Psychology and Aging
2018, Vol. 33, No. 1, 46–56

0882-7974/18/$12.00 http://dx.doi.org/10.1037/pag0000202

The Effects of Value on Context-Item Associative Memory in Younger and Older Adults

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Valuable items are often remembered better than items that are less valuable by both older and younger adults, but older adults typically show deficits in binding. Here, we examine whether value affects the quality of recognition memory and the binding of incidental details to valuable items. In Experiment 1, participants learned English words each associated with a point-value they earned for correct recognition with the goal of maximizing their score. In Experiment 2, value was manipulated by presenting items that were either congruent or incongruent with an imagined state of physiological need (e.g., hunger). In Experiment 1, point-value was associated with enhanced recollection in both age groups. Memory for the color associated with the word was in fact reduced for high-value recollected items compared with low-value recollected items, suggesting value selectively enhances binding of task-relevant details. In Experiment 2, memory for learned images was enhanced by value in both age groups. However, value differentially enhanced binding of an imagined context to the item in younger and older adults, with a strong trend for increased binding in younger adults only. These findings suggest that value enhances episodic encoding in both older and younger adults but that binding of associated details may be reduced for valuable items compared to less valuable items, particularly in older adults.

Keywords: executive function, memory, recollection, reward, value

Supplemental materials: http://dx.doi.org/10.1037/pag0000202.supp

Remembering the past often involves remembering an event as well as the details associated with the event in question. Memory for associated details of an event requires the binding of information in memory, and there is evidence that older adults have impairments in associative memory (Old & Naveh-Benjamin, 2008). Although aging is associated with declines in free recall and recognition performance (Dulaney, Marks, & Link, 2004; Spaniol, Schain, & Bowen, 2014), it has been robustly shown that older adults are often as good as younger adults at remembering valuable material (Ariel, Price, & Hertzog, 2015; Castel, Benjamin, Craik, & Watkins, 2002; Castel et al., 2011; Cohen, Rissman, Suthana, Castel, & Knowlton, 2016; Spaniol et al., 2014). In the value-directed remembering (VDR) paradigm, each item is associated with a point-value that participants earn for retrieving the item at test—for example, ranging from 1 to 12 points—which simulates material differing in value. The ability to selectively learn valuable items is crucial for achieving a high score, as participants are presented with more information than they can possibly memorize. Effective VDR depends on attentional control, goal maintenance, and inhibition of less important information (Balota & Faust, 2001; Waszak, Li, & Hommel, 2010; Zelazo, Craik, & Booth, 2004). Despite extensive support that VDR is intact in healthy aging, less is known about whether value enhances binding of incidental details to valuable items. Furthermore, it is unclear whether the effects of value on memory in older adults are primarily attributable to selective encoding or would also be present when this selectivity is not incentivized. One possibility is that value enhances the binding of associated episodic details such that memory for these items will be accompanied by information in the study episode. On the other hand, valuable items may capture attention to the extent that less relevant information (such as the color of a studied word) is not encoded. If so, memory for valuable items may be accompanied by fewer associated details. Although older adults may show similar VDR effects as younger adults, their effect of value on associative binding may differ between the two groups.

Formation of an episodic memory requires the binding of contextual details to the item. Several studies suggest that episodic memory is specifically impaired in older adults compared to memory based on feelings of familiarity that lack such binding (Koen & Yonelinas, 2014; Piolino et al., 2010). Although older adults have an impaired ability to encode or retrieve episodic details, paradoxically, they are also less able to ignore irrelevant details during encoding. Much research suggests that older adults are not as effective as younger adults at suppressing distracting informa-

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We thank Irene Chung, Julie Kim, and Uyen-Ly Nguyen for their assistance with data collection. Preliminary results of Experiment 1 were presented at the 57th Psychonomic Society Annual Meeting, Boston, MA, and of Experiment 2 at the 24th Cognitive Neuroscience Society Annual Meeting, San Francisco, CA. Abstracts for these presentations are archived online at www.psychonomic.org and www.cogneurosociety.org. This work was supported in part by a grant from the National Institutes of Health (National Institute on Aging), Award R01AG044335; to Alan D. Castel.

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tion (Amer & Hasher, 2014; Healey, Hasher, & Campbell, 2013; Lustig, Hasher, & Tonev, 2006; Stevens, Hasher, Chiew, & Grady, 2008). Amer and Hasher (2014) had participants complete a Stroop task, followed by a test of general-knowledge. Half of the answers to the test were provided as distractors during the Stroop task. Interestingly, compared with younger adults, older adults showed substantially increased performance on questions related to the distractors, suggesting that they were not only having difficulty suppressing these conceptual distractors, but rather that they were semantically processing them. Taking this idea further, research has shown that older adults' encoding of distractors and irrelevant contextual information interacts with the encoding of target items, via a theory they termed *hyper-binding* (Campbell, Hasher, & Thomas, 2010; Campbell, Trelle, & Hasher, 2014). This increased encoding of distractors in older adults is measured by implicit measures such as priming. It is uncertain whether such hyper-binding would make older adults more likely to bind episodic details to valuable items as well.

In numerous studies, older adults have been shown to have deficits in source memory compared to younger adults that are disproportionate to any deficits in item memory (see Johnson, Hashtroudi, & Lindsay, 1993 for a review). Source monitoring in older adults may be particularly challenging when they must differentiate between perceptual characteristics of possible sources (e.g., the spatial location of a stimulus, or which speaker had read the study item; Kausler & Puckett, 1981; Light & Zelinski, 1983; but see also Rahhal, May, & Hasher, 2002). Older adults appear to perform better on source monitoring tasks in which the sources differ in terms of the amount of cognitive operations performed (imagining a task vs. actually performing the task; Hashtroudi, Johnson, & Chrosniak, 1989). It is possible that the greater difficulty with source memory dependent on perceptual details reflects a deficit in binding these arbitrary details to items during encoding, and that this reduced binding may serve to direct attention to the item itself as a means to compensate for reduced memory. Item value may thus not attenuate this age related deficit in binding source details, but rather, may lead to greater focus on item memory at the expense of source details.

In contrast, other evidence suggests that older adults are able to bind contextual details to items during encoding, as older adults are able to use these details to cue item retrieval, and they benefit as much as younger adults when study and test context are identical (Naveh-Benjamin & Craik, 1995). These findings suggest that aging may not decrease contextual binding, but that older adults may have more difficulty explicitly accessing these memories by inducing the original context at test. This interpretation aligns with the view of Craik (1986) that older adults show deficits in self-initiated memory processes due to reduced cognitive resources. Mentally reinstating study context is likely resource demanding, while benefitting from congruence of contextual details at study and test does not require self-initiated processes. If value affects the binding of contextual details to valuable items, it may be that older adults would still show deficits in memory for these details due to difficulty reinstating these details at test. Thus, current views of encoding contextual detail memory in older adults do not provide a strong hypothesis regarding the effects of value on memory for these details.

One focus of the present study was to determine how value shapes the quality of memory, in terms of the degree of recollection versus familiarity, and the level of source memory detail in younger and older adults. The role of value in episodic binding has received limited research, especially for older adults. Hennessee, Castel, and Knowlton (2017) observed across three recognition experiments that younger adults more frequently experienced recollection (Remember responses) for retrieved high-value items, though there was little if any effect of value on familiarity. Additionally, recollected high-value items were more likely to be bound to the task-relevant point-value of an item but less likely to be bound to task-irrelevant word color than nonrecollected high-value items. This suggests that high-value items are encoded at a deeper level, perhaps via elaborative semantic encoding, and that value can influence the binding of episodic details. Value appears to reduce binding of task-irrelevant information in younger adults. Given that older adults show impairments to episodic memory (Koen & Yonelinas, 2014) value may not enhance recollection to the same extent as in younger adults. Additionally, does value affect binding of incidental details to studied items, and is any effect on binding similar for younger and older adults?

We were also interested in whether the effect of value on memory in older adults is based on strategic processing, or if it occurs relatively automatically. Selectively encoding valuable items in the VDR procedure appears to rely on shifting one's strategy use depending on the value of the item. In Ariel, Price, and Hertzog (2015) both older and younger adults used more effective learning strategies for high-value word pairs, including generating an image or word that mediated the relationship between the word pair, putting the word pair into a sentence, or thinking about how the word pair was semantically related. For both age groups, these encoding strategies improved retrieval relative to rote memorization. Another commonly used and effective strategy is to avoid attending to low-value items (Ariel et al., 2015; Robison & Unsworth, 2017). Ignoring low-value items is beneficial because when not all items can be memorized, reward is maximized when cognitive resources are devoted to high-value items. In most value and reward-based learning studies, there are incentives (e.g., money or point-values) and recommended goals (e.g., maximize score) to encourage such strategic encoding. In Experiment 2 we sought to measure whether older adults will show similar effects of value on memory when they are not engaging in strategic encoding. In support of more automatic effects of value at encoding, high-value cues have been shown to attract attention in an involuntary manner (Anderson, 2013; Hickey, Chelazzi, & Theeuwes, 2010). Unlike Experiment 1, in which value was manipulated by point-value, in Experiment 2, value was inherent to study items based on an imagined state of need (e.g., a blanket when imagining being cold) and encoding valuable items was not incentivized. Thus, this second experiment used a more naturalistic manipulation of value in an attempt to extend our results.

Experiment 1

Experiment 1 was designed to determine whether value affects the quality of recognition memory and associative binding of incidental details in younger and older adults. At study, each item was presented in one of four different colors and was associated with a point-value that would be earned for correct recognition. At test, for each item the participant deemed "old," they reported whether they recognized the item through remembering, knowing, or guessing (R-K-G) and then what color and point-value they believed were associated with the item at study. Remember and Know responses require the participant to introspect whether recognition was based on recollection of the study episode for the item or if they simply knew the item was presented before because of a strong sense of familiarity. A Guess response was included because subjects sometimes use the Know response as a proxy for guesses when no alternatives are explicitly allowed (Gardiner, Java, & Richardson-Klavehn, 1996), and the current task was relatively difficult. Both R-K-G responses and incidental detail retrieval were assessed to better determine whether value affects the overall quality of memory or memory for specific episodic details associated with the studied item.

First, we hypothesized that both older and younger adults would exhibit a value effect on memory with high-value items receiving a higher hit rate. This would follow a large literature demonstrating that VDR is preserved in healthy aging (Ariel et al., 2015; Castel et al., 2002, 2011; Cohen et al., 2016; Spaniol et al., 2014). Second, we hypothesized that high-value items would be associated with increased recollection for younger adults, but possibly not for older adults. We have previously observed that younger adults consistently show enhanced recollection of high-value items (Hennessee et al., 2017). Because older adults show impairments to episodic memory and rely more on familiarity during retrieval (Koen & Yonelinas, 2014; Piolino et al., 2010) we did not expect them to necessarily use recollection to the same extent. Third, we hypothesized that older adults would show less binding of incidental details with studied high value items at encoding, given previous work suggesting that older adults may not acquire incidental source information as well as younger adults (Johnson et al., 1993). Older adults may selectively allocate attentional resources to the valuable items at the expense of encoding incidental details. However, it is also possible that value could enhance binding of source details to items similarly for both age groups.

Method

Participants. Data from 33 older adults (18 women and 15 men) from Los Angeles were collected for this study. The age range was 59–91 ($M = 77.44$, $SD = 7.51$). Participants were required to have had no prior diagnosis of memory disorder (e.g., dementia), and they were in good health ($M = 8.10$, $SD = 1.60$) on a scale from 1 (*poor health*) to 10 (*excellent health*). The highest level of education achieved was college ($n = 16$), graduate school ($n = 15$), or high school ($n = 1$). Participants were paid $10 per hour of participation.

Data from 33 undergraduate students (22 women and 11 men) from University of California, Los Angeles (UCLA) were collected as a cross-sectional comparison group. Their age range was 18–28 ($M = 20.68$, $SD = 2.30$). These participants completed the study for course credit. Informed consent was acquired and the study was completed in accordance with UCLA's Institutional Review Board. All older and younger adults were fluent in English with no self-reported color blindness.

Materials. Stimuli consisted of 96 English words, including nouns, adjectives, and verbs. During encoding, 48 of these words were randomly presented and paired with a point-value of 1, 2, 3, 10, 11, or 12 presented to the right of the word (e.g., "rivers 3"). These values were chosen to maximize the difference between words with low (1-3pt.) and high (10-12pt.) value. Each word was printed in one of four ink colors: red, yellow, lime green, or cyan blue. Four colors were used as these were the most distinct colors in the e-prime presentation software. Participants were not asked to memorize the point-value or word color, as these were later used to assess incidental memory. Words had a mean frequency of 4466.12 ($SD = 237.11$) occurrences per million in the Hyperspace Analogue to Language corpus (Lund & Burgess, 1996), and whether a word was designated as low-value, high-value, or a distractor was counterbalanced. During the recognition test, all 96 words—half that were presented at study and half that were new—were presented randomly, without their point-value and printed in white. All materials were presented on a desktop computer running Windows 7. All words were printed in 18 pt., Courier New font with a black background. The study was programmed onto the computer and data were recorded using e-prime (ver. 2.0) software with a keyboard.

Procedures. Participants completed the study individually. They were instructed that they would view a large set of words, each associated with a point-value they could earn later for recognition. They were told that their goal was to maximize their score. All 48 study items were presented individually for 3 s per word with a 0.5-s fixation cross between words. Next, participants completed a brief distractor task to reduce mental rehearsal, which consisted of seven simple multiplication and division problems. Before starting the recognition test, the meanings of the terms "Remember," "Know," and "Guess," were explained using an adapted form of Gardiner and Java's (1990) instructions (see the Appendix). Each participant was asked what they believed it meant to remember a word, and for inadequate responses, the experimenter gave further instruction.

The recognition test was self-paced, and participants were informed that they would lose 2 points for incorrect responses to discourage the otherwise optimal strategy of labeling all items as "old." Participants first reported how certain they were that each word was presented before on a 6-point scale: 1 "Definitely NEW," 2 "Probably NEW," 3 "Maybe NEW," 4 "Maybe OLD," 5 "Probably OLD," or 6 "Definitely OLD." After choosing any of the three "old" responses, they further reported whether they recognized the item due to remembering, knowing, or guessing. Next, they were asked what point-value each item was initially associated with, and what color it was printed in, with possible choices listed on the screen. When items were rated "new," they completed a filler question where they rated the pleasantness of the word.

Data analysis. Data were analyzed using SPSS (ver. 23) and ANOVAs were Greenhouse-Geisser corrected. Words worth 1–3 points were considered low-value, whereas those worth 10–12 were high-value. Prior to analysis, for younger and older adults separately, the fastest and slowest 2.5% of recognition trials were excluded. In line with advice by Ratcliff (1993) these criteria were chosen to eliminate the small proportion of responses that may have had abnormally high or low response times (RTs) attributable to factors such as a participant needing procedural clarification or a participant blindly making a quick response to progress through the study quickly. The proportion of excluded trials did not significantly differ across new, low-value, and high-value items for younger adults, $F(2, 20) = 2.78$, $p = .086$, or older adults, $F(2, 12) = 1.57$, $p = .249$.

Three older adults were excluded from color retrieval analyses, because they showed no variance in color response. Two younger adults and four older adults were excluded from analyses examining R-K-G responses, as their false alarm rate for remembered items was over two standard deviations above the average for younger adults (M = .11, SD = .18), and older adults (M = .23, SD = .33), respectively.

To examine recognition performance, signal detection measures A_z and B''_D were used. Recognition sensitivity, A_z, measures one's ability to distinguish old items from new items, and ranges from 0 to 1, with chance performance at 0.5. Unlike most recognition performance measures, A_z is largely unaffected by response bias, and is computed as the area under a cumulative hit versus false alarm rate curve where each confidence response from highest to lowest is treated as a "yes" response (Stanislaw & Todorov, 1999). B''_D is a measure of response bias computed using hit and false alarm rates, with positive values here indicating a bias toward labeling an item as new (Donaldson, 1992).

Results

Value effects on recognition performance. Older adults recognized a significantly smaller proportion of words than younger adults, $t(64) = -2.96$, $p = .004$, $d = -0.73$ (see Table 1). However, the false alarm rates of older adults and younger adults did not significantly differ, $t(64) = 0.82$, $p = .413$, $d = 0.20$. This difference in hit rate resulted in older adults having a significantly lower recognition sensitivity (A_z) than younger adults, $t(64) = -3.25$, $p = .002$, $d = -0.82$. Response bias (B''_D) was not found to be significantly different between older and younger adults, $t(64) = -0.06$, $p = .955$, $d < -0.01$. Both groups had a slight bias to label items as new.

To determine the effects of value and age group on recognition, a 2 × 2 repeated measures ANOVA was computed (see Table 1). A Significant Value × Age Interaction was observed, $F(1, 64) = 5.35$, $p = .024$, $\eta^2 = .77$. Post hoc analysis revealed that younger adults were significantly more likely to recognize low-value items than older adults, $t(64) = 3.48$, $p = .001$, $d = 0.86$. However, the hit rate to high-value items was not significantly different between younger adults and older adults, $t(64) = 1.58$, $p = .119$, $d = 0.39$. Similarly, a Value × Age Interaction for recognition confidence was observed, $F(1, 64) = 4.87$, $p = .031$, $\eta^2 = .71$. Post hoc analysis revealed, older adults had significantly higher confidence ratings for high-value items than for low-value items, $t(32) = 4.68$, $p < .001$, $d = 0.81$. In contrast, younger adults confidence did not significantly differ between high-value and low-value items, $t(32) = 1.27$, $p = .213$, $d = 0.22$. Still, even for high-value items, younger adults had higher confidence ratings than older adults, $t(64) = 2.40$, $p = .019$, $d = 0.59$. Younger ($M = 2.67$, $SD = 0.57$) and older adults ($M = 2.71$, $SD = 0.65$) did not significantly differ in their confidence to new items, $t(64) = -0.26$, $p = .792$, $d = -0.07$. The total number of points earned in the study significantly differed between older adults ($M = 178.03$, $SD = 54.39$) and younger adults ($M = 203.79$, $SD = 48.50$), $t(64) = -2.03$, $p = .046$, $d = -0.50$. Thus, older adults' reduced hit rate was primarily due to impaired memory for low-value items, and their memory for high-value items was largely intact.

Value and experiences of remembering, knowing, and guessing. To determine whether age or value were associated with differences in experiences of recollection, a repeated measures Age × Value × Memory Type (R-K-G) ANOVA was computed. The three-way interaction and all analyses involving age group were not found to be significant ($p \geq .545$). A significant value × memory type interaction was observed, $F(1, 58) = 11.58$, $p = .001$, $\eta^2 = .17$. Post hoc analysis indicated that a significantly greater proportion of high-value items ($M = .50$, $SD = .25$) received a Remember response than low-value items ($M = .37$, $SD = .23$), $t(59) = 4.80$, $p < .001$, $d = 0.62$. In contrast, the proportion of items given a Know response did not significantly differ between high-value ($M = .23$, $SD = .19$) and low-value items ($M = .24$, $SD = .21$), $t(59) = -0.30$, $p = .766$, $d = -0.04$. Guessing was significantly more prevalent for low-value items ($M = .39$, $SD = .26$) than high-value items ($M = .27$, $SD = .24$), $t(59) = 4.65$, $p < .001$, $d = 0.56$.

Incidental detail retrieval. When examining color retrieval for correctly recognized items, the Age × Memory Type (Remember or Know) × Value Interaction was not found to be significant, $F(1, 38) = 0.12$, $p = .730$, $\eta^2 < .01$, and age group had no main effect or interactions with other variables in this analysis ($p \geq .239$). A Significant Value × Memory Type interaction was observed, $F(1, 38) = 4.36$, $p = .044$, $\eta^2 = .10$ (see Figure 1). Specifically, participants were more likely to retrieve the color of known high-value items ($M = .32$, $SD = .31$) than remembered high-value items ($M = .19$, $SD = .17$), $t(48) = 2.40$, $p = .020$, $d = 0.36$; this difference was not significant for remembered and known low-value items, $t(40) = 1.72$, $p = .093$, $d = 0.27$. Interestingly, for Remember responses, there was a higher color retrieval rate for low-value items ($M = .36$, $SD = .30$) than high-value items ($M = .20$, $SD = .17$), $t(54) = 3.29$, $p = .002$, $d = 0.46$; this difference was not significant for Know responses, $t(41) = 0.61$, $p = .545$, $d = 0.09$. Overall retrieval of word color for both groups was not significantly different from chance ($p \geq .461$), though low-value Remember responses were associated with memory for the associated color at a level above chance performance ($p = .007$). Thus, recollection of high-value items was associated with a decrease in color retrieval compared to recollection of low-value items.

Table 1
Experiment 1 Recognition Test Results

Result	Younger adults	Older adults
Hit rate	.68 (.15)	.56 (.17)
False alarm	.24 (.15)	.27 (.16)
A_z	.78 (.12)	.69 (.10)
B''_D	.16 (.33)	.16 (.26)
RT (ms)	3279 (528)	6697 (2216)

	Recognition by item value			
	Younger adults		Older adults	
	Low-value	High-value	Low-value	High-value
Hit rate	.67 (.18)	.68 (.16)	.51 (.21)	.62 (.17)
Confidence	4.31 (.71)	4.47 (.65)	3.53 (.75)	4.07 (.72)
R	.40 (.24)	.52 (.25)	.33 (.22)	.49 (.26)
K	.24 (.16)	.23 (.15)	.23 (.25)	.23 (.23)
G	.36 (.26)	.26 (.24)	.43 (.25)	.28 (.24)

Note. Standard deviations presented in parentheses. A_z = recognition sensitivity; B''_D = response bias; RT = response time; R = proportion remembered; K = proportion known; G = proportion guessed.

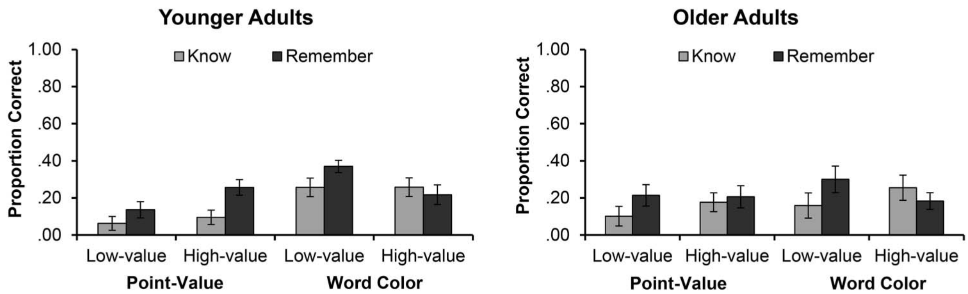

Figure 1. Incidental detail retrieval by word value and memory type (Remember or Know) for Experiment 1. Error bars represent one standard error from the mean.

When examining point-value retrieval for recognized items, the Age × Memory Type × Value Interaction was not found to be significant, $F(1, 38) = 3.69$, $p = .062$, $\eta^2 = .09$. Likewise, age group did not produce a significant main effect or any interactions ($p \geq .291$). A main effect of memory type was observed, such that correct point-value retrieval was significantly more likely after a Remember response ($M = .20$, $SD = .18$) than a Know response ($M = .11$, $SD = .15$), $F(1, 38) = 6.24$, $p = .017$, $\eta^2 = .14$. Although the three-way interaction was not statistically significant, it may bear mentioning that only younger adults showed a value × memory type interaction, $F(1, 25) = 5.53$, $p = .027$, $\eta^2 = .18$. Specifically, although younger adults more often retrieved high values through remembering than knowing, $t(29) = 3.48$, $p = .002$, $d = 0.67$, this difference was not significant in older adults, $t(20) = 0.95$, $p = .352$, $d = 0.21$. One limitation of this analysis was that participants were allowed to manually enter their response, and some reported point-values not used in this study (e.g., 6-points). The proportion of point-value responses that were invalid—anything except 1, 2, 3, 10, 11, or 12—was not significantly different between remembered ($M = .33$, $SD = .29$) and known ($M = .40$, $SD = .32$) items, $t(52) = -1.60$, $p = .117$, $d = -0.21$, suggesting that the above memory type effect was not solely due to a difference in invalid responding. When only valid point-value responses were examined, both age groups were more accurate than chance for recollected items ($p \leq .010$).

Discussion

The results of the current study support prior work that shows that older adults show impaired recognition relative to younger adults in a value-based memory task (cf. Castel, Farb, & Craik, 2007; Spaniol et al., 2014). Although older adults typically show an increased false alarm rate (Jacoby, 1999; Spaniol et al., 2014) in these types of tasks, the penalty for false alarms on this task may have led them to respond more conservatively. Consistent with our first hypothesis, high-value items were better recollected for both younger and older adults. Older adults show intact effects of value, using free recall (Ariel et al., 2015; Castel et al., 2011), and the current findings suggest that this also applies to recollection. Furthermore, in older adults, value was associated with increased confidence, suggesting that selectively encoded valuable items results in stronger memory traces. As previously observed with younger adults (Hennessee et al., 2017), high-value items were more likely to be recollected at test, and value did not have a substantial effect on knowing. These findings suggest that the relationship between value at encoding and increased recollection at retrieval may be relatively preserved in healthy aging.

Contrary to our second hypothesis, this benefit of value to recollection was intact in healthy older adults. Our third hypothesis, that older adults would show impaired binding of contextual information to valuable items, was not supported. The effects of value on memory for incidental details were similar for younger and older adults. Interestingly, although remembering was associated with more point-value retrieval, for word color there was a Value × Memory Type interaction such that recollected valuable items showed less retrieval. Point-value was a highly relevant detail on this task, so this detail may have been bound to well-encoded items. In contrast, word color was irrelevant to task performance, so when selectively encoding valuable items, participants may have focused on the item itself at the expense of encoding this detail. These findings are consistent with our previous work showing that although value increases recollection, it appears to decrease memory for irrelevant details associated with the studied item (Hennessee et al., 2017). These results are also generally consistent with the Arousal Based Competition (ABC) framework (Mather & Sutherland, 2011), in which arousal biases competition to encode high priority information at the expense of less important information. According to this framework, value may bias this competition, either based on top-down attention to the relevant aspects of valuable stimuli or on automatic increased salience of these stimuli at the expense of irrelevant dimensions. The present results extend this finding to older adults. Value may serve to focus attention on task-relevant information.

Experiment 2

To determine how value effects in healthy aging generalize to more naturalistic value judgments and stimuli, stimuli and methods were adapted from Lin, Horner, Bisby, and Burgess (2015). Lin et al. (2015) observed that younger adults had better memory for physiologically valuable items in imagined scenarios, but it was uncertain whether this form of value would also affect older adults' memory for items and item-context associations. Participants imagined being in different states of physiological need (e.g., hunger) and in different locations, then receiving two items sequentially. By examining both the congruency of the item with the state of need and participants' ratings of item value, we could dissociate whether value effects on recognition were due to the manipulation or to participants' appraisals of value. Unlike the point-values used in Experiment 1, value was manipulated here as an inherent property of the item. It is possible that older and younger adults will differ in terms of the effects of value on memory when they are not strategically attempting to maximize their score.

We predicted that both age groups would be more likely to recognize valuable items, showing that recognition memory can be enhanced by more naturalistic rewards. We also predicted that older adults would have worse retrieval than younger adults for the associated context for valuable items, as they may selectively allocate attentional resources to valuable items at the expense of this arbitrary detail. As in Experiment 1, it may be that value focuses attention on valuable items at the expense of context. On the other hand, the imagined context could lead to generation of semantic associations with the item which would lead to better memory for the context of high value items.

Method

Participants. Data from 30 older adults (10 women and 20 men) from Los Angeles were collected for this study. The age range was 62–92 (M = 78.43, SD = 7.40). This sample had no reported diagnoses of dementia, and a high self-reported health (M = 7.63, SD = 1.69). The highest level of education reported was college (n = 11), graduate school (n = 18), or unreported (n = 1). Participants were compensated $10 per hour of participation. Nine participants had participated in Experiment 1 and our pattern of results was largely unchanged when excluding these participants (Supplemental Material).

Data from 30 undergraduate UCLA students (17 women and 13 men) were used for cross-sectional comparison. Their age range was 18–25 (M = 20.53, SD = 1.68). They completed the study for course credit, and procedures conformed to the UCLA Institutional Review Board guidelines. All participants were fluent in English.

Materials and design.

Imagery task. During the encoding task, participants imagined being in one of four states of physiological need (hunger, thirst, cold, or tired) and in one of four locations (beach, kitchen, forest, or fields). No state-context combination was repeated. In four trials, a neutral condition was included where the subject was in no state of need. Instructions for neutral condition: "Imagine that you are just fine. You are not in any state of need, but just in an ordinary condition." Neutral trials allowed for examination of memory performance when value was not manipulated. Next, they viewed two images sequentially. Stimuli included 60 pictures of common items divided evenly into four categories meant to alleviate only one of the four states of need. These four categories included: food, drink, warmth-providing items (e.g., sweater, scarf), and items used for rest (e.g., bed, bath tub). Each presented item could either be congruent or incongruent with the current state of need. A congruent item represents something that helps alleviate that state of need, and should thus be valuable. In contrast, an incongruent item would not alleviate the need, making it low-value. These images were presented at a resolution of 130 × 130 on a white background. The item set was shortened from Lin et al. (2015) to avoid overtaxing older adult participants.

Forty images were presented at study. The recognition test included half of the items from the study phase, and the remaining 20 new items for a total of 40 items. Whether each item was presented at study or only at test was counterbalanced, and the order of images during both phases was randomized. Additionally, the order of which items on a trial were congruent or incongruent was counterbalanced, so that the effect of congruency was not confounded with item order. This study was programmed with e-prime software (ver. 2.0) on a Windows 7 desktop computer.

Procedures. Participants completed the study individually. Each imagery trial began with a 0.5 s fixation cross, followed by the location-state cue (e.g., thirsty in a forest) for 4 s, followed by another fixation cross for 4 s (see Figure 2). During the location-state presentation and fixation cross, participants were instructed to imagine being in the presented location with the state of need. Next, they saw two objects sequentially for 4 s each, with a 0.5-s blank screen in-between. Participants were instructed to imagine having the object, but not consuming it to alleviate their imagined need. To assess subjective value, each item was presented at the top of the screen and they reported how much they wanted it on a 6-pt scale (*not very much* to *very much*). They then used that scale to rate how vividly they imagined the location and state of need. For these questions, the relevant item was displayed and completion was self-paced. This was followed by a 1-s blank screen before the next trial began. The study phase consisted of 20 trials with 4 trials having a neutral state of need.

Next, participants completed 20 simple multiplication and division problems as a distractor task. During the recognition test, participants were shown each of the 40 test images randomly and asked whether they imagined the item earlier (yes/no) and how confident they were on a 6-pt confidence scale ranging from 1 "Definitely NEW" to 6 "Definitely OLD" (same as Experiment 1). For items rated "old," they indicated which location was previously associated with the item, with possible choices listed on the screen. This procedure was not used to assess state memory, as participants typically choose a state that is congruent with the item

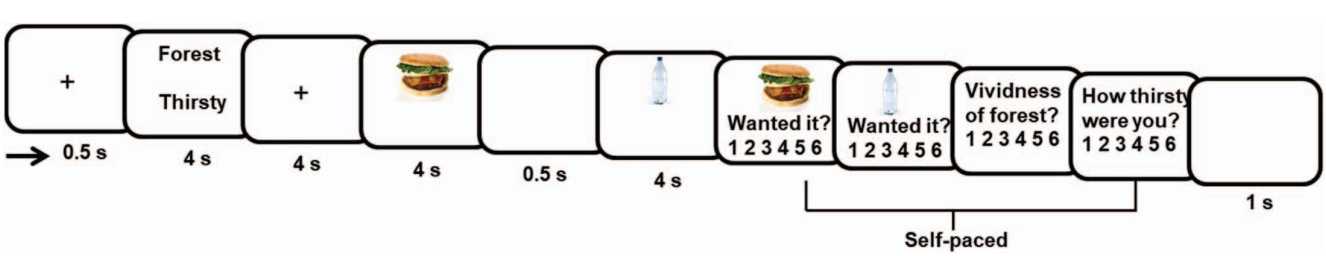

Figure 2. Study phase trial design (Experiment 2). Images courtesy of winnond and Suat Eman at FreeDigitalPhotos.net. See the online article for the color version of this figure.

(Lin et al., 2015). Instead, participants were presented with one of the states of need and rated whether they imagined that state with that item. Due to an error in the randomization, these data were not suitable for analysis. When items were rated "new," they instead completed a filler question where they rated how much they usually like the item. There was a 0.5-s fixation cross separating each test trial.

Data analysis. To examine the relationship between objective value, subjective value, and age group on recognition and incidental detail retrieval, repeated measures ANOVAs with Greenhouse-Geisser corrections were computed. Significant interactions were followed by post hoc *t* tests. Because only eight items had the state of need as neutral, no comparisons were planned for these items. Because of the relatively low trial count, we did not use a reaction time (RT) trim, like in Experiment 1. One older adult was excluded from subjective value analyses, because he or she gave all items a 1 rating, and another was excluded from confidence analyses for using the scale incorrectly.

Results

Value effects on recognition performance. Recognition performance was high, with no significant difference in hit rates between older and younger adults, $t(58) = 0.35$, $p = .731$, $d = 0.09$ (see Table 2). However, older adults had a significantly higher false alarm rate than younger adults, $t(58) = 2.70$, $p = .009$, $d = 0.70$. This increased false alarm rate led older adults to have a lower recognition sensitivity, A_z, than younger adults, $t(57) = -2.66$, $p = .012$, $d = -0.79$. The response bias measure, B''_D, was lower for older adults than younger adults, $t(58) = -2.76$, $p = .008$, $d = -0.71$, as older adults were slightly biased to label items as "old."

To examine whether the congruency of an item with its state of need—our measure of objective item-value—and age were related to recognition performance, a 2 × 2 repeated measures ANOVA was computed. The main effect of congruency was significant, as the hit rate was higher for valuable (congruent) items ($M = .88$, $SD = .19$) than incongruent items ($M = .80$, $SD = .22$), $F(1, 58) = 9.29$, $p = .003$, $\eta^2 = .14$. The main effect of age group was not significant, nor was the interaction ($p \leq .222$). A 2 × 2 repeated measures ANOVA examining congruency and age's relationship with confidence in retrieval also revealed a significant main effect of congruency such that valuable items ($M = 5.37$, $SD = 0.70$) were more confidently recognized than incongruent items ($M = 5.03$, $SD = 0.85$), $F(1, 57) = 11.78$, $p = .001$, $\eta^2 = .17$. The main effect of age and interaction were not found to be significant ($p \geq .520$). Thus, for both age groups, items that were valuable based on imagined state of need were selectively encoded, resulting in enhanced retrieval at test. Additionally, value resulted in increased confidence, suggesting that there was a stronger memory trace for valuable items.

The effects of high (5–6) and low (1–2) subjective value and age on hit rates were examined using a 2 × 2 repeated measures ANOVA. A significant main effect of subjective value was observed, as items with high subjective value ($M = .86$, $SD = .20$) were better recognized than low-value items ($M = .80$, $SD = .24$), $F(1, 55) = 5.51$, $p = .023$, $\eta^2 = .09$. The effect of age and interaction were not significant ($p \geq .812$). The number of items given a high subjective value rating did not significantly differ between younger ($M = 6.50$, $SD = 2.49$) and older adults ($M = 6.56$, $SD = 3.27$), $t(57) = -0.07$, $p = .946$, $d = -0.02$, though older adults gave more low ratings ($M = 9.00$, $SD = 3.78$) than did younger adults ($M = 7.13$, $SD = 2.33$, $t(57) = 2.29$, $p = .026$, $d = 0.61$. A 2 × 2 ANOVA examining subjective value and age showed that subjective value did not have a significant main effect on confidence, $F(1, 54) = 2.45$, $p = .124$, $\eta^2 = .04$. To examine whether subjective value varied predictably with objective value, a 2 (congruency) × 2 (age) ANOVA was computed. As expected, items congruent with the state of need ($M = 4.51$, $SD = 0.99$) received significantly higher subjective value ratings than incongruent items ($M = 2.42$, $SD = 0.75$), $F(1, 57) = 192.62$, $p < .001$, $\eta^2 = .77$. Overall, these results suggest that both the objective and subjective value of an item enhanced recognition, though only objective value was reliably associated with higher confidence. Furthermore, although older adults had worse overall recognition memory, both age groups exhibited these value-based enhancements of memory and performed comparably for items deemed valuable.

Value and context retrieval. When examining the proportion of trials with correct location retrieval, the main effect of age showed a strong trend, as younger adults ($M = .42$, $SD = .14$) were numerically more likely to retrieve the location than older adults ($M = .34$, $SD = .15$), $F(1, 57) = 3.93$, $p = .052$, $d = 0.55$. Both groups performed better than chance ($p \leq .003$). Additionally, an Age × Objective Value Interaction was observed, $F(1, 57) = 6.58$, $p = .013$, $\eta^2 = .10$ (see Figure 3). Post hoc *t* tests revealed that younger adults showed a strong trend to better remember the imagined location associated with items congruent with the state of need than incongruent items, $t(29) = 1.97$, $p = .058$, $d = 0.36$. In contrast, older adults showed a weak trend for better memory for imagined contexts on trials in which objects were incongruent with imagined need compared with valuable items, $t(28) = 1.74$, $p = .093$, $d = 0.32$. Older adults' location retrieval was similar to that of younger adults for incongruent items, $t(57) = 0.16$, $p = .873$, $d = 0.06$, but older adults showed

Table 2
Experiment 2 Recognition Test Results

Result	Younger adults	Older adults
Hit rate	.82 (.18)	.84 (.20)
False alarm	.13 (.17)	.26 (.20)
A_z	.91 (.05)	.83 (.17)
B''_D	.16 (.56)	−.24 (.56)
RT (ms)	2,580 (837)	4415 (1327)

	Recognition by item value			
	Younger adults		Older adults	
	Low-value	High-value	Low-value	High-value
Objective value				
Hit rate	.78 (.21)	.88 (.20)	.82 (.24)	.87 (.19)
Confidence	5.03 (.80)	5.44 (.45)	4.89 (1.14)	5.16 (1.15)
Subjective value				
Hit rate	.80 (.22)	.86 (.21)	.79 (.26)	.85 (.18)
Confidence	5.15 (.84)	5.29 (.60)	4.95 (1.09)	5.17 (1.21)

Note. Standard deviations presented in parentheses. A_z = recognition sensitivity; B''_D = response bias; RT = response time. Objective value congruency is presented:incongruent (low-value) and congruent (high-value).

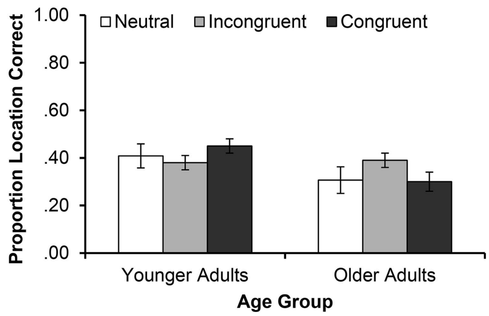

Figure 3. Proportion of correctly recognized items with their associated location retrieved at test by value and age group for Experiment 2. Error bars represent one standard error from the mean.

markedly lower context retrieval for valuable items, $t(57) = 2.98$, $p = .004$, $d = 0.78$. Thus, value may have strengthened the item-context association in younger adults, though it did not benefit older adults, and may have even reduced binding.

Discussion

Overall, these findings suggest that value effects on memory in older adults extend to more naturalistic stimuli and appraisals of value (i.e., physiological need) and can occur without any incentive for strategic encoding. In support of our first hypothesis, both age groups were more likely to recognize objectively and subjectively valuable items at test, extending previous work with memory tasks using arbitrary point-values. Subjective value ratings varied considerably, but in support of the value manipulation, congruent items received substantially higher ratings than incongruent items. A dissociation was observed between these two measures of value on recognition confidence, such that objective value, but not subjective value, was associated with greater confidence at recognition. Our second hypothesis, that older adults would show impaired context-item binding for valuable items, was supported. Younger adults showed a strong trend for increased binding between context and item for valuable items, whereas older adults did not show such a benefit, and in fact showed a numerical reduction in context memory for valuable items. One possible contributor to these results could be differences in mental imagery or arousal in older adults that impacted encoding of the context. However, the fact that older and younger adults showed similar effects of congruency with an imagined state of need suggests that older adults performed this aspect of the task successfully. It may be that older adults had more difficulty imagining the associated contexts at study. But, this would more likely result in only a main effect of age group, while the more interesting finding was the interaction with value and group. These results suggest that value is having different effects on encoding the imagined context in younger and older adults. Research has shown that older adults have worse memory for associated details (Ariel et al., 2015; Koen & Yonelinas, 2014), and the current findings illustrate that this deficit may be more prominent when encoding valuable items. Value may direct attention away from associated details, particularly for older adults, resulting in enhanced encoding of the valuable items.

General Discussion

In two experiments, we examined how value shapes the quality of recognition memory in younger and older adults. Whether value at encoding consisted of an associated point-value, congruency with a state of imagined physiological need, or subjective value rating, valuable items were better recognized or recollected. Thus, value effects generalize robustly to somewhat more naturalistic stimuli and measures of value. According to ABC theory (Mather & Sutherland, 2011), the amygdala modulates a frontoparietal memory network to selectively enhance processing of goal-relevant, and thus important, stimuli. It is likely that this goal-dependent modulation of memory processing also accounts for much of the value effects on memory observed in this study. Using the similar materials and procedure as Experiment 2, Lin et al. (2015) observed that amygdala activity at encoding correlated with successful retrieval. Our results suggest that this modulation by the amygdala may be relatively intact in older adults. Although older adults displayed worse recognition memory in both experiments, their ability to remember valuable items was comparable to younger adults. This supports a wide literature suggesting that value enhanced remembering is preserved in healthy aging (e.g., Ariel et al., 2015; Spaniol et al., 2014). With older adults' more limited memory, selectively encoding valuable items appears to be an adaptive strategy.

Given that older adults display robust enhancement of memory by value, the next question is what effect value has on the quality of their memory. In Experiment 1, both age groups had substantially increased remembering, but not knowing, for valuable items. This dissociation suggests that selectively encoding valuable items improves recognition primarily through enhancing recollection. We have observed that younger adults show increased recollection, but not familiarity, for valuable items (Hennessee et al., 2017), but we did not necessarily expect this to occur for older adults, as they generally exhibit episodic memory deficits (Koen & Yonelinas, 2014; Piolino et al., 2010). The current findings suggest that value promotes older adults' use of recollection during recognition. In both experiments, valuable items were more confidently recognized, further supporting that memory for valuable items is improved. These findings suggest that value strengthens episodic encoding in older adults resulting in a greater reliance on recollection at test.

A major focus of both experiments was to examine how memory for associated incidental details was affected by item value. In Experiment 1, remembering was associated with increased point-value retrieval, regardless of age group. In contrast, a Value × Memory Type Interaction was observed such that remembered high-value items showed *less* associated color retrieval than high-value known items and low-value recollected items. Though a reduction of detail retrieval during recollection may seem counterintuitive, these findings are consistent with Hennessee et al. (2017), and the different pattern of results for these details may stem from how they related to the task. Point-values were highly relevant to the task, and this finding suggests that when an item is deeply encoded—as observed by later recollection—there is greater binding between the item and its value. In contrast, details irrelevant to the task, such as word color, may not be attended to and thus not strongly bound to the item. Put another way, deeply encoding valuable items may bind relevant incidental details at the expense of irrelevant details. Emotionally arousing images lead to enhanced binding of within-object features, such as color and spatial location, as this arousal provides the focused attention necessary for binding to occur (see Mather & Sutherland, 2011 for a review). The current findings suggest that binding of task-relevant details is prioritized over irrelevant details. In fact, these irrelevant details may be bound to valuable items less well. Although no significant age effects were observed, a post hoc analysis suggested that whereas younger adults predominantly retrieved high point-values through recollection, older adults showed more familiarity for this detail. There may be age-related differences in the capacity to bind relevant details to valuable items, though this finding requires support from additional research.

In Experiment 2, older adults had worse memory for associated item context, consistent with research showing decreased memory for source details (Koen & Yonelinas, 2014). Specifically, an Age × Value Interaction showed that only younger adults had enhanced retrieval of context for valuable items. The direction of this effect was supported by younger adults' similar retrieval rates for incongruent items and their baseline memory performance when value was not manipulated. The imagined context was arbitrarily associated with the valuable item, but in everyday life item location is arguably one of the most important details to remember. When hungry, knowing you have an energy bar is only valuable if you can remember where it located. Thus, the association of item to a spatial context may be more relevant for valuable items than the association with arbitrary perceptual details of the item. Furthermore, the imagined context in the present task could enrich semantic encoding of the item. Considering the sizable amount of information provided on study trials, it is likely that older adults selectively attended to items at the expense of encoding the context. Unlike in Experiment 1, the reduced encoding of contextual details for valuable items in older adults may not be advantageous.

These results demonstrate that associative binding at encoding is sensitive to the importance of the to-be remembered information. These findings suggest that there may be capacity limitations in binding such that strategically focusing on item information reduces memory for irrelevant details. Because this effect was accompanied by better recollection of valuable items, and was similar for older and younger adults, it may be that this increased focus on important items during encoding is preserved in healthy aging and may underlie the good VDR performance in older adults. However, the results of Experiment 2 suggest that an increased focus on important items during encoding by older adults may also lead to reduced memory for contextual information that could be relevant. Because there was no incentive for selective encoding in Experiment 2, better learning of valuable items was unlikely intentionally strategic. Rather, the enhanced encoding of valuable items may have been relatively automatic. In older adults, resource limitations could lead to reduced encoding of contextual details when more attention is directed toward the important items. In younger adults, greater capacity could result in better binding of contextual details to important items. Our results suggest that aging may be accompanied by differences in the ability to encode contextual details, at least as measured by explicit memory for those details. Because older adults were sensitive to item value when presented at encoding, it was not the case that context memory deficits were entirely due to difficulty reinstating context at time of test. It would be interesting to see if older adults could demonstrate memory for contextual details using implicit measures, which would suggest that binding in explicit and implicit memory may be differentially affected in older adults.

The present results demonstrate that older adults selectively encode valuable items, leading to enhanced memory for these items. Furthermore, value increases recollection in older adults as much as in younger adults. Strongly encoding valuable items appears to promote binding of task-relevant details to items, though this may come at a cost to binding incidental perceptual and contextual details to the valuable item, particularly in older adults.

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(*Appendix follows*)

Appendix

Remember-Know-Guess Instructions (Adapted From Gardiner & Java, 1990)

Soon you will be shown a series of individual words and asked if you recognize the word from the studying phase or if it is a new word. Your ability to recognize the word is based on two processes: *remembering* and *knowing*. Before we get started, I will briefly describe what we mean by these two terms:

Often, when *remembering* a previous event or occurrence, we consciously recollect and become aware of aspects of the previous *experience*. At other times, we simply *know* that something has occurred before, but without being able consciously to recollect anything about its occurrence or what we *experienced* at the time. For example, if seeing a hammer reminds you that you nailed up a picture frame a few days ago, and you can remember what it was like nailing up that picture, you would label that *remembering*. In contrast, you may feel certain that the capital of France is Paris, but you may not be able to remember when or where you first learned this fact. You would label this *knowing*. The key distinction is that in remembering you can recall a specific experience, whereas in knowing, you cannot.

Before we go on, can you tell me what it means to remember given my earlier definition?

Today, remembering means that you consciously recall having seen the word previously in this study, and this can include any details related with that experience. This could be visual, such as being able to remember vividly what the word looks like. Also, if seeing the word earlier made you *think* of anything, and you can remember that on the recognition task, we will label that remembering. Now, please *only* give a remember response if you *are sure* that you have this conscious experience. In contrast, *knowing* means that you are certain you saw the word before, but you are unable to consciously remember the experience. A third response, *guessing*, will indicate that you are uncertain that you saw the word before.

Received April 11, 2017
Revision received August 23, 2017
Accepted September 8, 2017 ■