Published in final edited form as:

Psychol Aging. 2023 February ; 38(1): 30–48. doi:10.1037/pag0000720.

Value-Directed Memory Selectivity Relies on Goal-Directed Knowledge of Value Structure Prior to Encoding in Young and Older Adults

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Abstract

People are generally able to selectively attend to and remember high-value over low-value information. Here, we investigated whether young and older adults would display typical value-based memory selectivity effects for to-be-learned item-value associations when goal-directed information about the meaning of associated values was presented before and after encoding. In two experiments, both young and older adults were presented with one (Experiment 1) or multiple (Experiment 2) lists of words that were arbitrarily paired with different numerical values (e.g., DOOR – 8) or font colors (e.g., DOOR presented in *red*), which indicated each word's value. In Experiment 1, participants were told that the numerical value indicated the relative importance of each item either before they studied the list (pre-encoding), after they studied it (post-encoding), or not at all (no value control instructions). Older adults were significantly more selective in the pre-encoding condition relative to the other conditions, while younger adults were not selective in any condition on this single list (numerical) value task of Experiment 1. In Experiment 2, young and older adults were tested on four additional lists of both pre-encoding and post-encoding trials each after studying and recalling four lists of words without any value instructions. Results from Experiment 2 revealed that both young and older adults selectively prioritized high-value words on the pre-encoding trials, but not on post-encoding trials, on this color-based categorical (low-medium-high) value task. The current study highlights a critical role of goal-directed knowledge of value-based instructions prior to encoding to facilitate typically observed value-directed memory selectivity for important information.

Keywords

aging; memory; attention; prioritization; metacognition

Memory capacity in cognitively healthy humans is naturally limited. For better or for worse, we cannot accurately remember every event that transpires or every stimulus with which we

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Statement of Prior Dissemination: The ideas and data appearing in the manuscript have not been disseminated before. Both experiments were preregistered on AsPredicted.org. Reproducible analysis code, raw data, stimuli, and copies of the preregistrations are openly available on OSF: https://osf.io/qfg54/ (Schwartz et al., 2022).

come into contact. We can, however, attempt to selectively pay attention to what is most important, by using cognitive control mechanisms to upregulate attention when one's goals require it (Badre & Wagner, 2007; Evans & Herron, 2019; Jacoby, 1999; Moscovitch & Winocur, 2002; Stevens & Grady, 2007; Wilckens et al., 2012); one may try to suppress a negative memory (for a review, see Anderson & Hulbert, 2021; Bjork, 1989; Bjork et al., 1998), or, conversely, one might shift memorial resources towards items considered valuable, to bolster memory – a compensatory mechanism hypothesized to aid older adults in combating age-related declines in memory capacity (e.g., Castel, 2008; for a review, see Knowlton & Castel, 2022).

Value, a type of salient reward, plays a critical role in the formation and expression of memories. The value of information may bias attention and memory in an involuntary, bottom-up manner (Anderson, 2013; Ariel & Castel, 2014; Sali et al., 2014), as evidenced under incidental encoding conditions (Mather & Schoeke, 2011; Murayama & Kitagami, 2014), as well as in a top-down, strategic, and/or goal-directed manner. Prior work using a directed forgetting paradigm found that high-value words followed by an immediate "forget" cue were recognized at significantly higher proportions compared to to-be-forgotten low-value information, suggesting the role of an automatic reward-enhancement mechanism immediately overriding top-down regulatory processes to *forget* this information, which was reduced when the "forget" cue following the word was presented after a brief (5-s) delay (Hennessee et al., 2019). However, the mechanisms underlying value-directed memory selectivity and directed forgetting are likely dissociable (see Lo, 2021).

Top-down strategic and/or goal-directed control on value-based associations at memory encoding has been extensively studied in the lab through value-directed remembering paradigms, which typically find better memory performance for learned information arbitrarily associated with higher values (e.g., Castel et al., 2002; Middlebrooks & Castel, 2018; Stefanidi et al., 2018). In these studies, participants are presented with word-number pairs, and told that the number represents the relative importance of that word (its point value) for a later memory test. The participant's goal is to remember as many words as they can to maximize the number of points they earn. While participants generally cannot remember all items on a study list, most participants (both young and older adults) prioritize high-value over low-value items to maximize points (e.g., Murphy, Schwartz, et al., 2022; Siegel & Castel, 2018b), studying high-value items more frequently and for longer than low-value items (Middlebrooks & Castel, 2018; Robison & Unsworth, 2017). There are likely at least two processes at play, one that is more automatic involving the incidental encoding of words and values (and any associated details of words), and a more strategic process, in which people selectively focus on higher value words at study and use imagery or other strategies to remember these words. Older adults may show deficits in more automatic encoding of words and values but may offset these impairments by engaging in more strategic, effortful encoding of higher-value words. Specifically, Knowlton and Castel (2022) describe that more automatic processes and forms of incidental learning may be most affected by aging, but that older adults can utilize more strategic, effortful and intentional encoding to selectively remember high-value information, often at the expense of less important information.

While healthy older adults generally possess intact value-based memory prioritization on value-directed remembering tasks that engage reward-based learning through strategic encoding (see Knowlton & Castel, 2022), older adults tend to suffer from deficits on directed forgetting tasks – when one is instructed to forget certain information (e.g., Anderson & Hanslmayr, 2014; MacLeod, 1998). Directed forgetting can rely on either a change in mental context for information that should be remembered versus forgotten (Abel & Bäuml, 2017; Sahakyan & Kelley, 2002) and/or intact inhibitory mechanisms that guide one away from remembering information that is paired with “forget” instructions (Geiselman et al., 1983), and these inhibitory mechanisms tend to decline with age (e.g., Eich et al., 2021; Titz & Verhaeghen, 2010; Zacks et al., 1996). Thus, inhibitory control may be impaired, leading to recall of outdated and no longer relevant information in some situations.

Older adults may display deficits in remembering associated details and context when engaging in value-directed remembering, which could reflect a cognitive control mechanism that orients attention towards task-relevant high-value items and away from less relevant information (Hennessee et al., 2018). Thus, while value-directed remembering may enhance episodic encoding in both young and older adults, valuable items may suffer a reduction in the binding of associated details compared to less valuable items, especially in older adults. This may be due to an associative memory deficit in older adults (e.g., Castel & Craik, 2003; Naveh-Benjamin et al., 2007) that impairs the linking of items and their associated value. Hence, as older adults often display deficits in remembering associations, such as names and faces (Naveh-Benjamin et al., 2004), and may exhibit heightened forgetting and interference from prior valuable information (Murphy & Castel, 2022a), older adults may have difficulty learning value status if it is revealed after a delay in time.

In terms of strategies used to remember important information, both young and older adults report using both maintenance rehearsal strategies (e.g., rote repetition) and elaborative rehearsal strategies (e.g., mental imagery, sentence generation, and relational processing) to selectively remember high-value information (Ariel et al., 2015; Hennessee et al., 2017), with both young and older adults engaging areas of the brain associated with more semantic processing of words (i.e., semantic network activity involved in imagery) when selectively encoding high-value words (Cohen et al., 2014; Cohen et al., 2016). Despite age-related memory decline (Old & Naveh-Benjamin, 2008a, 2008b; Rönnlund et al., 2005; Spencer & Raz, 1995; Trelle et al., 2020) and increased unintentional forgetting (Maylor, 1993, 1996), healthy older adults tend to exhibit equivalent (or sometimes even superior) value prioritization relative to younger adults (Ariel et al., 2015; Castel et al., 2002, 2013; Siegel & Castel, 2018a; Spaniol et al., 2014). Yet, older adults also exhibit declines in cognitive control, as is evidenced by less effective top-down, goal-directed selectivity of to-be-forgotten or less valuable information than is typically shown in younger adults (Bowen et al., 2020; Gallant et al., 2018; Sahakyan et al., 2008; Titz & Verhaeghen, 2010; Zacks et al., 1996).

In most studies using the value-directed memory paradigm, the value-structure (e.g., a higher number indicates a more valuable word) was defined *before* to-be-remembered information was presented. What happens if the value information is only revealed or learned after items are already encoded? When no specific goal state is defined *a priori*, a participant's attention may be more evenly allocated across all items instead of selectively focusing on certain items during encoding (i.e., as a function of each item's associated value). When some of these learned items are later flagged as being more valuable than others, will people be able to engage in value-directed remembering, and would older adults have particular difficulty under these conditions? Critically, evaluating and selectively prioritizing to-be-learned information at the time of study can take a much different form in that time- and attentional-resources can be selectively prioritized towards the most valuable content, with fewer resources dedicated to the encoding of less valuable content (to limit cognitive load prior to the test).

It is evident that cognitive control mechanisms guiding learning and the subsequent expression of knowledge could hypothetically vary widely depending on *when* the value of information is made aware to an individual, and this may yield age-related impairments, given age-related deficits in associative memory and cognitive control for older adults. Knowlton and Castel (2022) suggest that automatic processes/incidental learning may be impacted by aging such that, compared to their young adult counterparts, older adults may not be able to as effectively engage cognitive control mechanisms that use value-based goals instantiated after initial learning to direct memory search and prioritize memory expression based on these post hoc item-value associations. Additionally, proactive interference (in which the prior encoding of similar information impairs current memory recall) may disproportionally impact older adults (Lustig et al., 2001) when learning the value of information after a period of time, suggesting that there may be several factors which need to be overcome by more strategic memory processes to successfully express knowledge as a function of its value in older age. Altogether, this provides an argument for why older adults may have more difficulty than younger adults with utilizing post-encoding value instructions to guide remembering.

When one learns that certain information is important only *after* encoding it, the accurate retrieval of this now high-value information may not necessarily be enhanced, as one may need to know the value during encoding in order to enhance later memory expression. In addition, people might incorrectly assume learning that information is important only after the fact can enhance memory for that information, when in fact learning the value, and enhancing motivation, after the fact has little effect on how well one can effortfully recall the earlier information (Kassam et al., 2009), although, this has not been examined in older adults. Thus, at least in young adults, there is evidence that reward at encoding, but not at retrieval, enhances memory for detailed events – likely driven by an attentional processing mechanism (da Silva Castanheira et al., 2022). Older adults, due to deficits in cognitive control, may be particularly at risk in situations when interference can influence memory for high-value information (Murphy & Castel, 2022a), such as when learning multiple lists where the value is only revealed after the initial encoding session. Interference may be particularly relevant if the value is only learned following a delay after encoding, as for older adults especially, the presence of interfering material could impair binding of values with the specific information learned earlier. With multiple words that could later be paired with each value, interference could arise in terms of linking the words with the specific values. Older adults may only be able to show value-based memory enhancements when strategic encoding can be used (as opposed to more automatic encoding) by allowing for learning the value of information during the initial encoding episode, and not when there is a delay before the value is learned as this may give rise to interference from prior information.

In the current set of experiments, we used a modified value-directed remembering paradigm to investigate whether typical value selectivity effects emerged when the value instructions were given *after* the encoding of to-be-learned information, compared to the standard condition when value instructions were provided prior to encoding. Of particular interest was whether aging differentially impacts value-based memory selectivity behavior across these two conditions. If typical value-based selectivity effects on memory performance are still observed in conditions where the importance of information is only known after encoding, it may suggest more flexible memory behavior arising from stably maintained associative memory traces of previously learned information and value cues, with an ability to operate a learned, goal-relevant value structure over the reinstated associative traces. Conversely, if typical memory selectivity effects are diminished when the task goal is not made aware to participants prior to encoding, this might implicate the utility of top-down, goal-directed selective encoding strategies that focus on memory for high-value information – based on knowing the relevance of value *a priori* – in facilitating typical value-directed remembering effects in standard paradigms where item-values are paired with the to-be-learned information at encoding; hence, associative value information may not be salient enough to be captured by more automatic, bottom-up cognitive control mechanisms in the absence of a goal prior to learning, and this may especially lead to the observation of age-related impairments in older adults.

Here, we consider that interactions between bottom-up, automatic (e.g., via reward saliency), and top-down, strategic (e.g., selective elaborative rehearsal) attentional cognitive control mechanisms during encoding, along with retrieval mechanisms (e.g., inhibition), possibly facilitate *pre-learning-invoked* goal-directed value-based associative memory prioritization, which may not be effectively engaged to the same extent when value-directed goals are absent *before* learning value-item associations. Thus, while bottom-up effects of value on memory likely contribute to value-directed encoding and retrieval of information, top-down, controlled processing of valuable information is another factor contributing to selective memory effects. Given age-related impairments in automatic processes facilitating encoding of high-value information, under some circumstances, older adults may be able to use strategic control to focus on high-value information during learning and thus selectively remember the higher-value items at test (Knowlton & Castel, 2022); we were particularly interested in if and how older adults may be able to engage selectivity when value was learned only after encoding a list of items.

In Experiment 1, young and older adult participants were given a single list of words, where each word was paired with a point value ranging from 1 to 10. Instructions to maximize their score (a summation of the points associated with correctly remembered words) were provided either before (i.e., pre-encoding instructions) or after (i.e., post-encoding instructions) the word list, or not at all (i.e., no value instructions). Thus, unlike the pre-encoding condition, participants in both the post-encoding and no value instruction condition did not receive any value instructions *prior to* the word list presentation, and were simply told that each word would be followed by a number ranging from 1 to 10. After study, participants were given a free recall test to assess their memory performance. We used a single-list design in Experiment 1 given that following the completion of one study-test cycle, participants would no longer be unaware of the critical value manipulation (i.e., we could not change the intrinsic value of a low-value number to then represent a high-value number). We therefore designed a different version of the task that could accommodate multiple study-test cycles by defining word-values by a perceptual feature instead of numerically: In Experiment 2, multiple lists were given, and the value structure was changed to a categorical form with words being either low, medium, or high in value as indicated by their font color. After completing a four-list block in which no mention of color-relevance was made, participants completed counterbalanced blocks of four pre-encoding lists and four post-encoding lists in which the color-value key denoting which font color represented which value (e.g., BLUE – HIGH, GOLD – MEDIUM, RED – LOW) was shown either before the word list presentation or after it, respectively. In both experiments, we examined participants' overall memory performance, as measured by the proportion of words correctly recalled, as well as their ability to prioritize words based on their memory performance as a function of value.

Experiment 1

In Experiment 1, an online sample of young and older adults completed one list of a modified value-directed remembering task (e.g., Castel et al., 2002). Participants were sequentially presented with 20 words randomly selected from a larger pool, with each word randomly paired with point values 1 through 10, with two words assigned to each point value. Participants were randomly assigned to either a pre-encoding, post-encoding, or no value instruction (control) condition, and were tested on their memory for the words with the goal of maximizing their point value (in the pre-encoding and post-encoding value instruction conditions) or simply remembering as many words as possible (in the no value instruction condition).

We expected that both young and older adult participants in the pre-encoding condition would be selective towards high-value words, replicating past findings (Castel et al., 2002, 2012; Middlebrooks & Castel, 2018; Stefanidi et al., 2018), but that those in the post-encoding condition would be significantly less selective. We also predicted that participants who did not receive value instructions (i.e., the control group) would exhibit no effect of value on memory, since the numbers themselves did not contain any inherent value with participants being unaware of their meaning. Regarding age group differences, we predicted that the difference in selectivity between the pre-encoding and post-encoding conditions would be larger in older relative to younger adults, as older adults may rely more on strategic encoding processes to selectively remember information (Castel et al., 2013) and thus may be more negatively impacted when the ability to engage in these strategies is reduced.

Method

Transparency and Openness

The deidentified data on which the study conclusions are based, the analytic code necessary to reproduce analyses, the materials used in this study, and the preregistration of the study design, hypotheses, and analytic plan are freely available on OSF (identifier: qfg54; link provided in the Author Note; Schwartz et al., 2022). There were some departures from the original preregistered plan based on new analytic knowledge gained between the time of originally writing the preregistration and analyzing the data. All manipulations and measures are reported, except for recall output order, which we do not report due to a technical error in the design that prevented us from analyzing this measure.

Participants

An *a priori* power analysis was conducted using G*Power 3.1 (Faul et al., 2009). A between factors analysis of variance (ANOVA) with 2 groups (age: *young, older*), 3 measurements (value instruction: *pre-encoding, post-encoding, no instruction*), .5 correlation among repeated measures, $\alpha = .05$, and a large effect size of Cohen's $f = .40$ indicated a sample size of about 20 participants per group (about 120 participants total) would be needed to achieve .95 power. To account for potential exclusions, we aimed to collect 30 participants per group ($n_{older} = 90$, $n_{young} = 90$; total $N = 180$).

Participants were recruited using Prime Panels from CloudResearch (www.cloudresearch.com). Like other online data collection platforms like Amazon Mechanical Turk, Prime Panels allows for researchers to target and collect large, diverse samples of young and older adult participants in a way that is both time and resource efficient (e.g., Chandler et al., 2019; Huff & Tingley, 2015; Murphy & Castel, 2022a; Silaj et al., 2021; Whatley et al., 2020). Upon consenting to participate in the experiment, young and older adults were randomly assigned to one of three between-subjects conditions: pre-encoding, post-encoding, and no instruction (control).

Our data collection resulted in $N = 344$ participants (pre-encoding: 52 older and 61 young, post-encoding: 59 older and 58 young, no instruction: 57 older and 57 young). We made exclusions based on residency outside the United States, ages outside the pre-registered range, insufficient web browser focus (i.e., less than 75% of time spent on the browser page during the experiment session), recall performance (not outputting a single word during test or recalling all words correctly indicating likely use of an external aid), and explicit report of using an external aid, resulting in the following exclusions: residency (2 older, 8 young), age (9 young), focus (5 older, 4 young), no recall output (6 older, 15 young), perfect recall performance (1 young), and external aid usage (1 older, 1 young).

The final sample comprised 154 older adults ($n_{pre\text{-}encoding} = 46$, $n_{post\text{-}encoding} = 54$, $n_{no\ instruction} = 54$) and 138 young adults ($n_{pre\text{-}encoding} = 47$, $n_{post\text{-}encoding} = 45$, $n_{no\ instruction} = 46$)[1]. Older adult participants ranged in age from 60 to 89 years ($M_{age} = 67.77$, $SD_{age} = 5.42$, $n_{female} = 73$) and young adult participants ranged in age from 18 to 29 years ($M_{age} = 24.33$, $SD_{age} = 3.50$, $n_{female} = 71$, $n_{other} = 1$). There was no difference in self-reported income between young and older adults, $t(289.95) = 1.48$, $p = .14$, Cohen's $d = .17$[2], but older adults reported higher levels of education, $t(286.74) = 3.64$, $p < .001$, Cohen's $d = .43$[3], compared to young adults.

Materials

A list of 20 concrete noun and verb words were used as the materials for the current study (e.g., alley, journal, ride). Each list contained words ranging in length from four to seven letters ($M = 4.99$, $SD = .98$). These words ranged from 5.48–12.65 and averaged a score of 8.81 ($SD = 1.57$) on the log-transformed Hyperspace Analogue to Language (HAL) frequency scale (Balota et al., 2007). Lower values on the HAL indicate lower frequency in the English language, with higher values indicative of higher frequency. To avoid specific item effects, 20 words were randomly drawn from a larger pool of 280 words for each participant, and this same pool has been used in past work (e.g., Middlebrooks, Kerr, et al., 2017; Siegel & Castel, 2019). The 20 sampled words were then randomly assigned to a list position and randomly paired with a point value from 1 to 10, with two words paired to each point value, resulting in a randomly ordered list of 20 words paired with point values (two 1-point items per list, two 2-point items, etc.). As such, word selection, list placement, point value allocation, and point value order were completely randomized for each participant. To illustrate, while one participant may have been presented with the word "alley" worth 3-points in the fourth serial position, another participant may have been presented with "alley" worth 9-points in the thirteenth serial position; further, a third participant may not have been presented with the word "alley" at all.

Procedure

Participants were randomly assigned to be in one of three conditions: pre-encoding, post-encoding, or no instruction. Participants first provided informed consent and demographic information prior to receiving task instructions that they would be shown a list of 20 words. Their goal was to remember as many words as possible. Participants in the pre-encoding value instruction condition were then told that each word would be paired with a point value ranging from 1 to 10 and that there would be two words at each point value. They were then instructed that they would receive the points associated with a correctly remembered word, and that their goal was to earn as many points as possible (a sum of all the points associated with correctly recalled words). They were also told that they would not be penalized for misremembering words, so if they were not sure, they knew to try and recall all words to the best of their ability. Participants in the other two conditions (post-encoding, no instruction) did not receive these value instructions prior to word list presentation. Instead, they were

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[1] Self-reported race for young (American Indian/Alaskan Native: 3.62%, Asian/Pacific Islander: 4.35%, Black: 16.67%, White: 69.57%, Other/Unknown: 5.80%) and older (American Indian/Alaskan Native: <1%, Asian/Pacific Islander: 0%, Black: 4.55%, White: 94.16%, Other/Unknown: <1%) adults.

[2] Self-reported income for young ($0-$24,999: 22.46%, $25,000-$49,999: 26.09%, $50,000-$74,999: 25.36%, $75,000-$99,999: 13.04%, $100,000-$124,999: 5.80%, $125,000-$149,999: 3.62%, $150,000+: 3.62%) and older ($0-$24,999: 18.18%, $25,000-$49,999: 26.62%, $50,000-$74,999: 21.43%, $75,000-$99,999: 15.58%, $100,000-$124,999: 5.84%, $125,000-$149,999: 6.49%, $150,000+: 5.84%) adults.

[3] Self-reported education for young (Some High School: 2.17%, High School Graduate: 29.71%, Some College/No Degree: 27.54%, Associate's Degree: 7.25%, Bachelor's Degree: 24.64%, Graduate Degree: 8.70%) and older (Some High School: <1%, High School Graduate: 17.53%, Some College/No Degree: 20.13%, Associate's Degree: 14.94%, Bachelor's Degree: 27.27%, Graduate Degree: 19.48%) adults.

told that each word would be followed by a number ranging from 1 to 10. All other instructions were identical.

During the study phase, each word-point pair was presented on the screen for 3 s each (totaling of 60 s for the entire list). When the study time elapsed for the final word, participants in the post-encoding condition were told that they would receive the points associated with a correctly remembered word, and that their goal was to earn as many points as possible, before they proceeded to the recall phase after 15 s. To equate the time in the period between study and test across conditions, participants in the pre-encoding condition and no instruction condition were shown a message saying that the task was *"loading" and to not refresh the page* for 15 s before advancing to the recall phase. The recall phase was identical for all three conditions. Participants were asked to type as many words as they could remember into a text box and that they only had to recall the word, not the number that it was paired with. Participants had 90 s total to output words and were allowed to move to the subsequent feedback screen by pressing the "next" button after at least 30 s had elapsed if they were no longer able to recall any additional words. Participants in the pre- and post-encoding conditions were then shown their point score out of a total 110 possible points. All participants were then asked whether they relied solely on their memory to complete the task, or if they utilized an external aid (e.g., a piece of paper and pen). All materials and procedures used in the current study were approved by the University of California, Los Angeles (UCLA) Institutional Review Board (IRB; "Memory, Attention, Emotion, and Aging" Protocol: #12–000617).

Results

We first analyzed overall memory accuracy between age groups and conditions using ANOVAs. Then, prioritization ability was examined in two different ways. We examined prioritization ability as a function of the relationship between item value and recall probability using multilevel modeling, as in prior related work (e.g., Middlebrooks, Kerr, et al., 2017; Middlebrooks et al., 2016; Siegel & Castel, 2018a, 2018b, 2019). This approach allowed us to examine if the relationship between value and recall varied as a function of age group and instruction condition while considering potential within-subject differences. We also used the selectivity index (SI; Castel et al., 2002), which provides a measure of participants' ability to prioritize high-value over low-value information; however, given limitations by which using the SI potentially introduces bias based on the number of words recalled (see Castel, 2008 for a discussion), we present the multilevel modeling results here as a more robust estimate of value-based prioritization. SI analyses (and associated figures) for Experiments 1 and 2 mostly converged with the findings from the item-value analyses presented here and can be found in the online Supplemental Materials.

All analyses and figures were conducted and generated in *R* (Version 4.1.1; R Core Team, 2021). ANOVAs were fit using `lmer` function from the *lme4* package (Bates et al., 2015), in the case of repeated-measures, or the `lm` function otherwise. *F* tests were conducted using the `joint_tests` function from the *emmeans* package (Lenth, 2021). Effect sizes were computed using the *effectsize* package (Ben-Shachar et al., 2020). Multilevel modeling was conducted using the *lme4* package (Bates et al., 2015), and the *sjPlot* (Lüdecke, 2021) package was used to compute odds ratios and generate the tables of model parameters presented in the Results.

Bayes factors (BF) were computed using the *BayesFactor* package (Morey & Rouder, 2021) with default priors ($\frac{\sqrt{2}}{2}$; Morey & Rouder, 2011) and 10,000 Monte Carlo simulations, and are reported as BF_{01} when evidence favors support for the null hypothesis, and BF_{10} when evidence favors support against the null hypothesis. We complement traditional null hypothesis significance testing with BFs for ANOVAs and *t*-tests to assess the relevant strength of evidence in support of or against the null hypothesis and aid the interpretation of our findings (Rouder et al., 2016; see Wagenmakers et al., 2018a, 2018b for a review of the benefits of using a Bayesian statistical approach in psychology research). BFs can generally be interpreted using the following classifications: $1 < BF \leq 3$ is *anecdotal* evidence, $3 < BF \leq 10$ is *moderate* evidence, $10 < BF \leq 30$ is *strong* evidence, $30 < BF \leq 100$ is *very strong* evidence, and $BF > 100$ is *extreme* evidence for H (Jeffreys, 1961; Lee & Wagenmakers, 2013).

Overall Memory

Few differences in overall memory performance were observed (Figure 1). A 2 (age group: *older, young*) × 3 (value instruction: *pre-encoding, post-encoding, no instruction*) between-subjects ANOVA[4] on recall accuracy (the proportion of words out of 20 correctly recalled) revealed no main effect of age group, $F(1, 286) = .03$, $p = .87$, $\eta_p^2 < .001$, $BF_{01} = 10.71$, no main effect of instruction condition, $F(2, 286) = .07$, $p = .93$, $\eta_p^2 < .001$, $BF_{01} = 47.39$, and no interaction, $F(2, 286) = .40$, $p = .67$, $\eta_p^2 = .003$, $BF_{01} = 9148.10$. Averaged across age group and instruction conditions, participants correctly recalled 24.5% of the list (approximately 4.9 words out of 20 possible). This analysis suggests that the value instruction condition did not influence the number of words participants recalled overall, and that older adults were equally as accurate in their memory as young adults were.

Recall by Value

We analyzed participants' recall accuracy as a function of item value employing a multilevel modeling approach (see Figure 2). Here, we accounted for both within- and between-subjects effects by first clustering recall data within each participant (level-1) and then examining the between-subjects factors of age group and value instruction condition (level-2). For a lengthier discussion of multilevel modeling (also known as hierarchical linear modeling or HLM) in this context, see Middlebrooks, Kerr, et al. (2017) and Siegel and Castel (2018a).

In a two-level logistic model, recall probability (using a binomial distribution, 0 = not recalled, 1 = correctly recalled) was modeled as a function of item value (level-1), age group (level-2), and value instruction condition (level-2). Item value was entered into the model as a group-mean centered variable (with item value anchored at the mean value of 5.5). The age groups (0 = young adults, 1 = older adults) and value instruction (0 = pre-encoding, 1

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[4] Formula: recall ~ 1 + age*instruction

= post-encoding, 2 = no instruction) were included as level-2 dummy-coded predictors. In this analysis, young adults were treated as the reference group for the age group predictor, and the pre-encoding condition was the reference group for the value instruction predictor. Further, given that the logistic model returns predictor estimates in logit units, which here would be the log odds of correct recall, we report exponentiated estimates, which are an odds ratio (*OR*). We report the *OR*s for the model as non-transformed estimates from a logistic regression are not directly interpretable (Norton et al., 2018). The *OR*s presented here thus represent the ratio of the probability that a word is correctly recalled to not recalled, with *OR*s > 1 indicating increased likelihood of recall and *OR*s < 1 indicating decreased likelihood of recall.

As shown in Table 1, there was no effect of value on recall accuracy for young adults in the pre-encoding condition, *OR* = 1.03, 95% CI = [.97, 1.10], *p* = .28. The lack of a value-recall relationship for young adults in the pre-encoding condition was consistent for young adults in the post-encoding condition, *OR* = 1.01, 95% CI = [.93, 1.10], *p* = .78, and in the no instruction condition, *OR* = .96, 95% CI = [.89, 1.05], *p* = .39, as indicated by a lack of significance of the dummy-coded comparison predictors. However, the effects of value significantly differed for older adults, as indicated by an interaction between the age group and value predictors, *OR* = 1.13, 95% CI = [1.04, 1.23], *p* = .005. Older adults had a positive effect on recall accuracy in the pre-encoding condition (see Figure 2B), which was obtained by reconfiguring the model to make them the reference group for the age variable, *OR* = 1.17, 95% CI = [1.10, 1.24], *p* < .001 (not shown in Table 1). For the effect of value on recall accuracy in the different instruction conditions for older adults, these too differed from young adults, as indicated by significant interactions between value and the predictors comparing the pre-encoding and post-encoding conditions, *OR* = .84, 95% CI = [.75, .95], *p* = .005, and the pre-encoding and no instruction conditions, *OR* = .88, 95% CI = [.78, .99], *p* = .03, respectively. When coding older adults as the reference group, value was significantly less predictive of recall accuracy in both the post-encoding, *OR* = .85, 95% CI = [.78, .93], *p* < .001, and no instruction conditions, *OR* = .85, 95% CI = [.78, .92], *p* <.001, relative to the pre-encoding condition.

In sum, these results suggest that young adults' memory was not sensitive to point value in any of the three encoding conditions, while older adults prioritized high-value words, but only when receiving value instructions prior to encoding. We provide convergent results using SI scores in the online Supplemental Materials.

Discussion

Results from Experiment 1 were largely consistent with our predictions. However, there were no differences in the overall number of words recalled between age groups or value instruction conditions. Older adults here performed just as well as their young adult counterparts but were significantly more selective in the pre-encoding instruction condition relative to the post-encoding and no instruction conditions, as evidenced by the analyses examining recall as a function of value and the selectivity index (Supplemental Materials). This suggests that older adults may be particularly reliant on strategic encoding processes to selectively remember information (Castel et al., 2013) and were negatively impacted when the ability to engage in these strategies was reduced (i.e., post-encoding and no instruction conditions). In other words, these older adults appeared to recall items without regard to their value, evidencing the possibility that they were unable to retroactively select and bring online associations between important values and words during retrieval.

To investigate and substantiate this account directly, a future study should directly test participants' ability to remember the actual values associated with each word following the free recall retrieval phase; this could either take the form of a cued recall test, where participants provide the numerical value they remembered being associated with that word during encoding, or an *n*-AFC recognition test where participants indicate which value of *n* choices was the actual value associated with that word during the initial encoding phase. These data would reveal the mnemonic integrity of the value information associated with the learned items, and could also be used to exclude participants who, for example, failed to indicate the items' values above chance levels.

Younger adults were not selective in any of the encoding conditions. It is not unusual for young adults to display minimal selectivity after only one trial of a value-directed remembering task. Contrary to the older adults in this study whose selective behavior in this task may have been guided by strategies to counteract a metacognitive belief that they cannot remember all the items (Knowlton & Castel, 2022), young adults may instead be overconfident and thus operate on the reversed belief that they can remember all the items. Prior investigations of value-directed remembering in young adults have used multiple study-test cycles, to invoke selective memory behavior as a function of increased task experience, as they become more aware that they cannot remember all of the presented, to-be-learned items at encoding and thus refine their strategy use based on the performance feedback they receive following each study-test cycle (Ariel, 2013; Castel et al., 2012; Middlebrooks, Kerr, et al., 2017; Robison & Unsworth, 2017; Siegel & Castel, 2018b). As there was only one study-test phase in Experiment 1, it is possible that the young adult participants did not yet adapt their strategy implementations towards a selective approach prioritizing high- over low-value information.

An alternative, albeit speculative, explanation for age-group differences in selectivity for the pre-encoding condition may instead concern the sampling of participants. Although both young and older adult participants were sampled from a US population online, older adults did report higher levels of education overall, which may reflect a sampling bias in the effort and engagement in the task between young and older adults, in addition to explaining why there were no age-group differences in recall accuracy between young and older adults. Considering this potential limitation in our sample, in addition to the natural limitation of this single list design, it was challenging to determine how selectivity changes as a function of value instruction condition without additional data. Thus, we refined our assay of value-based selectivity using multiple trials in a modified value-directed remembering paradigm for Experiment 2. Here, we aimed to tease apart differences in selectivity (or a lack thereof) between the pre- and post-encoding value instructions in a new sample of young and older adults by utilizing *multiple* lists, each with novel value structures that changed from list to list.

Experiment 2

We conducted a second experiment which included a series of multiple, unique word lists to investigate younger adults' lack of selectivity when value instructions were provided prior to encoding in Experiment 1. Prior work examining prioritization of information in memory has shown increased task experience (i.e., practice across multiple lists) to increase selectivity, which is likely due to a variety of factors such as increased familiarity with the task, trial-and-error learning of different strategies' effectiveness, and explicit feedback on performance provided after each list (Ariel, 2013; Castel et al., 2012; Middlebrooks, Kerr, et al., 2017; Robison & Unsworth, 2017; Siegel & Castel, 2018b). The need for multiple lists to yield selective memory effects may especially be the case when information is presented sequentially (Middlebrooks & Castel, 2018; Siegel & Castel, 2018a), as this presentation format may make value-based strategy execution more difficult relative to a simultaneous study format (Ariel et al., 2009; Dunlosky & Thiede, 2004; Middlebrooks & Castel, 2018; Robison & Unsworth, 2017).

We hypothesized that both young and older adults would demonstrate effective prioritization in memory when aware of value prior to encoding, but that both groups would still lack selectivity effects when removing the influence of encoding strategies by providing value conditions *after* encoding had already occurred. To incorporate multiple lists without sacrificing participants naiveté towards the meaning of value, we were unable to use explicit point values to indicate the relative importance of a word item. To illustrate, after the presentation of the first list, it would be evident on post-encoding value instruction condition lists that they should prioritize high-value information during encoding. Thus, we changed the value structure to a categorical format with words being of either low, medium, or high value according to the font color in which they were presented. By using font color as the indicator of word value, we were able to change which color represented which value from list to list. That is, on one list red words may have indicated high value, whereas on other lists they may have indicated medium or low value. The "key" designating the color-value combinations for a particular list was shown either before list presentation (i.e., pre-encoding value instructions) or after (post-encoding value instructions). The format of this paradigm ensured that when completing post-encoding lists, participants would not be aware of which color represented each value until they were shown the value key following the encoding of the words. Using this approach, we aimed to minimize the role of value-based encoding strategies on subsequent memory performance for post-encoding trials such that, to effectively maximize their point score at retrieval, both young and older participants would need to stably encode both the word item and its associated color. For pre-encoding lists, on the other hand, participants were aware of the value structure prior to word presentation and could thus engage in study strategies based on the known value (i.e., the color) of words.

Value instruction condition in Experiment 2 was manipulated within-subjects. All participants first completed four blocks of studying unique word lists and completing recall tests with no mention of value (despite words being presented in different colors). We considered this to be the no value instruction "control" condition. Then, in a counterbalanced fashion, participants completed four blocked lists of the pre-encoding condition, in which the value key was shown before study, and four blocked lists of the post-encoding condition, in which the value key was shown after study and before test. Each list contained a unique set of 18 words that were present on no other list and, on each list of 18 words, a third represented low value, a third represented medium value, and a third represented high value. To provide value-based performance feedback after each non-control trial, these value categories were assigned to 1 point, 5.5 points, and 10 points, respectively, for each correctly remembered word. To reduce potential interference (i.e., participants not remembering whether red words were high or low value on the current list), we used two different color trios that alternated from list to list.

Critically, we implemented a manipulation check after each non-control testing trial to ensure participants accurately understood the value structure on each list: participants were asked to indicate which color represented which value on the prior list. This was especially important to monitor in older adults, who have trouble task switching relative to young adults (for a review, see Kray & Ferdinand, 2014).

Method

Transparency and Openness

The deidentified data on which the study conclusions are based, the analytic code necessary to reproduce analyses, and the materials used in this study are freely available on OSF (identifier: qfg54; link provided in the Author Note; Schwartz et al., 2022). There were some departures from the original preregistered plan based on new analytic knowledge gained between the time of originally writing the preregistration and analyzing the data. All manipulations and measures are reported, except for recall output order, which we do not report due to a technical error in the design that prevented us from analyzing this measure.

Participants

An *a priori* power analysis was conducted using G*Power 3.1 (Faul et al., 2009). A within-between factors ANOVA with 2 groups (age: *young, older*), 8 measurements (4 *pre-encoding* trials, 4 *post-encoding* trials), .5 correlation among repeated measures, nonsphericity correction of 1, $\alpha = .05$, and an effect size of Cohen's $f = .15$ (the primary effect size of interest obtained in Experiment 1) indicated a sample size of 62 participants per group (total $N = 124$) would be needed to achieve .95 power. Similar to Experiment 1, we aimed to collect data from 90 non-colorblind participants per group ($n_{older} = 90$, $n_{young} = 90$; total $N = 180$) to account for potential exclusions.

Non-colorblind (self-reported) participants were recruited using Prime Panels from CloudResearch. Upon consenting to participate in the experiment, young and older adults were randomly assigned to one of two counterbalanced block orders: (1) control, pre-encoding, post-encoding, or (2) control, post-encoding, pre-encoding.

Our data collection resulted in $N = 177$ participants ($n_{older} = 90$, $n_{young} = 87$). None of the participants in Experiment 1 participated in Experiment 2. The same exclusion criteria were used as those in Experiment 1, resulting in the following exclusions: age outside desired range (1 older, 1 young), focus (2 older, 9 young), recall performance greater than 2.5 SDs above the mean (4 older), and external aid usage (6 older, 10 young).

The final sample consisted of 77 older and 67 young non-colorblind adults (total $N = 144$)[5]. Older adult participants ranged in age from 60 to 90 years ($M_{age} = 69.87$, $SD_{age} = 6.44$, $n_{female} = 45$) and young adult participants ranged in age from 18 to 29 years ($M_{age} = 23.42$, $SD_{age} = 3.04$, $n_{female} = 40$, $n_{other} = 1$). Similar to Experiment 1, older adults reported higher levels of education than young adults, $t(137.53) = 2.05$, $p = .042$, Cohen's $d = .34$[6]. Income information was not collected from participants in this experiment.

Materials

The same word stimuli from Experiment 1 were used in Experiment 2. Given there were now 12 lists for each participant, 216 words were randomly sampled from the same 280-word pool used in Experiment 1 for each participant (18 words per list). The 216 selected words were then randomly assigned to a list and serial position and were randomly paired with a value category (low, medium, high), with six words in each value category per list. As such, word selection, list placement, value category allocation, and value category order were completely randomized for each participant. To illustrate, while one participant may have been presented with the word "journal" as a low value word printed in red font in the fourth serial position of the first list, another participant may have been presented with "journal" printed in blue font as a high value word in the seventeenth serial position of the eighth list; further, a third participant may have not been presented with the word "journal" at all.

Procedure

Participants were randomly assigned to one of the two counterbalanced orders: (1) control, pre-encoding, post-encoding, or (2) control, post-encoding, pre-encoding. Participants first provided informed consent and demographic information prior to completing the four no value instruction (control) instruction lists. For these initial control trials, participants were instructed that they would be shown a list of 18 words with their only goal being to remember as many words as possible – the instructions made no mention of word value or color. During the study phase, each word was presented on the screen sequentially for 3 s each (for a total of 54 s for the entire list). Lists contained words printed in one of two color trios: (i) *blue-red-gold* and (ii) *green-orange-purple*. The color trios alternated from list to list, resulting in six lists of each color trio (two of each within each value instruction condition). To equate the time in the periods before study on control trials with the timing of viewing the value structure key in pre-/post-encoding trials, participants were shown a message during control trials saying that the task was *"loading" and to not refresh the page* for 8 s before advancing to the recall phase. Additionally, all trials – regardless of condition

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[5] Self-reported race for young (American Indian/Alaskan Native: 1.49%, Asian/Pacific Islander: 13.43%, Black: 23.88%, White: 53.73%, Other/Unknown: 7.46%) and older (American Indian/Alaskan Native: 0%, Asian/Pacific Islander: 0%, Black: 5.19%, White: 94.81%, Other/Unknown: 0%) adults.

[6] Self-reported education for young (Some High School: 0%, High School Graduate: 25.37%, Some College/No Degree: 17.91%, Associate's Degree: 16.42%, Bachelor's Degree: 29.85%, Graduate Degree: 10.45%) and older (Some High School: 0%, High School Graduate: 14.29%, Some College/No Degree: 15.58%, Associate's Degree: 15.58%, Bachelor's Degree: 36.36%, Graduate Degree: 18.18%) adults.

– contained a similar loading message in the period proceeding recall feedback before the next study trial. Similar to Experiment 1, participants were then asked to type the words they could remember in the displayed text boxes; they had 90 s to output words and could advance to the next trial by pressing the “next” button when they finished recalling words after at least 30 s had elapsed if they were no longer able to recall any additional words.

After completing the four control lists, participants were instructed that words would be worth particular values as denoted by the color in which they were printed for all subsequent lists. They were told that words would fall into one of three categories: low value (1 point), medium value (5.5 points), or high value (10 points) and that they would receive the points associated with a correctly remembered word, with the goal of earning as high a total point score as possible. Participants were further instructed that there were six words of each value category on each list and were shown an example of a potential color-value key with the caveat that the combinations would change from list to list (see Figure 3A). Crucially, participants were then told that, for some lists, they would know the value of each color *before* beginning the list, while for others, they would only view the color-value key *after* studying the list. They were also shown each of the color trios to familiarize them with the colors in which words would be printed (see Figure 3B).

Next, participants completed four blocked lists of the pre-encoding value instruction condition and four lists of the post-encoding value instruction condition, in accordance with the randomly assigned counterbalanced order (i.e., some participants instead completed four lists of the post-encoding value instruction condition before completing four lists of the pre-encoding value instruction condition). On the pre-encoding lists, the value key was shown for 8 s prior to presentation of the first word; on the post-encoding lists, the value key was shown for 8 s following the presentation of the last word. To equate time between study and test in each condition, on pre-encoding lists, the session loading message was shown for 8 s between the final word presentation and recall phase, as well as for 8 s before encoding phase list presentation on post-encoding lists. The recall phase for pre- and post-encoding trials was identical to the recall phase in the control trials. After submitting their recalled responses, participants were shown their total score out of 99 possible points.

Following the recall phase of both the pre- and post-encoding condition lists, we assayed participants’ memory for the color-value combination for that list. Participants were asked to select the color that corresponded to each of the three possible value categories (i.e., high, medium, or low). After completing the 12 total study-test phases, all participants were asked whether they relied solely on their memory to complete the task or if they utilized an external aid (e.g., a piece of paper). After responding to this question, the experiment was completed. All materials and procedures used in the current study were approved by the UCLA IRB (“Memory, Attention, Emotion, and Aging” Protocol: #12–000617).

Results

Here, we excluded lists for which at least one of the three color-value combinations that participants identified for that list was incorrect, to isolate pre- and post-encoding lists for which participants accurately identified the color-value combinations (e.g., a participant indicated that green was high-value on the just completed list when in fact it was medium-value, but correctly identified the other two color-value combinations). Performance was then averaged across the valid (100% color check accuracy) lists – to be certain that participants knew the precise value structure on trials submitted to each analysis – in each value instruction condition. All lists in the control condition were included since there was no color-value accuracy check on these lists.

Control trials were not analyzed as a function of value since there was no inherent value of the different colors at this point in the experiment, contrasting analyses of Experiment 1, where we analyzed memory performance in the no instruction condition as a function of numerical point values, to investigate potential incidental memory performance benefits from temporally and spatially proximate numerical cues devoid of any value-based context.

Here, we first analyzed color-value identification accuracy between value instruction conditions and age group. Next, we analyzed selectivity index scores between age groups and value instruction conditions (see Supplemental Materials). Finally, we analyzed recall accuracy as a function of value instruction condition, value category, and age group.

Color-Value Identification Accuracy

The proportion of lists in which participants accurately identified all the color-value combinations after recall was examined as a function of age group and value instruction condition, with a 2 (age group: *older, young*) × 2 (value instruction: *pre-encoding, post-encoding*) mixed-subjects ANOVA[7]. This analysis revealed no main effect of value instruction, $F(1, 142) = 1.01$, $p = .32$, $\eta_p^2 = .007$, $\text{BF}_{01} = 6.59$, or age group, $F(1, 142) = 2.41$, $p = .12$, $\eta_p^2 = .02$, $\text{BF}_{01} = 2.58$, but did reveal a weak significant interaction, $F(1, 142) = 4.45$, $p = .04$, $\eta_p^2 < .03$, $\text{BF}_{10} = .04$. Post-hoc paired-samples *t*-tests revealed no significant differences between older ($M = .72$, $SD = .37$) and young ($M = .67$, $SD = .38$) adults, $t(142) = 1.55$, $p = .12$, Cohen's $d = .20$, or between pre-encoding ($M = .68$, $SD = .38$) and post-encoding ($M = .71$, $SD = .38$) lists, $t(142) = 1.00$, $p = .32$, Cohen's $d = .12$, with respect to the accuracy of participants identifying the color-value combination of the previous list. Further, as previously detailed, only the lists in which participants correctly identified *all* color-value combinations were included in subsequent analyses.

Overall Memory

A 2 (age group: *older, young*) × 3 (value instruction: *pre-encoding, post-encoding, no instruction*) mixed-subjects ANOVA on recall accuracy[8] (Figure 4) revealed no main effect of age group, $F(1, 142.18) = .15$, $p = .70$, $\eta_p^2 = .001$, $\text{BF}_{01} = 7.53$. There was a significant main effect of instruction condition, $F(2, 264.54) = 5.52$, $p = .005$, $\eta_p^2 = .04$, $\text{BF}_{10} = .20$, with post-hoc paired-samples *t*-tests indicating higher recall accuracy in the pre-encoding ($M = .36$, $SD = .48$) condition relative to the no instruction ($M = .29$, $SD = .46$) condition, $t(265) = 3.30$, $p_{adj} = .003$, Cohen's $d = .28$, $\text{BF}_{10} = 2.89$, with no other significant comparisons between post-encoding ($M = .35$, $SD = .48$) and no instruction conditions, $t(265) = 1.90$, p_{adj}

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[7] Formula: accuracy ~ 1 + age*instruction + (1 | participant)

[8] Formula: recall ~ 1 + age*instruction + (1 | id)

= .18, Cohen's $d = .16$, $BF_{01} = 3.16$, nor between pre- and post-encoding conditions, $t(266) = 1.35$, $p_{adj} = .54$, Cohen's $d = .12$, $BF_{01} = 5.06$. The interaction between age group and value instruction condition was not significant, $F(2, 264.54) = .11$, $p = .90$, $\eta_p^2 < .001$, $BF_{01} = 1113.36$.

Recall by Value

A 2 (age group: *older, young*) × 2 (value instruction: *pre-encoding, post-encoding*) × 3 (value category: *low, medium, high*) mixed-subjects ANOVA on recall accuracy[9] (Figure 5) revealed no main effect of age group, $F(1, 277.60) = 1.09$, $p = .30$, $\eta_p^2 = .004$, $BF_{01} = 6.13$, and no main effect of instruction condition, $F(1, 234.55) = .82$, $p = .37$, $\eta_p^2 = .005$, $BF_{01} = 8.34$. There was a significant main effect of value category, $F(2, 282.76) = 35.87$, $p < .0001$, $\eta_p^2 = .27$, $BF_{10} = 7.82\times10^6$, which was qualified by a significant instruction condition × value category interaction, $F(2, 273.21) = 32.31$, $p < .0001$, $\eta_p^2 = .17$, $BF_{10} = 5.45\times10^9$.

To break down this interaction, we conducted follow-up within-subjects ANOVAs examining value category within each instruction condition. In these follow-up ANOVAs, there was no main effect of value category in the post-encoding condition, $F(2, 260) = 1.90$, $p = .15$, $\eta_p^2 = .01$, $BF_{01} = 39.13$. However, there was a significant main effect of value category in the pre-encoding condition, $F(2, 264) = 52.62$, $p < .0001$, $\eta_p^2 = .29$, $BF_{10} = 4.25\times10^{11}$, with post-hoc paired-samples *t*-tests indicating higher recall accuracy for high-value ($M = .44$, $SD = .50$) words relative to medium-value ($M = .34$, $SD = .47$) words, $t(264) = 7.61$, $p_{adj} < .0001$, Cohen's $d = .75$, $BF_{10} = 1.62\times10^6$, and low-value ($M = .30$, $SD = .46$) words, $t(264) = 9.76$, $p_{adj} < .0001$, Cohen's $d = .97$, $BF_{10} = 1.91\times10^{10}$, but not for medium-value relative to low-value words, $t(264) = 2.15$, $p_{adj} = .10$, Cohen's $d = .22$, $BF_{01} = 1.39$. The omnibus ANOVA revealed no other significant two-way or three-way interactions: age group × value category, $F(2, 282.76) = .99$, $p = .37$, $\eta_p^2 = .01$, $BF_{01} = 3.14\times10^{-5}$; age group × instruction condition × value category, $F(2, 273.21) = 1.66$, $p = .19$, $\eta_p^2 = .01$, $BF_{01} = 9.40\times10^{-6}$.

We provide partially convergent results using SI scores in the online Supplemental Materials. Specifically, SI scores indicated selectivity for high-value words in both young and older adults within the pre-encoding instruction condition; however, there was a weak high-value word selectivity effect for only young adults within the post-encoding instruction condition.

Furthermore, an exploratory two-level logistic model treating value category as a continuous numerical predictor (similar to that presented in Experiment 1) is presented in the Supplemental Materials. This exploratory analysis yielded results generally consistent with the categorical value ANOVA (Figure 5) while also providing additional insight into emerging age-related differences in value-directed recall probability.

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[9] Formula: recall ~ 1 + age*instruction*value + (1 | participant:value) + (1 | participant:instruction)

List Effects on Memory

In order to determine if task experience influenced memory performance and value selectivity across each list, within each of the two critical encoding conditions, we ran an additional mixed-subjects ANOVA with age group, value instruction, and value category on recall accuracy while now including within-block list order (i.e., *1, 2, 3, 4*) as an additional predictor[10]. These results uncovered a significant, albeit weak, main effect of list order on recall accuracy in Experiment 2, $F(3, 288.07) = 2.99$, $p = .032$, $\eta_p^2 = .006$, $\mathrm{BF}_{10} = .04$. However, no two-, three-, or four-way interactions containing list order were significant in this model, all *p*s > .11. Therefore, this model revealed no meaningful pattern of results supporting a benefit of list order for value-directed prioritization effects on memory.

We also conducted another exploratory two-level logistic model (where value category was treated as a continuous numerical predictor, above) including within-block list order as an additional fixed effects predictor (Supplemental Materials). This analysis revealed there to be no effect of value on memory as a function of list order for young adults in the pre-encoding condition, as well as for older adults in both the pre- and post-encoding conditions; however, young adults in the post-encoding condition did display a prioritization effect that decreased with each subsequent list.

Discussion

Results from Experiment 2 partially replicate the findings from Experiment 1. In Experiment 2, both young *and* older adults were selective towards high value words in the pre-encoding condition, but not in the post-encoding condition – when assessed across multiple lists – implicating a critical role of pre-encoding knowledge of value structure for value-directed selectivity effects at the time of knowledge expression. Furthermore, contrary to expected canonical age-related differences in value-directed selectivity effects – where young adults' typically display a memory advantage for low-value information over older adults, which is then reduced for high-value information (see Castel et al., 2012; Knowlton & Castel, 2022) – we did not find an interaction between age group and item value in the categorical analysis presented above. However, there was a weak, but significant interaction ($OR = 1.06$, 95% CI = [1.01, 1.11], $p = .024$) between age group and item value in an exploratory logistic mixed effects model we conducted where value was instead treated as a continuous predictor (see Supplemental Materials, Figure S3). Visual inspection of the data presented in the categorical analysis here (see Figure 5) does appear to follow the foregoing expected pattern of results in that young adults' mean recall accuracy is numerically higher than that of older adults for the low-value items, and this difference in mean recall accuracy converges between young and older adults as item-value increases. It could then be that this analysis was slightly underpowered to uncover this effect in the categorical value ANOVA presented here, which could be due to the difficulty of this color-value-word associative memory task. Perhaps some combination of fewer trials per list, repeated encoding exposures, and/or removing the medium value association to just have two value goal states (i.e., low and high values only) may have increased our sensitivity to detect these expected advantages

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[10] Formula: recall ~ 1 + age*instruction*value*list + (1 | participant:value) + (1 | participant:instruction) + (1 | participant:list)

in young adults' memory selectivity for low-value items. We discuss further limitations of the task design and suggestions for future investigations in more detail within the General Discussion.

General Discussion

Selective memory mechanisms facilitate prioritization of more valuable over less valuable information, and may be intact in healthy older adults (Knowlton & Castel, 2022). Many prior investigations of prioritization ability in memory define the goal-directed value structure of stimuli prior to encoding, allowing participants to engage both top-down (i.e., elaborative rehearsal, overtly directing attention away from low-value information) and bottom-up (i.e., increased pupil dilation for high-value information) value-directed encoding strategies that produce typically observed value-based selectivity findings at retrieval (e.g., Ariel & Castel, 2014; Ariel et al., 2015; Middlebrooks & Castel, 2018; Robison & Unsworth, 2017). However, value-based prioritization of information *after* it had already been learned was, to this point, unclear, and it may be that older adults have difficulty in terms of selectivity under these uncertain conditions due to working memory and cognitive control impairments.

Using a single trial design with numerical point values in Experiment 1, only older adults who were informed of the value of information *prior* to studying it produced memory performance sensitive to value, while older adults who were informed *after* study could not effectively prioritize the to-be-learned information. Young adults were not sensitive to value in either condition, perhaps reflecting the need for multiple trials with performance feedback to produce selective memory effects (e.g., Castel, 2008; Knowlton & Castel, 2022). In Experiment 2, we adapted the paradigm to include multiple trials. Older adults in Experiment 2 displayed a similar pattern of results to those in Experiment 1 – memory prioritization was observed in pre-encoding value instruction trials, but not in post-encoding trials. In contrast to Experiment 1, young adults in Experiment 2 were selective in pre-encoding trials, suggesting that multiple trials with feedback may be necessary to refine value-based encoding strategy use in this condition (Middlebrooks & Castel, 2018; Schwartz et al., 2020; Stefanidi et al., 2018). However, similar to older adults, no value-based selectivity effects were found in post-encoding trials, suggesting that prioritization ability is critically dependent on knowing the value of information prior to encoding it.

Despite recalling just as many words when made aware of the value of stimuli after already learning it, participants in the post-encoding condition (between-subjects in Experiment 1) and those completing post-encoding trials (within-subjects in Experiment 2) could not retroactively prioritize the high-value words to produce typically observed value-based selective memory effects, as evidenced by recall being insensitive to value. This critical finding identifies a limitation on the ability to dynamically prioritize information in memory at retrieval when value-based goal states are only made available to participants *after* associative memories between to-be-learned information and their arbitrary point-based (Experiment 1 – only older adults with 1 study-test cycle) or perceptual category-based (Experiment 2 – both young and older adults with multiple study-test cycles) associations have been encoded.

Reduced prioritization ability for value-based information after encoding may be particularly worse in individuals with major depressive disorder who exhibit reduced sensitivity to reward (e.g., Satterthwaite et al., 2015; Shankman et al., 2013), individuals with lower working memory capacity (Hayes et al., 2013; Robison & Unsworth, 2017), reduced processing resources in cognitive aging (Castel & Craik, 2003; Craik et al., 2010), or when attention is divided in multitasking scenarios (e.g., Middlebrooks, Kerr, et al., 2017; Siegel & Castel, 2018b). Although, it is also possible that using more explicit goal-directed associative memory instructions within this task could have facilitated post-encoding value-based selective memory effects (e.g., explicitly instructing participants to effortfully encode both the word *and* number/color associated with it).

In Experiment 2, participants were not explicitly instructed to learn word-color associations, and inclusion of these instructions could have potentially strengthened word-color associative memory, better facilitating post-encoding value-directed prioritization effects via goal-directed reinstatement of word-color associations at retrieval. Thus, our null selectivity effects in the post-encoding condition should not preclude the possibility that post-encoding selection mechanisms are insensitive to value, but rather they may rely on goal states that more explicitly guide rich encoding of item-value associations in memory beyond the prescribed goal state of maximizing one’s point score. Overall, these results are informative for understanding potential boundary conditions under which young and older adults prioritize learned information for later recall. Future work should systematically study how differences between motivated remembering and forgetting (e.g., Adcock et al., 2006; Bowen et al., 2020; Mather & Schoeke, 2011; Miendlarzewska et al., 2016; Murphy & Castel, 2021, 2022b; Spaniol et al., 2014) interact with the time during the task where young and older adult participants are made aware of the relevant reward-oriented goal state.

Also evident from the present findings is older adults’ maintained ability to prioritize high-value information at least as effectively as young adults. While neither young nor older adults were able to retroactively prioritize information when instructed post-encoding, older adults were more selective than their young adult counterparts in Experiment 1, and equivalently as selective in Experiment 2. As evidenced by selectivity effects emerging exclusively for older adults on the single trial measure used in Experiment 1, we speculate that older adults may have a greater awareness of the need to prioritize high-value information in the task initially, arising from accurate metacognitive monitoring and/or knowledge of age-related declines in memory such that they are aware that not all items in the task can be remembered (e.g., Castel, 2008; Knowlton & Castel, 2022). This hypothesis is supported by prior evidence of relatively intact metacognitive monitoring with age (Kuhlmann & Touron, 2011; Devolder et al., 1990; Halamish et al., 2011), and perhaps reflects a strategic use of available cognitive resources to compensate for age-related declines in memory (Castel, 2008). Further, young adults may, however, require multiple trials to reach a state of awareness that they must selectively encode information to maximize their performance (Ariel, 2013; Castel et al., 2012; Middlebrooks, Kerr, et al., 2017; Robison & Unsworth, 2017; Siegel & Castel, 2018b). In a sense, the older adults’ approach to this type of prioritization task is seemingly more adaptive and efficient than that of the young adults. Instead of requiring multiple trials to realize that selectively encoding high-value information will better optimize performance, compared to attempting to remember all information equally (i.e., regardless of value), older adults may realize from the start that using selective encoding strategies is more practical without additional task experience/explicit points-based feedback on performance. Young adults, on the other hand, may need to experience and be informed of their suboptimal (points-based) performance before adopting selective encoding strategies that would have benefited their performance if utilized early in the task.

Furthermore, older adults in Experiment 2 were equivalently as accurate in identifying color-value combinations in our manipulation check and equivalently as selective on pre-encoding trials compared to their young adult counterparts, despite concerns about older adults' ability to switch between tasks and value instruction rules given prior work implicating an increase in task-switching impairments with age (e.g., Kray & Ferdinand, 2014). To successfully complete the multiple word lists task used in Experiment 2, participants had to dynamically switch back-and-forth between color triads from list-to-list – while remembering which color indicated which value – to prioritize words based on this associative information; they did so just as well as young adults did. Additionally, task switching was required between blocks with the added value instructions and the point-oriented goal focus instantiated after the first block of no value (control) trials. Still yet, participants had to vie with the time points at which the value/color combinations were revealed, some being before study list presentation, and some after. It is notable, then, that older adults were just as effective as young adults here at juggling these changing task demands and conditions.

Interestingly, both young and older adults' memory seemed to benefit from the shift to a point-oriented goal focus in the pre-encoding condition, as indicated by higher accuracy on these trials relative to when the primary goal was solely just to remember as many words as possible (see Experiment 2 *Results, Overall Memory* contrast between pre-encoding and control conditions, collapsed across age group). Thus, participants' overall memory performance may be improved under value-based strategic encoding conditions, in which effective elaborative encoding strategies may be used (Ariel et al., 2015; Hennessee et al., 2017) relative to non-value-based encoding conditions where the goal is just to maximize memory performance (independent of particular item characteristics, like value). Furthermore, to our surprise, there were no age differences in recall accuracy in either experiment, contrasting what would be expected from research investigating age-related differences in recall accuracy (see Rhodes et al., 2019 for a meta-analysis). Despite claims suggesting the reliability of data collected in online settings to be generally matched in fidelity to laboratory samples for young and older adults (e.g., Buhrmester et al., 2011; Bui et al., 2015; Casler et al., 2013; Gosling et al., 2004; Greene & Naveh-Benjamin, 2022; Mason & Suri, 2012), Greene & Naveh-Benjamin (2022) suggest it is also possible that low-effort participants confounded to a particular age-group (e.g., young adults) could lead to an underestimation of an otherwise true age effect. On the other hand, we speculate that it is also possible that the older adults sampled in both experiments presented here may represent an upper bound of memory performance ability. Future work should carefully investigate whether these findings replicate in more diverse, heterogeneous samples of older adults and/or if the same pattern of results emerge when testing young and older adults on other online recruitment platforms (e.g., Prolific), or, in a controlled, in-person laboratory setting instead of an unmonitored remote setting, while also taking into consideration that the ability to engage these processes that facilitate value-directed remembering may be impaired in, or even a diagnostic sign of, more pathological aging as observed in Alzheimer's disease (Castel et al., 2009; Wong et al., 2019). Future studies should also closely examine and manipulate the framing in which task goals are prescribed to participants (e.g., Murphy & Knowlton, 2022), in addition to the strategies participants use when remembering high value items.

It is important to note a few additional limitations of the current study. The task difficultly in Experiment 2 was high, with approximately 40% of trials across young and older adults excluded due to participants incorrectly identifying the value-color combinations. It is clear that participants had difficulty correctly identifying the value structure from trial-to-trial. It is possible that the difficulty of task switching between color triads may have particularly impacted performance on post-encoding trials, subsequently causing a lack of selectivity. If the difficulty of the task did specifically impact post-encoding trial performance, reducing task difficulty in future studies could allow for the inclusion of a greater percentage of trials and possible selectivity effects. Reducing task difficulty by increasing value identification accuracy could be accomplished by changing the value structure to only two values (i.e., low- and high-value words), increasing the amount of time for which the color-value key is presented while also validating perceptual encoding of the color-value key via eye-tracking and an explicit test of color-value combinations before initiating memory encoding trials, and/or reducing elapsed time between color-value key presentation and test by decreasing the number of words per list.

It is also important to consider studying these effects in more applied, naturalist contexts that may contain more emotional aspects and longer delays between study and test. For example, in other contexts, studies have shown global enhancement of information learned prior to an arousing or stressful event (see Cahill & McGaugh, 1998; McGaugh, 2004). More recently, Dunsmoor et al. (2015) showed enhanced consolidation of items that were conceptually related to information later paired with an aversive shock. Interestingly, this emotionally based retroactive memory enhancement was found following both a 6- and 24-hr delay but was not present immediately. These results suggest that at least some types of information can be retroactively strengthened in memory, although it is unclear how aging might influence these mechanisms and if emotional conditions may be unique in cuing certain memories.

An open question that remains regards the mechanism guiding prioritized, value-based retrieval of high-value information: are attention-based strategies at encoding pre-filtering out less important information at the time of encoding, and/or are goal-directed, mnemonic post-encoding filters selectively driving reinstatement for more valuable information aligned with task goals? Furthermore, how would such a mechanism/ensemble of multiple selective memory processes predict value-based selective behavior for word list based free recall memory tasks, where participants can selectively rehearse high value items until test while simultaneously being presented with the other, less valuable items – reflecting strategic behavior manifested at test arising from an encoding-retrieval interaction – compared to a long-term episodic memory task for visual information where rehearsal strategies would be difficult to leverage in a similar manner? Studies investigating the behavioral and neural mechanisms driving reinstatement of item-value associations when value-based goal states are invoked before *and* after encoding would provide complimentary evidence to prior recognition-based paradigms in which memory selectivity is still observed despite the inability to effectively use retrieval strategies (Elliott et al., 2020; Elliott & Brewer, 2019; Hennessee et al., 2017, 2018; Spaniol et al., 2014).

We note that in our present sample, like many studies of adult development and cognitive aging, the younger participants were more racially diverse than those in the older adult group and thus the present sample may not represent a wider and more diverse older adult population at-large (see Dupree & Kraus, 2022, for a discussion of the possible impacts of demographic information on psychological research; see also Greene & Naveh-Benjamin, 2022, for how the online sampling of older adults could influence research findings). As such, future research would benefit from a more diverse sample, and possibly one that does not only directly compare university students with a select sample of mostly healthy and educated older adults, but rather examines these issues in a more diverse lifespan sample. It would also be informative to examine how a wider range of other variables that may play a mechanistic role in the present task, such as fluid intelligence and frontal lobe function, may influence how young and older adults perform and can engage in strategic value-based and flexible remembering (e.g., Aizpurua & Koutstaal, 2010; Murphy et al., 2021). While value-directed memory effects have been documented under a variety of circumstances, including when attention is divided (Middlebrooks, Kerr, et al., 2017; Siegel & Castel, 2018b; cf. Elliott & Brewer, 2019; Siegel et al., 2021), when attention is involuntarily captured by emotional stimuli (Eich & Castel, 2016), in spatial memory paradigms (Schwartz et al., 2020; Siegel & Castel, 2018a,b; Siegel et al., 2021), in recognition memory paradigms (Elliott et al., 2020; Elliott & Brewer, 2019; Hennessee et al., 2018; Middlebrooks, Murayama et al., 2017; Spaniol et al., 2014), in young adults with lower working memory capacity (Hayes et al., 2013; Robison & Unsworth, 2017), in cognitively healthy older adults (Ariel et al., 2015; Castel et al., 2013; Siegel & Castel, 2018a; Spaniol et al., 2014), and, to a lesser extent, in both patients with Alzheimer's disease (Castel et al., 2009; Wong et al., 2019) and attention-deficit/hyperactivity disorder (Castel, Humphreys, et al., 2011; Castel, Lee, et al., 2011), it would be useful to determine if these past findings persist under the specific learning conditions tested in the present studies, and in a more diverse lifespan sample.

From remembering what medications interact with one another to have mild versus severe side effects (Friedman et al., 2015; Hargis & Castel, 2018), to important information associated with faces you encounter around town (DeLozier & Rhodes, 2015; Hargis & Castel, 2017; Murphy, Silaj, et al., 2022), being able to selectively attend to and remember the most important information in line with one's goal pursuits is necessary given the abundance of information we are exposed to each day. While past work has shown a general ability to selectively prioritize high-value information in memory expression during cognitively demanding conditions (e.g., Middlebrooks, Kerr, et al., 2017; Siegel & Castel, 2018b) and older age (Castel et al., 2002; Siegel & Castel, 2018a), we are often only made aware of the value of information *after* a larger set of information (including unimportant information) has already been learned. The results from the current study suggest that both young and older adults appear unable to produce typically observed value-based memory selectivity effects if made aware of goal-relevant value structures *after* encoding item-value associations in memory. These findings bring into question how the underlying mechanisms guiding value-based selective memory behavior rely on time-dependent goal states, associated reward saliency, and potential mnemonic and non-mnemonic influences on value-based strategic behavior for memory prioritization, manifested at retrieval, that may arise from an encoding-retrieval interaction.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This research was supported in part by the National Institutes of Health (National Institute on Aging; Award Number R01 AG044335 to Alan D. Castel). The authors have no conflicts of interest to disclose. We thank Kara Hoover, Katie Silaj, and Dillon Murphy for helpful comments.

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Public Significance Statement

The present study examines how expectations and goals can influence selective memory for important information in young and older adults. We found that awareness of a value-directed goal state prior to learning may be necessary for effective value-based prioritization of important information in memory, and that younger adults may require several trials of learning to effectively engage processes that maximize memory efficiency compared to older adults who quickly engage these processes. Overall, we provide novel evidence regarding the conditions under which young and older adults engage selective memory processes for important information based on when value-directed goals are implemented.

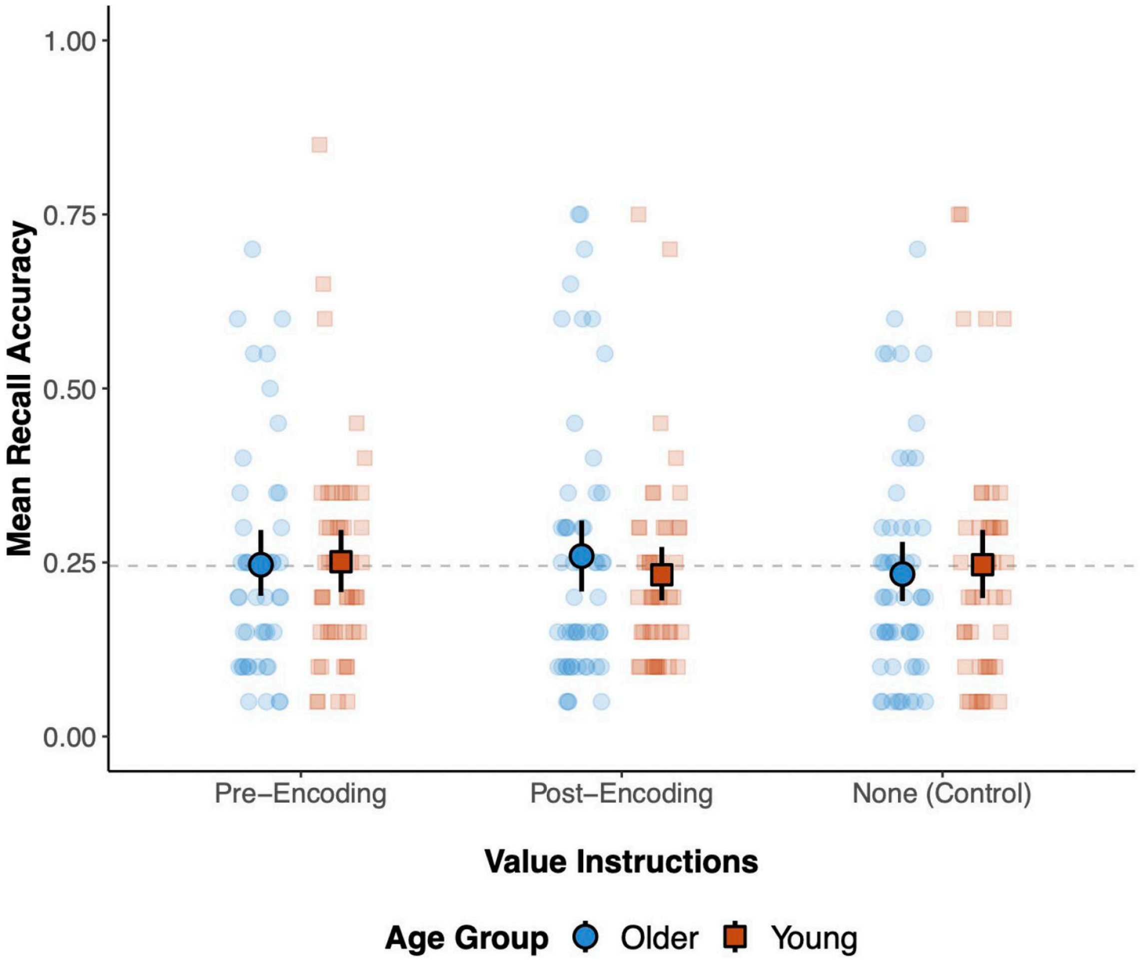


Figure 1.

Recall accuracy as a function of age group and value instruction condition in Experiment 1. Error bars indicate the non-parametric bootstrapped 95% confidence interval of the mean (1,000 iterations). Jittered points represent each participant's mean score, and these were only jittered along the x-axis for visibility. The dashed line represents the grand mean of recall accuracy across all age groups and value instruction conditions. For each value instruction on the x-axis, the left set of points (blue, circle) represents data from older adults, while the right set of points (red, square) represents data from young adults.

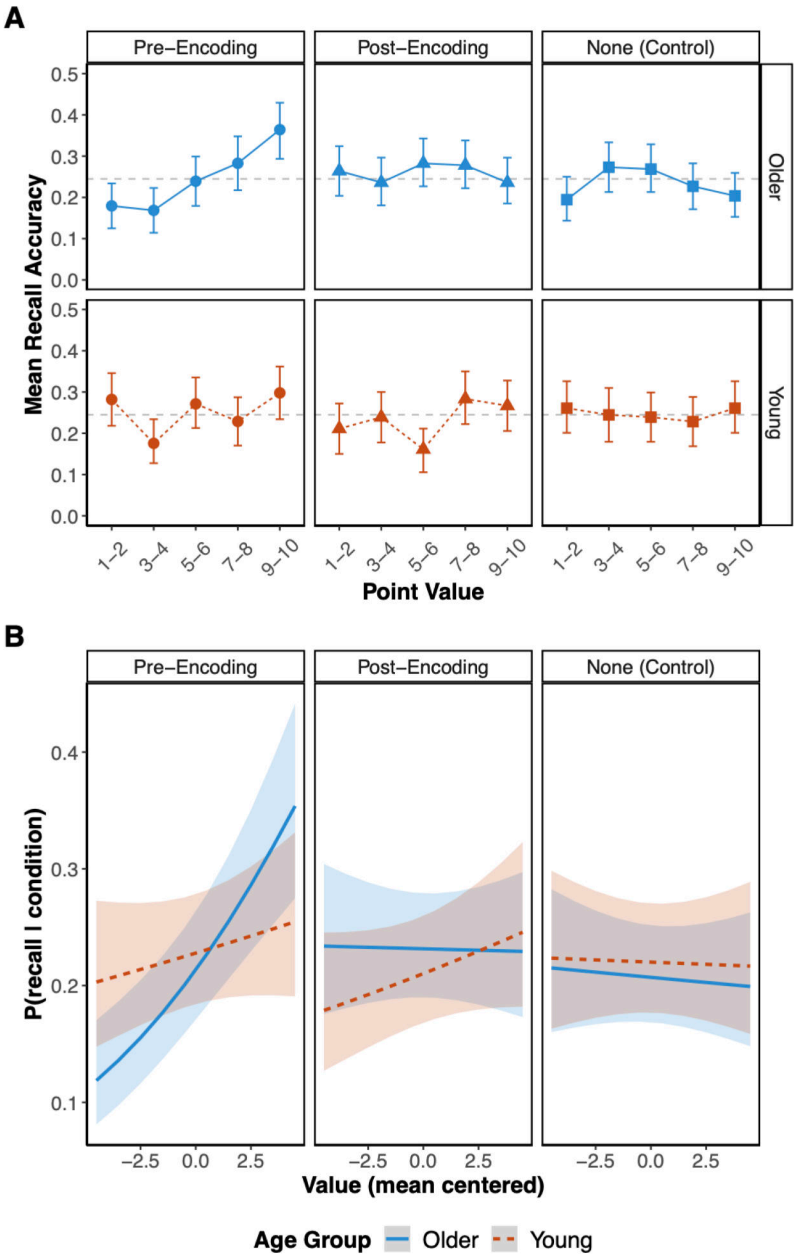
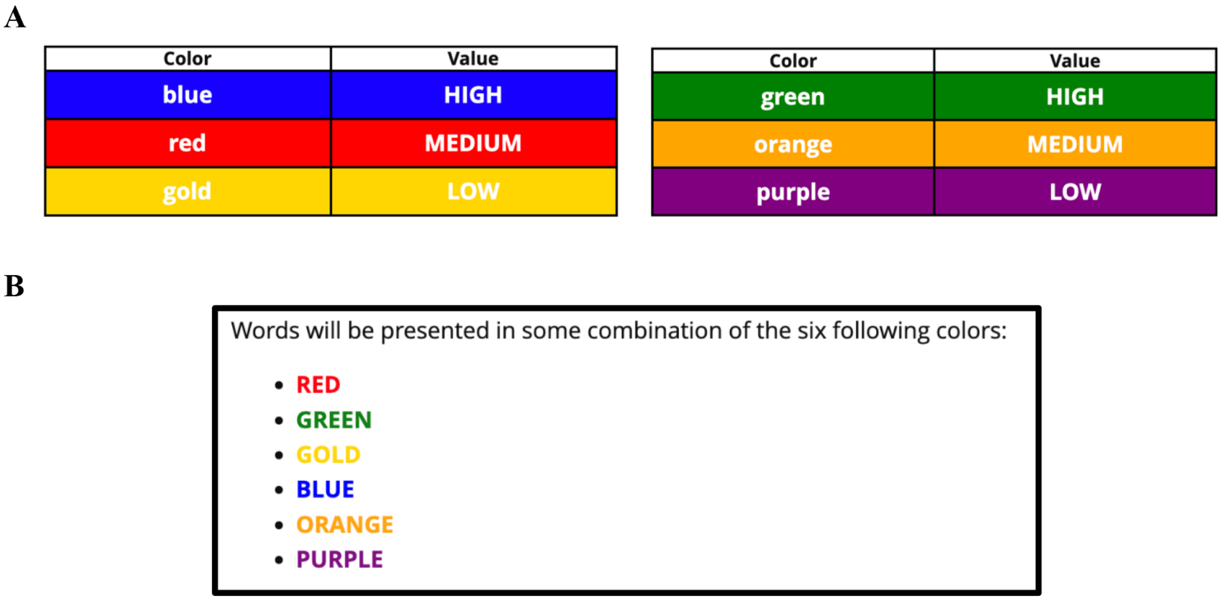


Figure 2.

(A) Recall accuracy as a function of point value in older and young adults in Experiment 1. Error bars indicate the non-parametric bootstrapped 95% confidence interval of the mean (1,000 iterations). (B) The predicted probabilities of recall, given the condition for young (red, dashed) and older (blue, solid) adults, as a function of item value, from the logistic mixed effects model. Ribbons represent the 95% confidence interval of the predicted probability.



A

Color	Value
blue	HIGH
red	MEDIUM
gold	LOW

Color	Value
green	HIGH
orange	MEDIUM
purple	LOW

B

Words will be presented in some combination of the six following colors:

- RED
- GREEN
- GOLD
- BLUE
- ORANGE
- PURPLE

Figure 3.

(A) Example of a *blue-red-gold* and *green-orange-purple* color-value key that participants may have been shown either pre- or post-encoding in Experiment 2. The color used as the background row color in the key was the same color that words were presented with on the screen in relevant trials. Keys all displayed the value from high (top) to low (bottom), with the color position randomly shuffled across lists per participant. (B) The instructions participants were shown to familiarize them with the colors in which words would be printed in both pre-/post-encoding value instruction trials.

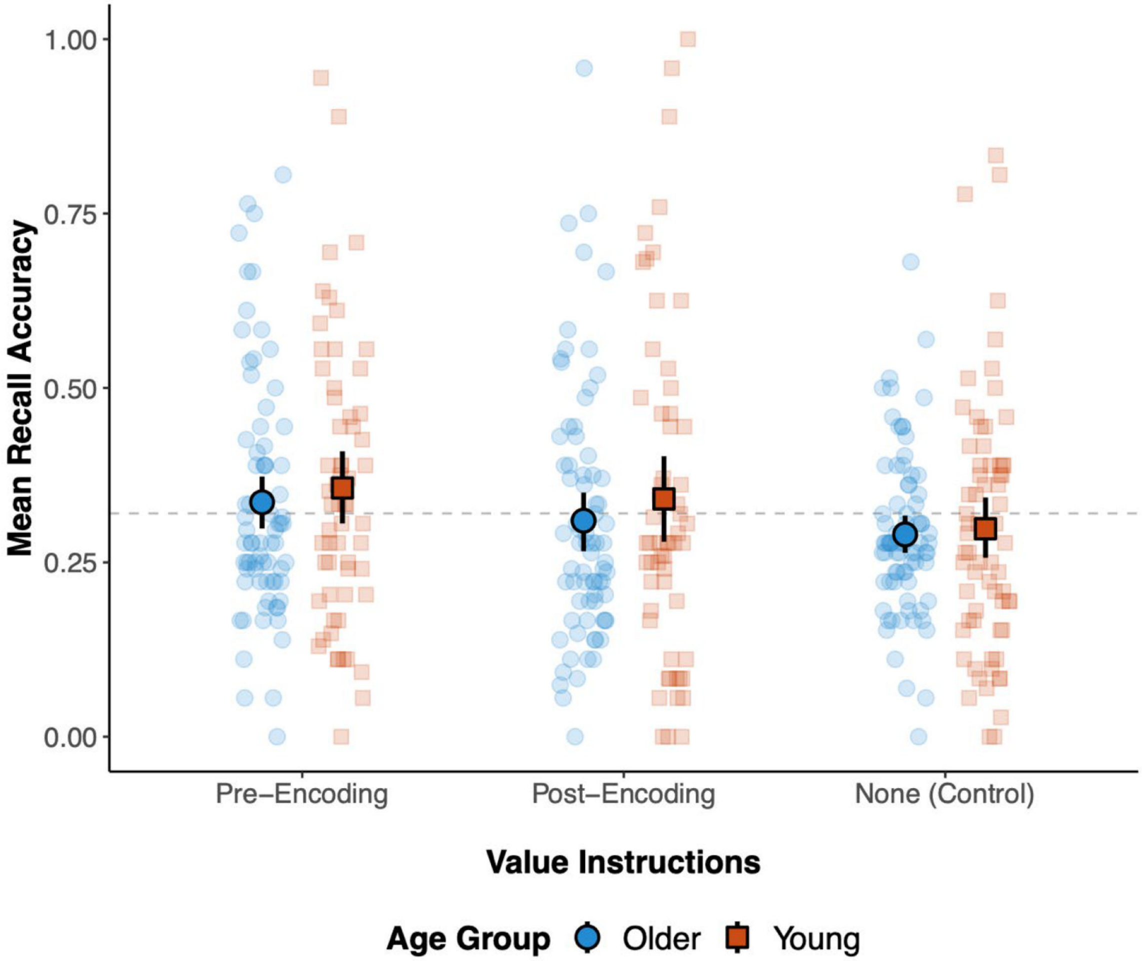


Figure 4.

Recall accuracy as a function of age group and value instruction condition in Experiment 2. Error bars indicate the non-parametric bootstrapped 95% confidence interval of the mean (1,000 iterations). Jittered points represent each participant's mean score, and these were only jittered along the x-axis for visibility. The dashed line represents the grand mean of recall accuracy across all age groups and value instruction conditions. For each value instruction on the x-axis, the left set of points (blue, circle) represents data from older adults, while the right set of points (red, square) represents data from young adults.

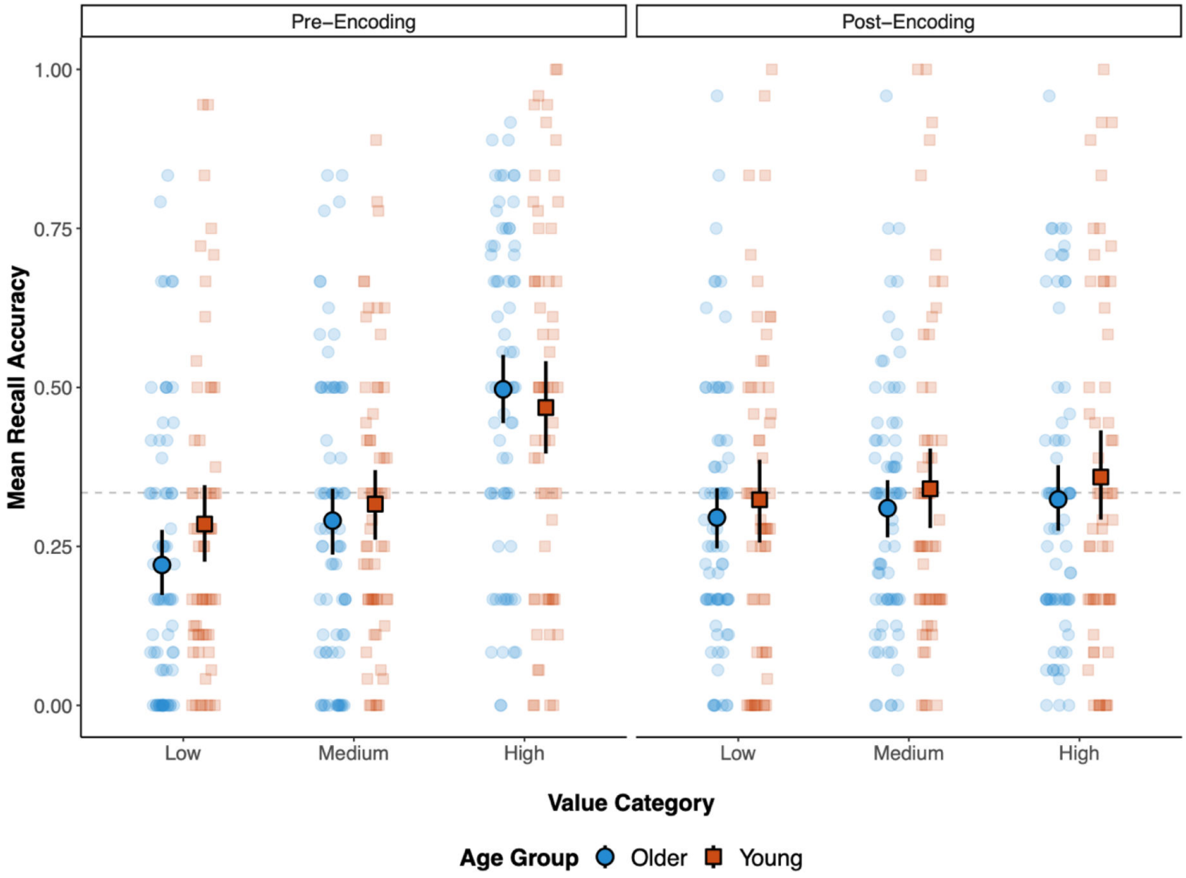


Figure 5.

Recall accuracy as a function of point value in older adults (blue, circle) and young adults (red, square) in Experiment 2. Error bars indicate the non-parametric bootstrapped 95% confidence interval of the mean (1,000 iterations). Jittered points represent each participant's mean score, and these were only jittered along the x-axis for visibility. The dashed line in both panels represents the age-group mean of recall accuracy collapsed across the pre-/post-encoding value instruction conditions.

Table 1

Two-Level Logistic Mixed Effects Model of Recall Accuracy Predicted by Item Value, Age Group, *Value Instruction Condition*

Predictor	*OR*	*SE*	*95% CI*	*p*
Value	1.03	.03	.97 – 1.10	.284
Age	.92	.18	.63 – 1.35	.669
Age × Value	**1.13** **	**.05**	**1.04 – 1.23**	**.005**
Value Instructions				
Pre- vs. Post-Encoding	.90	.18	.62 – 1.32	.598
Pre-Encoding vs. None (Control)	.96	.19	.65 – 1.40	.818
Age × Value Instructions				
Pre- vs. Post-Encoding	1.23	.33	.72 – 2.09	.446
Pre-Encoding vs. None (Control)	1.01	.27	.59 – 1.71	.983
Value × Value Instructions				
Pre- vs. Post-Encoding	1.01	.04	.93 – 1.10	.779
Pre-Encoding vs. None (Control)	.96	.04	.89 – 1.05	.391
Age × Value × Value Instructions				
Pre- vs. Post-Encoding	**.84** **	**.05**	**.75 – .95**	**.005**
Pre-Encoding vs. None (Control)	**.88** *	**.05**	**.78 – .99**	**.033**

Note. In this model, recall accuracy was coded as 0 (not recalled) or 1 (correctly recalled). A binomial distribution with a logit link function was used to address the binary dependent variable. The age predictor was dummy-coded such that young adults were the reference group, while the value instructions predictor was dummy-coded such that the pre-encoding condition was the reference group. Value was entered into the model as a group-mean centered variable. The model was fit using the glmer function from the *lme4* package (Bates et al., 2015) in *R* (Version 4.1.1; R Core Team, 2021), using the bobyqa optimizer and 2×10^5 maximum model evaluations before failing to converge. Here, odds ratios (*OR*) represent the exponentiated estimates from the model fit. Formula: recall ~ 1 + age*instruction*value + (1 + value | participant). Significant predictors are bolded in the table.

[*] p < .05

[**] p < .01

[***] p < .001