively encode valuable items. However, older adults showed a reduced directed-forgetting effect compared to younger adults that was maintained across the 24-hr retention interval. In Experiment 2, older adults showed both intact directed-forgetting and similar incidental detail retrieval compared to younger adults. These findings suggest that older adults maintained selectivity to value, demonstrating that aging does not impact the differential encoding of valuable information. Furthermore, younger and older adults may be similarly goal-directed in terms of item features to encode, but that instructions to forget presented items are less effective in older adults.

ARTICLE HISTORY
Received 5 January 2023
Accepted 6 November 2023

KEYWORDS
Aging; older adult; memory; value; directed-forgetting

Given the vast amount of information people acquire on a typical day, it is adaptive to selectively encode relevant information and ignore or forget unnecessary information. Indeed, there is a wide literature showing that higher value information is better encoded and remembered than lower value information (Adcock et al., 2006; Castel et al., 2013; Cohen et al., 2016; Mason et al., 2017; Spaniol et al., 2013; Stefanidi et al., 2018). This effect is described as *value-directed remembering* and is often tested by pairing to-be-learned items with either a monetary or abstract point-value that is earned for later retrieval with

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Data, materials, and analytic code are accessible at: https://osf.io/w2f43/.

the explicit goal to maximize one's accumulated rewards (Castel et al., 2002). Although memory performance declines with aging, this ability to selectively learn valuable information remains fairly intact (e.g., Cohen et al., 2016; Knowlton & Castel, 2022; Mason et al., 2017; Spaniol et al., 2013). However, additional research is needed to understand how this preserved ability to selectively learn valuable by older adults coexists with findings of reduced ability to inhibit encoding of irrelevant information in aging (Zacks & Hasher, 1994; Zacks et al., 1996).

For example, though selectivity based on value in memory is spared in aging, directed-forgetting is generally impaired (Hogge et al., 2008; Zacks et al., 1996). In the item-method directed-forgetting paradigm, participants are cued to either remember or forget items, such as words, immediately after each is presented. Participants are tested on all items, but a directed-forgetting effect, where "to-be-remembered" (TBR) items are recalled better than to "to-be-forgotten" (TBF) items, is typically observed (Bjork & Woodward, 1973; Hogge et al., 2008). This effect is stronger in younger adults than older adults, which could reflect encoding differences for TBR items (Basden et al., 1993; Bjork & Woodward, 1973; Hogge et al., 2008; Sahakyan & Delaney, 2003) or attentional inhibition differences for TBF items (Zacks & Hasher, 1994; Zacks et al., 1996). The attentional inhibition framework suggests that inhibition of TBF items frees up processing resources by immediately terminating rehearsal so that TBR items can be encoded better, as well as reducing interference from the TBF items during retrieval (Hasher & Zacks, 1988; Hasher et al., 1999; Zacks et al., 1996). By this framework, voluntary forgetting requires cognitive control, which declines in older age (Spreng & Turner, 2019), potentially explaining why older adults show enhanced memory of task-irrelevant items (Weeks et al., 2016).

Like directed-forgetting, value-directed remembering is supported in part by differential use of item-specific learning strategies. Younger and older adults report using more elaborative learning strategies when encoding high-value word pairs (i.e., mental imagery, putting items in a sentence) relative to low-value pairs, and these strategies produced superior memory over rehearsal (Ariel et al., 2015; Cohen et al., 2017). Such elaborative strategies enhance encoding through providing deeper semantic and associative processing that strengthens the memory trace (Craik & Lockhart, 1972; Richardson, 1998). Indeed, functional magnetic resonance imaging (fMRI) research indicates that greater activation in ventrolateral and dorsolateral prefrontal cortex and lateral temporal cortex is observed when younger and older adults selectively encode valuable items relative to when they encode low-value items (Cohen et al., 2016; Spaniol et al., 2015), and that these regions support deep semantic processing (Binder & Desai, 2011; Binder et al., 2009). But, there is some uncertainty as to how such activation benefits encoding and whether these activation differences reflect differences in utilizing mnemonic strategies.

Value has also been shown to encourage greater allocation of selective-attention in younger adults, similar to directed-forgetting; when participants are given a limited amount of time to encode items, they spend a disproportionate amount of time attending to valuable items (Ariel et al., 2009, 2015), and this increased encoding duration is linked with better subsequent retrieval (Castel et al., 2013). The agenda-based regulation theory of study-time allocation posits that time, cognitive resources, and effort are allocated based on a goal-oriented agenda that aims to maximize performance (Ariel et al., 2009). Therefore, in situations where one can only remember a subset of viewed information, this agenda favors allocation of resources toward selectively learning more valuable information. In line with this reasoning, participants frequently report that they actively ignore low-value items (Ariel et al., 2015; Robison & Unsworth, 2017), which, on average, results in better memory for valuable items and a higher score. Moreover, when high-value cues precede items, older adults show increased frontostriatal connectivity, suggesting they may be engaging in anticipatory cognitive control processes to strengthen memory for these items (Bowen et al., 2020; Braver, 2012; Chiew & Braver, 2013; Fröber & Dreisbach, 2012). Although it is likely that increased attention to valuable items often coincides with greater use of elaborative strategies, this may also simply strengthen memory via prolonged mental rehearsal.

While value-directed remembering and directed-forgetting both draw on cognitive control and selective attention, valuable items may be automatically encoded. Cohen et al. (2017) suggests that even when participants report that they do not deliberately attempt to selectively learn valuable items, value effects on memory can persist. Value effects have also been observed for items participants have been directed to forget (Hennessee et al., 2019), when attention and working memory are burdened with a simultaneous distractor task (Middlebrooks et al., 2017), and even during incidental encoding (Madan & Spetch, 2012; Mather & Schoeke, 2011; Murayama & Kitagami, 2014). Thus, although learners often actively use different learning strategies or allocate attention based on item-value, some of the benefits of value are likely independent of these deliberate mechanisms.

Along these lines, it is possible that value strengthens memory in a relatively automatic fashion based on an item's proximity to reward or value cues. During encoding, value may enhance episodic binding of information, which would predict better incidental memory for high-value items. This work has largely focused on the mesolimbic reward system, suggesting that recruitment of these dopaminergic regions is increased for valuable items relative to low-value items, thus promoting consolidation of these items (Adcock et al., 2006; Bowen et al., 2020; Carter et al., 2009; Spaniol et al., 2013). Memory consolidation is not observed immediately after learning, suggesting that automatic effects of memory may be more prevalent after a retention delay (Murayama & Kuhbandner, 2011; Sharot & Yonelinas, 2008). In a study of the effects of anticipated monetary reward on episodic memory, both older and younger adults showed value effects on uncorrected hit rates but only after a delay (Spaniol et al., 2013). Furthermore, confidence was only sensitive to reward for younger adults at a delay. Although these findings are consistent with the consolidation hypothesis, they are limited due to methodology that did not allow for corrected hit rates, and older adults reliably false alarm more than younger adults (McCabe et al., 2009). Thus, further research is needed to determine the effect that retention interval has on both value effects and directed-forgetting and whether deficits in memory control are exacerbated after a period of consolidation.

In a recent directed-forgetting study (Hennessee et al., 2019), we examined contributions of strategic and relatively automatic encoding mechanisms to value-directed recognition in younger adults by including a variable delay before the directed-forgetting cue. Prior work with this method established that when the cue is delayed, people largely maintain the item in mind via rehearsal (Gardiner et al., 1994) as expending cognitive resources to elaboratively encode such items is counterproductive when a forget cue may shortly appear (Woodward et al., 1973). In contrast, items paired with an immediate learn cue promote deliberate, and often elaborative, encoding. During the recognition test, participants evidenced strong directed-forgetting effects and valuable items showed better subsequent memory than low-value items, even when paired with a forget cue at encoding. This suggests that a relatively automatic process, such as dopaminergic signaling, likely enhances memory for valuable items in younger adults. In contrast past research has found that instructing participants to deeply encode stimuli eliminated age group differences in the directed-forgetting effect, which may suggest that it is driven primarily by elaborative encoding differences of TBR items (Gamboz & Russo, 2002; Sego et al., 2006). It is unclear whether older adults would also show this relatively automatic effect of value for TBF items.

The current study was designed to investigate how age affects value-directed remembering and directed-forgetting, and whether the processes supporting these phenomena interact. While value-directed remembering and remembering based on item-specific instructions are conceptually similar they may rely on processes that are differentially affected by aging. In Experiment 1, we used a directed-forgetting paradigm in which younger and older adults studied words associated with point-values and were followed by a cue to either "Remember" the word for a later test or "Forget" the word. In a between-subjects manipulation, recognition and confidence were assessed either immediately after encoding or 24 hours later. In line with past research, we predicted that the directed-forgetting effect would be larger in younger adults, compared to older adults, and that this effect would strengthen with a retention delay (Bowen et al., 2020). Additionally, we hypothesized that differences in directed-forgetting would be driven by older adults having better memory for TBF items, consistent with age-related impairments in attentional inhibition (Zacks et al., 1996). Finally, we predicted that an age x value x cue interaction may be observed with value enhancing memory for TBF items in younger, but not older adults, if value exerts greater automatic strengthening of memory in younger adults (Hennessee et al., 2019). In a second experiment, we investigated whether potential differences in directed-forgetting and attentional inhibition in older adults would generalize to the encoding of incidental details. It seemed possible that any age-related differences in encoding items designated as to-be-forgotten might generalize to the encoding of irrelevant task details. Such a finding would be in line with the hyper-binding effect (Campbell et al., 2014; Weeks et al., 2016), which involves older adults being more likely to bind irrelevant distractors to target items during encoding.

Experiment 1

Materials and methods

Participants

In-lab testing was interrupted during the COVID-19 pandemic, so data collection took place online using Prolific and a university research subject pool ("SONA"). Data were collected online on Prolific from 90 younger adults and 108 older adults; half of each sample was assigned to the delayed testing condition, where their recognition test was delayed 24 hours, and the other half was assigned to an immediate testing condition. Participants on Prolific were eligible for the study if their first language was English and if they did not have a diagnosed ongoing mental health illness or condition. Additional data were collected online from 90 undergraduate students at University of California, Los

Angeles (UCLA) using a shared pool of psychology research subjects ("SONA"). Participants in the 24-hour delay condition who did not return for testing on Day 2 were excluded ($n_{Younger} = 22$, $n_{Older} = 8$). Younger adult age ranged from 18–39 years (*M* = 25.01, *SD* = 6.01), whereas older adults ranged from 65–89 years (*M* = 69.80, *SD* = 4.12). In a preliminary analysis of recognition sensitivity using a 2 (Value: high, low) x 2 (Cue: TBR, TBF) x 2 (Platform: Prolific, Sona) ANOVA, platform did not have a significant main effect on recognition sensitivity, $F(1, 134) = 0.70$, $p = .404$, $\eta_p^2 = .01$, and interactions between platform and cue/value were non-significant (all *p*'s > .31), so younger adult data from both platforms were pooled together. Participants on Prolific received $10 per hour of participation, whereas SONA participants received course credit. Informed consent was acquired, and the study was conducted, in accordance with UCLA's Institutional Review Board.

Our sample size was based on a target of approximately 50 participants per delay condition and age group. This target was determined by our prior work on memory for value and contextual information in older and younger adults (Hennessee et al., 2018) which used samples of 30–40 participants. We increased this number given data quality issues in online testing conditions. A post hoc power analysis conducted in G*Power (ver 3.1) indicated that the achieved sample size after exclusions described below provided an estimated .97 chance to detect a medium-sized effect (ANOVA with 2 × 2× 2 × 2 interaction, Cohen's f = .25) and a chance of .80 to detect a small/medium sized effect (Cohen's f = .185). We decided to use a somewhat larger sample size for this online study compared to in-person testing because of data quality concerns (Clifford & Jerit, 2014; Oberauer & Greve, 2022; Tanberg et al., 2022). However, note that data quality of online studies is often comparable to in-lab studies, particularly when instruction and attention checks are included (Arndt et al., 2022; Douglas et al., 2023; Gagné & Franzen, 2023; Kees et al., 2017), and data quality on Prolific has been found to be higher than other online platforms (Peer et al., 2022). Following these best practices for online data collection, participants completed both a pre-task instructional check (consisting of three multiple choice questions that had to be answered correctly to continue) and a post-task questionnaire where they listed any strategies used, any distractions that occurred (e.g., TV on, listening to music, talking to friends), and rated how distracted they were on a scale from 1 (Not at all distracted) to 10 (Very distracted) (Oppenheimer et al., 2009). Participants in online experiments tend to underestimate or underreport distraction ratings (on a Likert scale) despite listing numerous potential distractions in their environment. In one online study, the majority of participants said they were "not at all distracted" by different Internet browser windows, their e-mail inbox, music playing, or other listed distractions, with a minority feeling "slightly" distracted (2 or 3 on 8-pt Likert scale) and only a few who admitted to feeling "strongly" distracted (4 or 6 on 8-pt Likert scale) (Greifeneder, 2016). In light of this, we excluded participants who reported being moderately distracted during the task (rating ≥4 on 10-pt Likert scale). To ensure participants were not clicking through the test phase without paying attention, we excluded from analysis those who had an average reaction time ≤600 ms, similar to past research (Keating et al., 2017; Wise & Kong, 2005). Participants were also excluded if they reported that they wrote down words during encoding or said that, in their opinion, their data should not be used (Aust et al., 2013). Based on these criteria, 16 young adults and 3 older adults were excluded from analyses. Six young adult participants were also excluded for having a recognition sensitivity to to-be-learned items (A_z, see Data Analysis section) over 2.5 SDs below the mean of their age x delay group. This resulted in a final sample size of 97 older adults (50 females; 24-hr delay: $n = 49$, mean age = 70.27, no-delay: $n = 48$, mean age = 69.30) and 136 younger adults (94 females; 24-hr delay: $n = 63$, mean age = 28.26, no-delay: $n = 73$, mean age = 24.47).

Materials

Stimuli consisted of 96 English words (nouns, adjectives, and verbs). Items were selected to have a similar frequency of use ($M = 4466.12$ occurrences per million, $SD = 237.11$) according to the Hyperspace Analogue to Language corpus (Lund & Burgess, 1996). At encoding, 48 of these items were randomly selected and paired with either a point-value of 3 or 12 presented for one second before the word appeared. These values were chosen to ensure a strong difference between low-value and high-value items. Then, the word was presented for two seconds, followed by a cue to learn ("LLLL") or forget ("FFFF") that item, which lasted one second. All words were displayed in black color on a white background. Following the cue, a blue fixation cross appeared for five seconds between trials. Each possible point-value x cue combination was assigned to an equal number of trials. Although words were intended to be randomly assigned to be either studied or new at testing, due to a technical error all participants received the same list of 48 study items. There were no significant differences in length or frequency between words that appeared on the study list and those that were new at test (t's < 0.73, p's > .467) or between words that appeared as high and low value across subjects (t's < 0.45, p's > .655).

During the recognition test, all 96 words (half new) were presented in random order and without point-values. All materials were presented using lab.js (https://labjs.felixhenniger.com/) and were printed in 32 pt. sans-serif font. The experiment was hosted on a custom lab server.

Procedure

Participants were first informed that they would view many items paired with point-values they would earn for later retrieval, and that their goal was to maximize this score. They were told that items paired with a learn cue were to be remembered for a later memory test, whereas those with a forget cue did not need to be learned. Before starting the task, participants completed three multiple choice questions to make sure they understood the instructions, including the trial cues and overall goal. To minimize post-encoding rehearsal, participants in the immediate testing condition then watched an eight-minute animated video by Pixar about two robots that did not contain any dialogue.

Lastly, participants completed a self-paced recognition test. Those in the immediate testing condition completed this right after watching the video, while those in the delayed condition completed it in a second session approximately 24 hours later. Participants were informed to disregard that some items were paired with a forget cue during encoding, and that they would still earn the previously associated point-value for retrieving those items. To discourage the strategy of giving all items an old response, participants were told they would lose 2 points for incorrect responses. Participants rated how confident they were that an item was or was not presented by using a 6-point scale: 1 "Definitely NEW," 2 "Probably NEW," 3 "Maybe NEW," 4 "Maybe OLD," 5 "Probably OLD," or

6 "Definitely OLD." All procedures were kept consistent between the online and in-person participants.

Data analysis

For both Experiments 1 and 2, differences in recognition performance by our key variables of interest were analyzed using SPSS with main effects and interactions tested using repeated measures ANOVAs with type-III sum of squares. For significant interactions, we report post hoc comparisons of marginal means with Bonferroni-adjusted p-values, and in some cases, describe mean differences to better understand the effects (e.g., memory for TBR vs. TBF). Overall recognition sensitivity was analyzed using A_z, which is largely unaffected by response bias, and ranges from 0 (lowest sensitivity) to 1 (highest sensitivity), with chance performance at .5. This value is computed as the area under the hit rate by false alarm rate curve where each value of confidence is sequentially treated as an "old" response (Stanislaw & Todorov, 1999). Value has been previously shown to influence episodic memory (e.g., Hennessee et al., 2018), so we further examined effects of our independent variables on the proportion of items receiving the highest confidence rating ("Definitely Old"). Cohen's d and partial eta-squared effect sizes are reported.

Results

Effects of age group, value, cue, and delay on recognition sensitivity

Differences in recognition sensitivity, as measured with A_z, were first examined in a 2 age group (young, old) x 2 value (low, high) x 2 cue (TBF, TBR) x 2 retention interval (immediate, delayed) ANOVA (Table 1). First, main effects were observed for value, $F(1, 229) = 5.89$, $p = .016$, $\eta_p^2 = .03$, cue, $F(1, 229) = 269.79$, $p < .001$, $\eta_p^2 = .54$, and retention interval, $F(1, 229) = 89.98$, $p < .001$, $\eta_p^2 = .28$, as high item value, immediate testing, and the TBR cue led to better recognition sensitivity than their corresponding conditions. The main effect of age was not significant, $F(1, 229) = 0.41$, $p = .524$, $\eta_p^2 < .01$. Second, a significant age group x cue interaction was observed, $F(1, 229) = 4.46$, $p = .036$, $\eta_p^2 = .02$, where the directed-forgetting effect on recognition (TBR – TBF items) was significant for both age group, $p < .001$, but larger for younger adults ($M = .14$) than for older adults ($M = .11$). This appears to have been driven by numerically better memory for TBF items in older adults ($M = .71$, $SD = .13$) versus younger adults ($M = .69$, $SD = .13$), $p = .142$, partially supporting our hypothesis that older adults would show deficits in inhibiting TBF

Table 1. Experiment 1 recognition sensitivity by condition.

	Younger Adults		Older Adults	
	Low-Value	High-Value	Low-Value	High-Value
8-Min Retention				
TBR	.85 (.12)	.87 (.10)	.90 (.09)	.90 (.09)
TBF	.74 (.15)	.75 (.13)	.81 (.15)	.82 (.15)
24-Hr Retention				
TBR	.79 (.13)	.79 (.13)	.73 (.16)	.75 (.17)
TBF	.61 (.13)	.64 (.12)	.60 (.14)	.62 (.16)

Note. Standard deviations presented in parentheses. TBR = To-be-remembered items, TBF = to-be-forgotten items.

items. Third, a cue x retention interval interaction was observed, $F(1, 229) = 8.92$, $p = .003$, $\eta_p^2 = .04$ as the directed-forgetting effect was significant for both retention intervals, $p < .001$, but was larger with the 24-hr retention interval ($M = .15$) than with immediate testing ($M = .10$). Fourth, the age group x retention interval interaction was significant, $F(1, 229) = 9.20$, $p = .003$, $\eta_p^2 = .04$, as both age groups had lower sensitivity in the delayed testing condition, $p < .001$, but the longer retention interval produced a steeper reduction in recognition sensitivity for older adults ($M = .18$) than for younger adults ($M = .09$). More specifically, in the immediate testing condition older adults ($M = .86$, $SD = .16$) showed higher recognition sensitivity than younger adults ($M = .80$, $SD = .15$), $p = .009$, whereas in the delayed testing condition older adults ($M = .67$, $SD = .16$) and younger adults ($M = .71$, $SD = .16$), did not significantly differ in sensitivity, $p = .096$. All other interaction terms were not significant (all p's > .284). Importantly, the effect of value was similar in older and younger adults as the interaction between age and value was not significant $F(1, 229) = 0.001$, $p = .976$, $\eta_p^2 < .01$.

Effects of age group, value, cue, and delay on high-confidence recognition responses

To better understand the effects of age on recognition sensitivity described above, further analysis was conducted examining the proportion of highest confidence responses to each item ("Definitely Old"). In a 2 age group (young, old) x 2 value (low, high) x 2 cue (TBF, TBR) x 2 retention interval (immediate, delayed) ANOVA, main effects were observed for value, $F(1, 230) = 10.77$, $p = .001$, $\eta_p^2 = .05$, cue, $F(1, 229) = 401.47$, $p < .001$, $\eta_p^2 = .64$, and delay, $F(1, 229) = 64.29$, $p < .001$, $\eta_p^2 = .22$, as high item value, immediate testing, and the TBR cue led to more high confidence responses than was observed for their corresponding conditions. The main effect of age group was not significant, $F(1, 229) = 0.13$, $p = .716$, $\eta_p^2 < .01$. Importantly, a significant age group x cue interaction was observed, $F(1, 229) =$

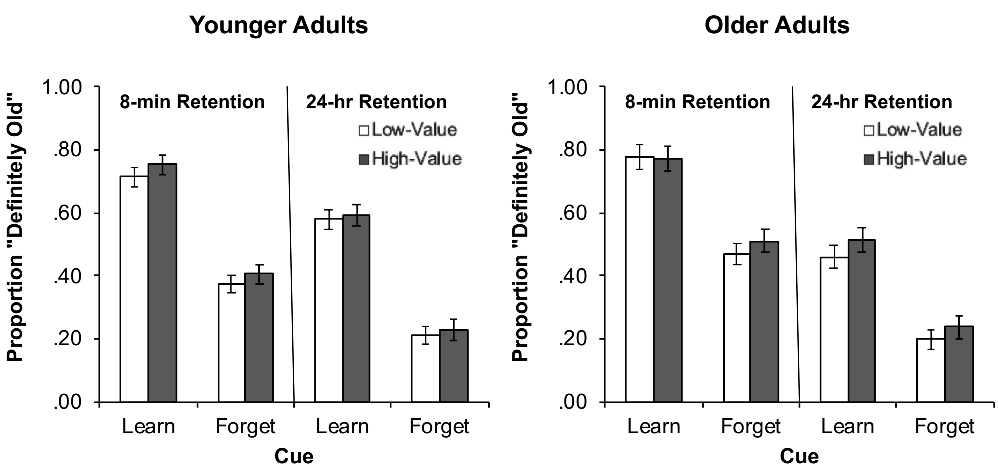

Figure 1. Proportion of items given the highest confidence response ("Definitely old") at Experiment 1 retrieval split by age group, retention interval, item-value, and directed-forgetting cue. Error bars represent one standard error from the mean.

6.08, $p = .014$, $\eta_p^2 = .03$, driven by the findings that older adults ($M = .35$, $SD = .23$) were marginally more likely to recognize TBF items with very high confidence relative to younger adults ($M = .30$, $SD = .22$), $p = .106$ (Figure 1); this finding, along with a similar finding for recognition sensitivity above, provided partial support for our hypothesis that older adults would show deficits in inhibiting TBF items. A significant age group x retention interval interaction was also observed, $F(1, 229) = 4.82$, $p = .029$, $\eta_p^2 = .02$. Older adults ($M = .63$, $SD = .30$) were marginally more likely than younger adults ($M = .56$, $SD = .28$) to remember items with high confidence when testing was not delayed, $p = .068$, whereas older adults ($M = .35$, $SD = .30$) and younger adults ($M = .40$, $SD = .30$) did not significantly differ here with delayed testing, $p = .202$. All other interactions were not significant (all p's > .147). There was no interaction between age and value for high confidence responses $F(1, 229) = 0.15$, $p = .695$, $\eta_p^2 < .01$.

Discussion

Overall, the findings of Experiment 1 are consistent with research showing that selectively encoding information based on value is intact in cognitively normal older adults (Cohen et al., 2016; Spaniol et al., 2013), whereas their ability to inhibit unnecessary information is impaired relative to the young. First, we observed main effects of the directed-forgetting cue, retention interval, and item value, suggesting that these manipulations were successful. However, as predicted, the directed-forgetting effect was substantially stronger for younger adults than for older adults. This finding was consistent with prior aging studies (Bowen et al., 2020; Hogge et al., 2008). Although recognition sensitivity for TBF items was only numerically higher in older adults relative to younger adults, older adults did show a trend to be more likely to remember these TBF items with very high confidence than did younger adults. High confidence retrieval responses have been previously linked with increased experiences of episodic recollection in a remember-know paradigm (Wixted & Stretch, 2004; Yonelinas & Parks, 2007), so older adults here likely remembered TBF items in a more episodic manner than younger adults. Together, these findings suggest that older adults had a modest impairment in inhibiting the processing of TBF items despite intact selectivity for value in encoding. We note that moderate ceiling effects may have been present for older adult recognition sensitivity for TBR items (e.g., high-value item M =. 90, $SD = .09$, Table 1), so we cannot rule out that these older adults were high-performers overall.

A second aim of this study was to examine age-related differences in memory consolidation by having one participant sample complete the test shortly after encoding, and, in the second sample, delaying recognition testing by approximately 24 hours. This delay reduced recognition sensitivity across both groups, but a significant age x retention interval interaction suggested that older adults show worse long-term consolidation relative to younger adults. We note that with the between-subjects design it is impossible to rule out the possibility that older adults showed a greater impact of delayed testing because, as an example, older adults in the delayed testing condition could have been lower functioning to begin with. However, because participants were randomly assigned to the two conditions and the mean age of participants in the two conditions was similar, we believe that the robust age x retention interval interaction ($p = .003$) was more likely due to deficits in consolidation or more rapid memory decay in older adults rather than differences due to sampling. Because a significant age x retention interval x cue interaction was not observed, it appears that older adults' more robust memory for TBF items did not translate into more durable memory traces relative to younger adults. Furthermore, even though these results suggest that memory decay was more rapid in older adults, effects of value were similar for the two age groups across the retention interval. Lastly, value x cue interactions were not significant here, suggesting that value neither further enhanced memory for TBR items nor were relatively automatic effects of value on memory for TBF items observed, as was observed in Hennessee et al. (2019).

Experiment 2

Experiment 1 illustrated that while recognition memory likely decays faster in older adults and older adults have reduced ability to inhibit irrelevant items during encoding, they showed similar selectivity for value as younger adults. Experiment 2 was designed to further examine whether deficits in inhibitory control of memory in older adults generalize to the encoding of incidental details, specifically the item's value or its print color. Apart from the inclusion of these two details, which involved the value cue being presented simultaneously with its corresponding item displayed in red or blue, Experiment 2's design, procedure, and materials were kept consistent with Experiment 1. These two details were selected to delineate differences in incidentally encoding details that are task-relevant (point-values) from encoding details that are task-irrelevant (print color), and memory for these details in younger adults has been examined in our prior work (Hennessee et al., 2017, 2018, 2019). In these studies, we found that for both older and younger adults, recollected high-value items were more likely to be bound to the task-relevant point-value of the item but less likely to be bound to a task-irrelevant one (word color) than non-recollected high value items (Hennessee et al., 2017, 2018). These results suggest that selectivity afforded by value can focus attention on relevant aspects of the stimulus for older adults. However, it is unclear whether difficulties in inhibiting to-be-forgotten material would lead older adults to also have strong incidental detail memory for those features.

In the present study, we first hypothesized that older adults would show strong memory for the task-relevant point-values, as we have observed in younger adults (Hennessee et al., 2018, 2019), but we further predicted that they would also show strong memory for task-irrelevant print colors, unlike younger adults. Such a finding would be consistent with research on the hyper-binding of distractors to target items during encoding in older adults (Campbell et al., 2014; Weeks et al., 2016). Here, we expected that this hyper-binding would extend to the incidental encoding of irrelevant details. As older adults in Experiment 1 were more likely to remember TBF items with very high confidence, we further hypothesized that retrieval of incidental details for these items may also be enhanced. If older adults have impairments in inhibition, they should remember more incidental details as compared to younger adults, even for TBF items. Finally, we hypothesized that remembered high-value items would be associated with better incidental detail memory as compared to low-value items, due to the enhanced binding of contextual elements.

Materials and Methods

Participants

Data were collected from 63 younger adults and 69 older adults via Prolific. As in Experiment 1, participants from Prolific were eligible if English was their first language and they did not have any diagnosed current or ongoing mental health or neurological condition. Additionally, participants were eligible if they did not have any impairments in their color vision; we confirmed this in a posttest survey and one subject was excluded from further analysis for reporting significant impairment that would prevent them from distinguishing red from blue. Participants were also excluded for having mean reaction time less than or equal to 600 ms ($n = 2$), reporting moderate distraction (rating ≥4) during the task ($n = 5$), writing down words during encoding ($n = 6$) or having Az for to-be-learned items at least 2.5 SDs below the mean of their age group ($n = 2$). The final sample size was 116 including 57 younger adults ages 20–42 years ($M = 33.11$, $SD = 5.61$, 16 females) and 59 older adults ages 65–79 ($M = 70.44$, $SD = 3.25$, 37 females). Post hoc power analysis conducted in G*Power (ver 3.1) indicated that the achieved sample size of 116 provided an estimated .76 chance to detect a medium-sized effect (ANOVA with $2 \times 2 \times 2 \times 2$ interaction, Cohen's $f = .25$) and a .80 chance to detect an effect size of Cohen's $f = .263$. Participants received $12 per hour of participation. Informed consent was acquired, and the study was conducted, in accordance with UCLA's Institutional Review Board.

Materials

The same stimuli from Experiment 1 were used with minor changes listed below. First, the value was presented to the right of the word ("rivers 3"). Second, words were displayed in either blue (RGB value: 0, 0, 255) or red (RGB value: 255, 0, 0) font to provide a second dimension for source retrieval. Point-values were presented concurrently with the items in this experiment, and both point-values and print color only had two possible values, so that we could directly compare the encoding of these two details. Participants were not asked to memorize item values or color, thus these two dimensions provided an assessment of incidental source memory. Each possible value x color x cue combination was assigned an equal number of trials, and all words were randomly assigned to each of these variable combinations or to be a new item at testing. The words that were assigned to be high and low value did not significantly differ in terms of frequency or length (t's < 0.45, p's > .65). During the recognition test, all 96 words (half new) were presented in random order in black ink and without point-values. All materials were presented using lab.js (https://labjs.felixhenninger.com/) and were printed in 32 pt. sans-serif font with a white background. As with Experiment 1, the experiment was hosted on a custom lab server.

Procedure

Participants completed the study online via Prolific, and they were given the same instructions as in Experiment 1 before encoding the same set of 48 items randomly selected from the full list of 96 English words. Next, to minimize post-encoding rehearsal, participants watched the same eight-minute Pixar video about two robots that was used in the immediate testing condition of Experiment 1. Lastly, participants completed a self-paced recognition test in which they rated how confident they were that an item was or was not presented before using the same six-point scale. After an old response (4–6), they reported via forced choice whether the item was worth 3 or 12 points and whether it was presented in red or blue ink. After new responses (1–3), as a filler task, they instead rated how pleasant the item was to them on a six-point scale.

Data analysis

Our procedure of data analysis for Experiment 2 mirrored that of Experiment 1. Differences in recognition sensitivity (Az), proportion of very high confidence memory for old items ("Definitely Old"), and the retrieval of incidental details by our key variables – age group, directed-forgetting cue, item-value, and detail type (point-value or color) – were examined using repeated measures ANOVAs. Significant interactions were further probed via post hoc comparisons of marginal means with Bonferroni-adjusted p-values. Note that incidental detail retrieval was only examined for correctly recognized old items. Five participants did not have incidental memory scores for some conditions (e.g., no recognized low-value TBF items), and were excluded from analyses involving incidental detail retrieval.

Results

Effects of age group and condition on memory performance and confidence

In a 2 age group (young, old) x 2 value (low, high) x 2 cue (TBF, TBR) ANOVA predicting recognition sensitivity, we observed a significant effect of cue, $F(1, 114) = 177.90$, $p < .001$, $\eta_p^2 = .61$, such that TBR items ($M = .83$, $SD = .13$) showed better subsequent memory than TBF items ($M = .67$, $SD = .15$, Table 2). A significant main effect of age group, $F(1, 114) = 8.31$, $p = .005$, $\eta_p^2 = .07$, indicated that sensitivity was greater in older adults ($M = .78$, $SD = .17$) relative to younger adults ($M = .72$, $SD = .17$). A main effect of value was also observed, $F(1, 114) = 8.20$, $p = .005$, $\eta_p^2 = .07$, with better memory for high-value items ($M = .76$, $SD = .13$) relative to low-value items ($M = .74$, $SD = .13$). A significant age group x value interaction was

Table 2. Experiment 2 recognition sensitivity by condition.

	Younger Adults		Older Adults	
	Low-Value	High-Value	Low-Value	High-Value
Cue				
TBR	.79 (.15)	.80 (.15)	.83 (.14)	.89 (.10)
TBF	.63 (.15)	.64 (.17)	.69 (.16)	.72 (.19)

Note. Standard deviations presented in parentheses. TBR = To-be-remembered items, TBF = to-be-forgotten items.

also observed, $F(1, 114) = 5.07$, $p = .026$, $\eta_p^2 = .04$, as older adults displayed a significant effect of value such that high-value items had greater recognition sensitivity ($p < .001$), whereas younger adults did not show a value effect ($p = .668$, Table 2). Non-significant interactions included age group x cue x value, age group x cue, and cue x value (all p's > .51). The non-significance of the age x cue interaction suggests that that, contrary to our predictions, older adults did not show evidence of deficits in directed-forgetting. In specifically examining TBF items, marginal means indicated that older adults had greater recognition sensitivity than younger adults ($p = .015$), but this was mirrored by their greater memory for TBR items ($p = .008$); together, these post hoc tests suggest that the better performance of older adults on TBR items was not accompanied by more effective inhibition of TBF items. Thus, we observed a strong directed-forgetting effect on recognition, this difference between recognition for TBR and TBF items was not affected by age, and only older adults showed an effect of item-value on memory.

We conducted a 2 age group (young, old) x 2 value (low, high) x 2 cue (TBF, TBR) ANOVA predicting the proportion of items remembered with highest confidence. Main effects for age group, value, and cue were observed, and all in the same direction as the recognition sensitivity analyses above. A main effect of cue, $F(1, 114) = 237.22$, $p < .001$, $\eta_p^2 = .68$, indicated that TBR items ($M = .59$, $SD = .27$) were much more likely than TBF items ($M = .23$, $SD = .18$, Figure 2) to be remembered with the highest confidence. A main effect of value, $F(1, 114) = 18.23$, $p < .001$, $\eta_p^2 = .14$, indicated that high-value items were more likely to be remembered with very high confidence ($M = .44$, $SD = .20$) than low-value items ($M = .38$, $SD = .21$); note that although younger adults did not display an effect of value on overall recognition sensitivity, they did recognize high-value items ($M = .39$, $SD = .29$) with the highest level of confidence more often than low-value items ($M = .34$, $SD = .30$, $p = .012$). The three-way interaction and all two-way interactions were not significant (all p's > .42). Because all interaction terms including age group were non-significant, these findings suggest that value enhanced high confidence memory for items largely regardless of age. Lastly, older adults ($M = .45$, $SD = .27$) were more likely than younger

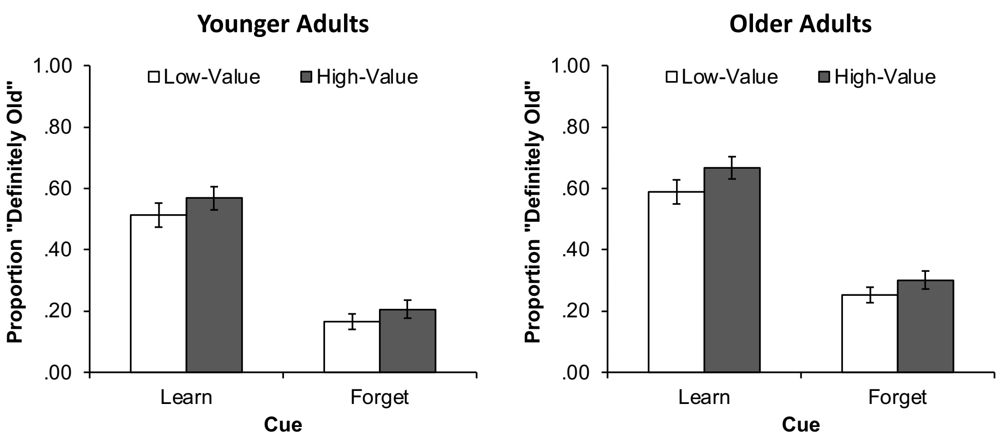

Figure 2. Proportion of items given the highest confidence response (“Definitely old”) at Experiment 2 retrieval split by age group, item-value, and directed-forgetting cue. Error bars represent one standard error from the mean.

Table 3. Experiment 2 incidental memory by condition.

	Younger Adults		Older Adults	
	Point-Value	Color	Point-Value	Color
Overall	.59 (.13)	.52 (.10)	.59 (.15)	.53 (.11)
Cue x value				
TBR, high-value	.61 (.23)	.52 (.16)	.66 (.24)	.54 (.19)
TBR, low-value	.63 (.24)	.54 (.18)	.58 (.27)	.53 (.19)
TBF, high-value	.36 (.28)	.54 (.26)	.42 (.31)	.57 (.23)
TBF, low-value	.69 (.29)	.51 (.25)	.62 (.28)	.52 (.26)

Note. Incidental detail retrieval of item point-values and colors for younger and older adults presented both overall and split by cue and value combinations. Standard deviations presented in parentheses. TBR = To-be-remembered items, TBF = to-be-forgotten items.

adults (*M* = .36, *SD* = .28) to report remembering old items with the highest confidence level, $F(1, 114) = 6.06$, $p = .015$, $\eta_p^2 = .05$.

Memory for incidental details

In a 2 age group (young, old) x 2 cue (TBF, TBR) x 2 detail (point-value, color) x 2 value (low, high) ANOVA examining rates of successful incidental retrieval to correctly recognized old items, a main effect of detail was observed, $F(1, 109) = 6.75$, $p = .011$, $\eta_p^2 = .06$, with greater retrieval observed for point-values (*M* = .57, *SD* = .14) compared with colors (*M* = .53, *SD* = .11). This advantage for point-value retrieval was in line with our prediction that this task-relevant detail would be better remembered than the task-irrelevant presentation colors. A main effect of cue was also observed, $F(1, 109) = 15.11$, $p < .001$, $\eta_p^2 = .12$, with greater retrieval of details observed for TBR items (*M* = .58, *SD* = .11) relative to TBF (*M* = .53, *SD* = .11). A main effect of value was observed, $F(1, 109) = 6.22$, $p = .014$, $\eta_p^2 = .05$, with greater retrieval of details observed for high-value items (*M* = .58, *SD* = .16) relative to low-value items (*M* = .53, *SD* = .14). The main effect of age group was not significant, $F(1, 109) = 0.42$, $p = .838$, and all interactions involving age were not significant (all *p*'s > .07), suggesting similar incidental detail retrieval across the two age groups. This finding was contrary to our prediction that older adults would show additional binding of incidental details to TBF items. A significant cue x detail x value interaction was observed, $F(1, 109) = 28.20$, $p < .001$, $\eta_p^2 = .21$ (Table 3), and the three two-way interactions involving these variables were significant (all *p*'s < .002). Post hoc analysis of marginal means revealed that: (1) correct point-value retrieval was more common than color retrieval across all combinations of value and cue (all *p*'s < .009), (2) differences in point-value retrieval due to item-value were only observed for TBF items ($p < .001$), with retrieval for low-value TBF items (*M* = .65, *SD* = .28) exceeding that of high-value TBF items (*M* = .39, *SD* = .29), and (3) point-value retrieval for high-value items was much more common for TBR items (*M* = .64, *SD* = .23) relative to TBF items (*M* = .39, *SD* = .29, $p < .001$). These results suggest that the VDR and directed-forgetting cue were synergistic in supporting incidental detail retrieval with the best recall of point-value retrieval associated with high-value TBR items and low-value TBF items. Color retrieval was fairly limited across various combinations of value and cue and was only marginally better than chance for younger adults, $t(56) = 1.90$, $p = .063$, $d = .25$, and for older adults, $t(58) = 1.91$, $p = .062$, $d = .25$.

Discussion

In Experiment 2, we sought to determine whether inhibition impairments in older adults would extend to the encoding of irrelevant incidentally encoded details and whether memory for incidental details was affected by value or instruction to remember or forget the item. As in Experiment 1, the directed-forgetting manipulation successfully resulted in greater recognition sensitivity to TBR items relative to TBF items. A main effect of value indicated that recognition sensitivity was elevated for higher-value items, though a value x age interaction occurred such that older adults, but not younger adults showed an effect of value on recognition sensitivity. However, when examining high-confidence memories, both age groups showed robust effects of item-value such that high-value items were more often remembered with the highest degree of confidence. Research has shown that high value is related to increased episodic recollection at testing, and that recollected items are remembered with high confidence (Wixted & Stretch, 2004; Yonelinas & Parks, 2007). Although valuable items were not recognized at higher rates for younger adults, this finding suggests that a stronger memory trace was developed for valuable items, and this effect was similar for both age groups. Another notable divergence from Experiment 1 was that older adults did not show a reduced directed-forgetting effect. Indeed, overall recognition sensitivity was somewhat stronger in older adults, although this pattern was not present for the high confidence recognition or the differences between TBR and TBF items. These results suggest that this sample of older adults, who participated in online studies, was relatively cognitively fit, and future research could examine these questions with a more diverse sample of older adults that may be more typical.

Incidental detail retrieval here was characterized by a cue x detail x value interaction and main effects of all three variables. Point-values were more likely to be remembered than item colors, across all conditions, which was in line with previous research (Hennessee et al., 2017, 2018; Yin et al., 2021) and the fact that points were relevant to the task and colors were task-irrelevant. Incidental detail memory was generally stronger for items designated as TBR, and as TBR items were recognized with greater recognition sensitivity, this suggests that when participants were deeply encoding these items, associative binding of the point-value occurred. The three-way interactions were most apparent regarding the effects of item-value on point-value retrieval: for TBR items, point-value retrieval was strongest when the item was high-value, whereas for TBF items, point-value retrieval was highest when the item was low-value. Put another way, binding the point-value to the item was most successful when both the item-value and directed-forgetting cue consistently indicated that the item should be learned (high-value & TBR) or should not be learned (low-value & TBF), and it seems likely that this consistency between cues facilitated better incidental detail memory. Alternatively, participants may have inferred point value from the strength and quality of memory for the word, leading to a metacognitive phenomenon in which people infer that forgotten information is of lower value, consistent with a forgetting bias (Castel et al., 2012; Rhodes et al., 2017; Witherby et al., 2019). As TBF items were only weakly remembered, participants may have assumed that they were associated with low point values. In support of this possibility, participants tended to judge even high value TBF words to have been associated with the low value. Thus, the point value judgments may have reflected metacognitive processing to a great extent in and not solely memory retrieval (see also Castel et al., 2012; Rhodes et al., 2017).

Contrary to our predictions, incidental detail retrieval here was largely consistent across younger and older adults, as evidenced by lack of significance in both the age group main effect and all interactions involving age group. In Experiment 1, there was modest support for older adults having deficits in inhibition, as observed in other studies (Zacks & Hasher, 1994; Zacks et al., 1996), as older adults had marginally higher recognition sensitivity for TBF items relative to younger adults and they were marginally more likely to remember TBF items with high confidence. However, in Experiment 2, older adults did not show deficits in directed-forgetting as better memory for TBF items was offset by better memory for TBR items. There were also no deficits in retrieving incidental details of these items. Although we hypothesized that older adults would be more likely to bind task-irrelevant colors in item memory, consistent with the hyper-binding effect (Campbell et al., 2014), these results instead suggest a similar pattern of incidental detail retrieval in older and younger adults. However, a plausible reason for the lack of a difference between the groups was the poor overall memory for the color of the studied words. For both age groups, memory for word color was only marginally above chance. If a more salient irrelevant detail had been tested it is possible that it would be disproportionately remembered by older as compared to younger adults.

General discussion

In this study, we sought to determine the extent that attentional inhibition deficits in older adults (Zacks & Hasher, 1994; Zacks et al., 1996) would be present when selectively learning valuable information, and to better characterize whether this affects the incidental encoding of item details. Across two experiments, we observed that older adults displayed strong memory performance overall and a comparable ability to selectively learn high-value items as younger adults, as has been demonstrated in previous work (Cohen et al., 2016; Mason et al., 2017; Spaniol et al., 2013). Furthermore, results provided only modest support for attentional inhibition deficits in older adults. Older adults in Experiment 1 displayed weaker directed-forgetting, numerically better memory for TBF items, and poorer retention over a 24-hr interval, all relative to younger adults. However, in Experiment 2, both directed-forgetting and incidental detail retrieval was comparable across the two age groups, though the two details tested may not have effectively probed incidental memory.

Older adults' significantly smaller directed-forgetting effect and numerically stronger memory for TBF items in Experiment 1, relative to younger adults, was consistent with a modest deficit in attentional inhibition. Although much research has shown this effect due to an impairment in encoding TBR items (e.g., Bjork & Woodward, 1973; Hogge et al., 2008), in the current study, memory for TBF items was numerically elevated in older adults (though not significantly), consistent with an inhibition-focused account such that increased rehearsal and processing of TBF items leads to decreased encoding of TBR items (Zacks & Hasher, 1994; Zacks et al., 1996). More specifically, it seems likely that older adults did not inhibit these TBF items to the same extent, thus leading to increased encoding duration and a stronger memory trace. Accordingly, there was a trend for older adults to retrieve TBF items with very high confidence ("Definitely Old") more frequently than younger adults at test; as high confidence is strongly related to episodic recollection (Wixted & Stretch, 2004; Yonelinas & Parks, 2007), it seems likely that stronger episodic memories were developed in older adults for these items. Although the pattern of these findings regarding TBF items followed supported deficits in inhibition in older adults (Zacks & Hasher, 1994; Zacks et al., 1996), given that these age group differences did not reach statistical significance, an alternate interpretation is that attentional inhibition was relatively intact in these older adults.

In Experiment 2, we investigated whether age group differences in directed-forgetting would extend to the encoding of incidental item details. Although we observed a strong directed-forgetting effect, it did not significantly differ as a function of age group (unlike in Experiment 1). Older adults showed a comparable directed-forgetting effect relative to younger adults and showed somewhat higher overall recognition sensitivity, with increased recognition of both TBR and TBF items. Additionally, effects of item-value on recognition differed as a function of age group as only older adults showed a value-based enhancement of recognition sensitivity. Value effects on memory were present in younger adults though, as both age groups were much more likely to remember high-value items with the highest confidence. As high confidence is linked with more recollective memories (Wixted & Stretch, 2004; Yonelinas & Parks, 2007), this suggests that both age groups developed stronger memory traces for valuable items. Retrieval of incidentally encoded item point-values and presentation color likewise was comparable across the two age groups. Similar to previous work in younger adults (Hennessee et al., 2017, 2018; Yin et al., 2021), memory for point-values was superior to memory for incidental item colors. As these point-values indicated how much the item would contribute to their final score, allocating attention to and thus encoding point-values was highly adaptive. In contrast, item color was completely irrelevant to the task, thus encoding this detail would not be useful for successful subsequent memory. Indeed, here, as in our previous work, memory for item color was not significantly better than chance (Hennessee et al., 2017, 2018).

Taken together, these two experiments suggest that older adults do not show strong attentional inhibition deficits when selectively learning information that differs in value or its likelihood of being tested (i.e., directed-forgetting cue). Although older adults showed a significantly reduced directed-forgetting effect in Experiment 1, age group differences both in recognition sensitivity and high-confidence memory for TBF items were not statistically significant. In Experiment 2, both directed-forgetting effects on memory and incidental detail retrieval was comparable for the two age groups, suggesting a similar ability to selectively encode TBR items. Based on previous demonstrations that older adults more often bind irrelevant distractors to target items during encoding (Campbell et al., 2014; Weeks et al., 2016), we hypothesized that older adults might be more likely to retrieve task-irrelevant word colors in the current paradigm. However, incidental detail retrieval was comparable across age groups here with color memory near chance levels for both younger and older adults. Our hypothesis that older adults would show elevated incidental retrieval for TBF items, in line with theories of attentional inhibition deficits, was not supported as no interactions involving age group for incidental retrieval were significant. Some work has highlighted age differences in selective-attention as a causal factor behind selective learning differences (Ariel et al., 2009, 2015); because both item memory and memory for associated details did not differ as a function of age group here, it seems likely that substantial differences in selective-attention were not present.

Similarly, older adults in both experiments evidenced strong selective encoding of valuable information. Even across a 24-hr retention interval, in which memory appeared to decay more rapidly in older compared to younger adults, older adults showed comparable value sensitivity to younger adults, as has been reported in previous research (Bowen et al., 2019; Spaniol et al., 2013). This suggests that older adults' preferential encoding of valuable information and consolidation of that information in memory is intact. Value-based enhancement of episodic memory has previously been found to be comparable in younger and older adults (Hennessee et al., 2018), which may result from recruitment of a dopaminergic and mesolimbic reward system that promotes both encoding and memory consolidation for valuable items (Bowen et al., 2019; Carter et al., 2009; Spaniol et al., 2013). The results here suggest that the value of studied items may be a particularly effective cue that allows them to selectively encode high-value items at the expense of low-value items. One possibility is that value engages automatic reward processes that may be intact in older adults (Hennessee et al., 2019). Another possibility is that, unlike experiences with explicit directed-forgetting, older adults may have more real-world experience with learning information that differs in value and have developed adaptive strategies to focus on what matters most. We note that older adults in both experiments showed relatively high memory performance as they had similar recognition sensitivity as younger adults in Experiment 1, and slightly higher sensitivity in Experiment 2. In our previous work with older adults recruited locally and tested in-person, older adults showed recognition sensitivity impairments relative to younger adults (Hennessee et al., 2018), so it is plausible that recruiting participants online via Prolific selected for higher functioning older adults. That said, even though older adults showed worse memory performance in that previous study, they, like the older adult samples of this study, showed strong value effects on memory. As other research has found that early stages of Alzheimer's disease can impact the effects of value on selectivity (Castel et al., 2009; Wong et al., 2019), future research could examine how older adults with different levels of cognitive function may perform in the present task, to better understand differences between healthy and pathological aging.

In conclusion, we observed that intact selective encoding of valuable information in older adults was accompanied by weaker directed-forgetting effects and marginal increases in highly confident memories for TBF items in one experiment, but intact directed-forgetting and incidental detail retrieval in the second experiment. Although these findings are somewhat contradictory, because the findings of Experiment 1 were largely based on marginal effects, we argue that our data more strongly support an account of intact use of attentional inhibition in older adults in the present task. Furthermore, we posit that this is likely due to the goal-driven nature of this learning context, and that learning information that differs in value may be a case in which older adults are able to effectively and adaptively filter information in memory (see also Knowlton & Castel, 2022). Older adults' intact ability to selectively encode valuable information resulted in similar long-term consolidation of these valuable items, despite older adults showing generally worse memory decay during a 24-hr retention interval. Taken together, these findings support emerging theories of how inhibition and value function to guide memory in younger and older adults.

Acknowledgments

We thank Hanieh Fahami for assistance with data collection. Preliminary results for Experiment 2 were presented at the 32nd American Psychological Society Annual Convention, Chicago, IL.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by a grant from the National Institutes of Health (National Institute on Aging) to A. Castel (R01AG044335) and a grant from the National Science Foundation to B. Knowlton (BCS-2048692).

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