Title

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Forget Me Not: Encoding Processes in Value-Directed Remembering

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Abstract

Valuable items are often remembered better than less valuable items, but research on the mechanisms supporting this value effect is limited. In the current study, we sought to determine how items might be differentially encoded based on their value. In Experiment 1, participants studied words associated with point-values which were followed by a cue to either "Remember" the word for a later test or "Forget" the word. While to-be-forgotten words were recognized at a lower rate than to-be-remembered words, there was a significant effect of value for to-be-forgotten words when the "Forget" cue was presented immediately after the word, suggesting a relatively automatic enhancement of encoding by value. In Experiment 2, we examined to what extent subjects engage in more effective encoding strategies for high-value items. Subjects studied a list of words with different point-values, and were instructed either to construct a mental image of the item, use rote rehearsal to learn the items, or were not given any study strategy. There were significant effects of value for items that were studied under rote rehearsal or when no strategy instruction was given. However, effects of value were nearly eliminated when subjects used a mental imagery strategy for all items as this strategy boosted memory for low-value items. In Experiment 3, we sought to replicate Experiment 2 with a different deep encoding manipulation. Subjects were instructed to generate and say aloud a sentence containing each item. Consistent with Experiment 2, this manipulation eliminated the effects of value on recognition memory. Thus, it appears that subjects engage in more effective encoding strategies for high-value words because the benefit of value was substantially reduced when subjects were instructed to use deep encoding strategies. Together, these results suggest that valuable items are encoded more effectively due to both automatic and strategic mechanisms.

Keywords: recognition; memory; value; recollection; strategy; directed-forgetting

Word Count: 6576

When more information is present than can be remembered, learners typically selectively encode valuable items at the expense of less important ones (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Ariel, Price, and Hertzog, 2015). Selective encoding is used frequently in everyday life, such as attempting to remember one’s grocery list or focusing on important information in a textbook chapter. In free recall and recognition testing, items are more likely to be remembered when paired with a high monetary-value or point-value at study (i.e., where goal is to earn a high score) (Adcock et al., 2006; Castel, Murayama, Friedman, McGillivray, & Link, 2013; Cohen, Rissman, Suthana, Castel, & Knowlton, 2016; Mason, Farrell, Howard-Jones, & Ludwig, 2017; Shigemune, Tsukiura, Kambara, & Kawashima, 2014; Spaniol, Schain, & Bowen, 2013; Stefanidi, Ellis, & Brewer, 2018; Wolosin, Zeithamova, & Preston, 2012). This phenomenon has been labeled *value-directed remembering* (e.g., Castel, Benjamin, Craik, & Watkins, 2002). On one hand, people may be strategic and engage in deeper, more effective encoding of information they deem to be important to remember. For example, after a delicious meal one may try to “make a mental note” of the restaurant so it can be revisited. On the other hand, valuable information may be automatically strengthened in memory through effects of reward on memory representations. For example, a delicious meal may be remembered well because of the rewarding and pleasurable aspects of the experience even if no effort is made to encode the memory effectively. This more automatic effect of value is supported by a wide literature showing that valuable items are better remembered even when encoding is incidental (Madan & Spetch, 2012; Mather & Schoeke, 2011; Murayama & Kitagami, 2014) or an implicit memory test is administered (Madan, Fujiwara, Gerson, & Caplan, 2012). These two mechanisms are not mutually exclusive, and it is possible that the two contribute differentially depending on the circumstances.

Potential Mechanisms Supporting Value-Directed Remembering

Research on explicit strategy use during the selective encoding of valuable material is somewhat limited. In Ariel, Price, and Hertzog (2015) both younger and older adults reported using more elaborative encoding strategies when learning high-value word pairs (i.e., mental imagery, putting items in a sentence), and using these strategies was associated with better recall than simple rote rehearsal. These elaborative strategies use deeper semantic and associative processing, which produces a stronger memory trace (Craik & Lockhart, 1972; Richardson, 1998). In Cohen, Rissman, Hovhannisyan, Castel, and Knowlton (2017), a large proportion of participants also reported using different mnemonic strategies based on item-value. Interestingly, many of these participants reported that they did not even attempt to selectively learn valuable items, but despite this supposed indifference to value, they still exhibited better memory for valuable material. This suggests that although learners often differentially employ mnemonic strategies based on item-value, some of the benefits of value are likely independent of strategy use.

Although it is possible value enhances memory primarily due to deeper, elaborative encoding, another possibility is that valuable items are selectively-attended, resulting in increased mental rehearsal. Indeed, when participants are given a limited time to study items differing in value, they will allocate a substantially disproportionate amount of time to studying the highest-value items (Ariel, Dunlosky, & Bailey, 2009; Ariel, Price, & Hertzog, 2015; Castel et al., 2013). This allocation of study-time coincides with enhanced retrieval of the valuable items (Castel et al., 2013), and suggests that this value-related selective-attention is often intentional. According to the agenda-based regulation framework of study-time allocation, time, resources and effort are allocated based on a goal-oriented agenda that aims to maximize performance (Ariel, Dunlosky, & Bailey, 2009; Dunlosky & Ariel, 2011). Thus, if one can only remember a subset of the items being studied, the agenda will favor allocation of these things towards the most valuable items. In line with this framework, a commonly reported strategy is to ignore low-value items resulting in higher scores (Ariel, Price, & Hertzog, 2015; Robison & Unsworth, 2017). Additionally, valuable items may benefit from enhanced semantic processing. High-value cues have been shown to result in increased activity in ventrolateral prefrontal cortex (VLPFC), pre-supplementary motor area, and posterior lateral temporal cortex (Cohen, Rissman, Suthana, Castel, & Knowlton, 2014; Cohen et al., 2016). These three regions have all been associated with deep semantic processing (Binder et al., 2009; Binder and Desai, 2011). In Cohen et al. (2016), younger adults who effectively increased activity in these regions for valuable items showed the strongest benefits of value, whereas older adults who decreased activity for low-value items performed best. It has not yet been determined whether such semantic processing differences are due to conscious strategy use.

Whereas the above literature suggests that value’s effect on memory is supported by learners’ intentional use of agenda-based encoding strategies and selective direction of attention, other researchers have focused on mechanisms that may support value’s effect on memory in a relatively automatic fashion based on proximity to reward or value. Much of this work follows from studies of the mesolimbic reward system, suggesting that activity in these dopaminergic regions is increased for valuable items compared to less valuable items, which promotes the consolidation of memory for valuable items (Adcock et al., 2006; Carter, MacInnes, Huettel, & Adcock, 2009; Spaniol, Schain, & Bowen, 2013). More specifically, the nucleus accumbens and ventral tegmental area (VTA) are activated in response to high-value cues and this response is thought to underlie anticipation of large gains and losses (Carter et al., 2009). According to one popular hypothesis, dopaminergic signaling from the VTA in response to rewarding stimuli modulates hippocampal activity, and this signaling strongly influences whether new learning is persistently stored in long-term memory (Bethus, Tse, & Morris, 2010; Rossato, Bevilaqua, Izquierdo, Medina, & Cammarota, 2009; see Sugrue, Corrado, & Newsome, 2005 for a review).

Overview of the Current Experiment

In the current study, we sought to determine the contributions of strategic and automatic encoding mechanisms in value-directed recognition. One method of examining the relative contribution of different encoding mechanisms was devised by Gardiner, Gawlik, and Richardson-Klavehn

(1994), who used a directed-forgetting procedure with a cue to remember or forget the word presented either immediately or a few seconds after the word was presented. In this way, the effects of directed-forgetting could be measured, as well as the effects of elaborative encoding, which occurred when participants received a cue to remember immediately after the item was presented. When the cue was delayed, participants appeared to engage in maintenance rehearsal until the cue was presented, with little time for further elaborative rehearsal before the next item appeared. In Experiment 1 we used a similar directed-forgetting paradigm where each item was designated as to-be-remembered (TBR) or to-be-forgotten (TBF) after a variable delay during study, and then both TBR and TBF items were presented at test. The learn cue was either presented immediately after the word or after a 5 s delay, and value was manipulated by pairing each item with a point-value (3 or 12 pts.) that would be earned for later recognition. Delaying the cue leads participants to primarily keep an item in mind through maintenance rehearsal, as it is not in their interest to expend cognitive resources elaborately encoding the item when a forget cue may appear (Gardiner, Gawlik, & Richardson-Klavehn, 1994; Woodward, Bjork, Jongeward, 1973). Thus, trials with a delayed cue encourage increased maintenance encoding at the expense of elaborative encoding. In contrast, an immediate “Remember” cue encourages elaborative encoding, as evidenced by improved recollection (Gardiner, Gawlik, and Richardson-Klavehn, 1994). Thus, if value’s effect on recognition is primarily due to increased maintenance rehearsal, valuable items should be remembered relatively better when the directed-forgetting cue is delayed, whereas if participants engage in more elaborative encoding for high-value items, this effect should be greatest for items with an immediate Remember cue. Finally, if value's effect on recognition is largely automatic, this would be observable by value enhancing memory despite an immediate forget cue. Based on the findings of Ariel, Price, and Hertzog (2015) and Cohen et al. (2017), we hypothesized that value effects would be most pronounced on trials supporting elaborative encoding.

Experiment 1

Method

Participants

Data from 34 undergraduate students from University of California, Los Angeles (UCLA) were collected. Two participants were excluded from all analyses for having recognition sensitivity (see Data Analysis section) more than 2.5 standard deviations below average, resulting in a total sample size of 32 (23 women and 9 men). Their age range was 18-38 (M = 21.50, SD = 3.46). This sample size was selected as it would allow for an approximate power of .81 to detect a medium-sized effect, as computed using GPower (version 3.0; Heinrich Heine Universität Düsseldorf; http://www.gpower.hhu.de/en.html). 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.

Materials

Stimuli consisted of 96 six-letter English words, including nouns, adjectives, and verbs. These words were selected to have a similar frequency (*M* = 4466.12 occurrences per million, *SD* = 237.11) in the Hyperspace Analogue to Language corpus (Lund & Burgess, 1996). During encoding, 48 of these words were randomly presented and paired with a point-value of 3 or 12 presented to the right of the word (e.g., “rivers 3”). These values were chosen to maximize the difference between low (3 pts.) and high (12 pts.) value items while only having two options for later source retrieval. Each word was printed in either red (RGB value: 255, 0, 0) or blue (RGB value: 0, 0, 255). Participants were not asked to memorize the point-value or word color; these details were used to assess incidental memory. Finally, each word was associated with either a learn (“LLLL”) or forget (“FFFF”) cue. Of the 48 study items, each possible point-value x word color x learn cue combination was assigned an equal number of trials, and all words were randomly assigned to each of these variable combinations or to be a new item at testing. During the recognition test all 96 words (half new) were presented in random order without a point-value and printed in black ink. All materials were designed and presented on a desktop computer using the Collector program (Gikeymarcia/Collector, n.d.; https://github.com/gikeymarcia/Collector). All words were printed in 29 pt. Open Sans font with a white background.

Procedure

Participants completed the study individually in a private computer lab. They were told they would view a large number of words, each paired with a point-value they would earn if they could remember the item, and that their goal was to maximize their score. They were told that items paired with a learn cue (“LLLL”) were to be learned for a later memory test and items paired with a forget cue (“FFFF”) could be forgotten. Each of the 48 study items were split into two cue delay blocks. In the short cue delay block, all items were presented individually for 2 s each, a learn/forget cue was presented for 1 s, and then there was a fixation cross for 5 s (Figure 1). In the long delay block, the order of the learn/forget cue and fixation cross were reversed, though the total duration of encoding was equal. Whether the long delay or short delay block was presented first was counterbalanced across participants. After encoding, a brief distractor task was completed to reduce additional rehearsal, which consisted of 10 simple multiplication and division problems.

Finally, a self-paced recognition test was completed. Participants were informed that they should disregard that some items were previously paired with a forget cue, as they would still earn their associated points. Additionally, to discourage them labeling all items as old, they were told they would lose 2 points for incorrect responses and to answer as accurately as possible. Participants first rated how confident they were that each item was or was not 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". For items rated as old (4-6), they then reported whether each item was worth 3 or 12 points and whether it was printed in red or blue ink. For items rated as new (1-3), they completed a filler question where they rated the pleasantness of the word.

Data Analysis

Data were analyzed using SPSS (ver. 22) and ANOVAs were Greenhouse-Geisser corrected. Recognition performance was examined using the signal detection sensitivity measure A_z. Recognition sensitivity, A_z, measures one's ability to distinguish old items from new ones and ranges from 0 to 1 with chance performance at 0.5. Unlike most measures of recognition performance, this measure is largely unaffected by response bias and is computed as the area under the hit rate by false alarm rate curve where each confidence response from highest to lowest confidence is treated as an "old" response (Stanislaw & Todorov, 1999). Memory performance for incidental details (i.e., color and point-value) was near chance, thus these data were excluded from analysis.

Results

Recognition Performance and Directed-Forgetting

Participants achieved a relatively high overall recognition sensitivity, measured with A_z (M = .81, SD = .07), due to having a fair hit rate (M = .72, SD = .13) and a low false alarm rate (M = .21, SD = .11). A robust main effect of cue was observed, $F(1,31) = 83.51$, $p < .001$, $\eta_p^2 = .73$, such that TBR items (M = .82, SD = .07) were recognized with higher sensitivity than

TBF items (*M* = .73, *SD* = .07). Thus, the cue was effective in modifying encoding. Item-value was also effective in modifying encoding, as high-value TBR items (*M* = .83, *SD* = .08) were recognized with higher sensitivity than low-value TBR items (*M* = .81, *SD* = .07), $F(1,31) = 4.78$, $p = .037$, $\eta_p^2 = .13$.

Effects of Elaborative Encoding

To determine the extent that elaborative encoding contributed to value-directed remembering, we next examined the effects of Cue and Delay for high-value and low-value items (Figure 2). A significant Value x Cue x Delay interaction was observed, $F(1,31) = 5.19$, $p = .030$, $\eta_p^2 = .14$. For high-value items, most importantly, the Cue x Delay interaction was not significant, $F(1,31) = 0.06$, $p = .802$, $\eta_p^2 < .01$, though a substantial main effect of Cue was observed, $F(1,31) = 50.69$, $p < .001$, $\eta_p^2 = .62$, such that TBR items were better remembered than TBF items. Sensitivity did not significantly differ between valuable TBR items paired with an immediate or delayed learn cue, $t(31) = 0.91$, $p = .371$, $d = 0.17$. These results indicate that participants better remembered valuable items associated with a learn cue, but that having that cue immediately after learning, thus allowing for the maximum amount of elaborative encoding, did not significantly affect later retrieval.

When examining low-value items, a significant main effect of Cue was again observed, $F(1,31) = 46.84$, $p < .001$, $\eta_p^2 = .60$, such that TBR items were better remembered than TBF items. Although a significant Cue x Delay interaction was observed, $F(1,31) = 8.14$, $p = .008$, $\eta_p^2 = .21$, this was largely due to performance differences for TBF items as no significant difference was observed between low-value items given an immediate or delayed learn cue, $t(31) = 1.04$, $p = .306$, $d = 0.21$.

Automatic Effects of Value on Memory

Relatively automatic contributions to value-directed remembering were examined by looking at performance for items paired with an immediate "Forget" cue (Figure 3). Greater recognition sensitivity was observed for high-value items than low-value items followed by an immediate forget cue, $t(31) = 2.87$, $p = .007$, $d = 0.51$. Note that both high-value items, $t(31) = 14.38$, $p < .001$, $d = 2.54$ and low-value items, $t(31) = 7.78$, $p < .001$, $d = 1.38$ were recognized with better than chance performance.

Discussion

Participants showed strong directed-forgetting, suggesting that this manipulation was effective in altering encoding. Perhaps most importantly, we observed a strong value-directed remembering effect for items paired with an immediate forget cue. As deliberate encoding is substantially reduced with an immediate forget cue (Bjork, 1989; Wylie, Fox, & Taylor, 2008), this suggests that a relatively automatic process is contributing to value's effect on memory. One candidate mechanism is that valuable items are producing increased activity in reward-related dopaminergic systems, and this activity enhances encoding of these items. Prior work in healthy subjects has shown enhanced memory for items presented in temporal proximity to rewards (Murayama & Kitagami, 2014), consistent with the idea that the presentation of unexpected reward increases dopamine release in hippocampus, enhancing encoding of proximal material. In a neuroimaging study of value-directed remembering, younger adults were shown to have increased activity in midbrain dopaminergic regions in response to the value cue (Cohen et al., 2016) consistent with the hypothesized role of this system in value effects on memory.

Contrary to our predictions, we did not observe a significant increase in recognition sensitivity when participants were given an immediate cue to remember the word, thus prolonging the period for elaborative encoding. Although TBR items were much more likely to be remembered than TBF items, performance did not significantly differ whether the cue came immediately after the word or after a 5 s delay. When the cue was presented after the delay, there was only 1 s until the next word appeared. It seems unlikely that 1 s of encoding was enough to fully use more complex elaborative strategies such as mental imagery or putting items into a sentence. Although studies involving multiple study-test lists with feedback find that participants selectively apply elaborative strategies based on item-value (Ariel, Price, & Hertzog, 2015; Cohen et al., 2017) it may be that such differences in elaboration are less pronounced when learning a single list without intermittent feedback. This feedback may help them develop more selective encoding strategies (Cohen et al., 2017). Thus, participants may have engaged primarily in maintenance rehearsal in all conditions except the immediate forget condition. We also only observed a significant benefit of increased maintenance rehearsal for low-value items (see Supplemental Data); this manipulation may have counteracted the common strategy of deliberately ignoring items of low value during the study phase (Ariel, Price, & Hertzog, 2015; Robison & Unsworth, 2017).

Experiment 2

In Experiment 1, we found evidence of relatively automatic enhancement of encoding of high-value words, in that these words were recognized better than low-value words after an immediate “Forget” cue. Effects of value were relatively small for conditions in which participants were instructed to remember items, suggesting that value did not affect encoding strategies. However, a limitation of Experiment 1 was that the directed-forgetting manipulation may have discouraged participants from differentially engaging in effortful encoding strategies. Participants may have focused attention on whether or not the items were TBR or TBF and they may have found it too demanding to also vary encoding strategy by value. In order to assess whether participants are able to engage in elaborative encoding of high-value items, in Experiment 2 we removed the directed-forgetting manipulation and instead simply instructed participants to learn using different encoding strategies. In three between-subjects groups, participants were either given no instruction regarding what strategy to use or they were instructed to use a mental rehearsal strategy or a mental imagery strategy for all learned items. After recognition testing, participants reported whether they adhered to their assigned strategy. We hypothesized that if differences in recognition accuracy between high- and low-value items were due in part to differences in the depth of encoding, instructing participants to encode all learned items with an elaborative mental imagery strategy would mitigate these differences. Our previous work has shown that high-value items are more likely to be recollected at test (Hennessee, Castel, & Knowlton, 2017; Hennessee, Knowlton, & Castel, 2018). Thus, if participants were achieving superior recollection of high-value items because of differential use of elaborative encoding strategies, we predicted that instructing participants to use a mental imagery strategy for all learned items would reduce this difference in recollection. Alternatively, if the effects of value are restricted to automatic strengthening of memory representations, there may continue to be a difference between high-value and low-value items, even though overall recognition may be better when this elaborative encoding task is used. To assess recollection, we used a Remember-Know-Guess design where participants introspected whether each item they classified as “old” was accompanied by recollection of the study episode including associated details (Remember response), a strong sense of familiarity (Know response), or whether their recognition response was a guess (Gardiner & Ramponi, 1998; Tulving, 1985). We also assessed memory for the highest confidence responses (‘Definitely Old’) as there are appreciable differences between confidence and recollection (Gardiner & Java, 1990) that may also lead these responses to be differentially affected by encoding strategy. In this way, we were able to assess whether value affected the quality of recognition and how this compared with the effect of encoding instruction.

Method

Participants

Data from 108 UCLA undergraduate students were collected for this experiment.

Participants in the rehearsal and imagery conditions who reported using the pertinent strategy less than 50% of the time were excluded from all analyses, leaving 36 participants in the No Instruction condition, 20 participants in the Mental Rehearsal condition, and 24 participants in the Mental Imagery condition. Our key findings for Experiment 2 were largely replicated when using a stricter exclusion criteria of 80% strategy use (Supplemental Data). This final sample of 80 students (59 females and 21 males) had an age range of 18-27 years (*M* = 20.20, *SD* = 1.64). This sample size was selected as it would allow for an approximate power of .85 to detect a medium-sized instruction condition by value interaction, as computed using GPower. 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.

Materials

Stimuli included 96 English nouns, and the first letter of each word was capitalized. All words were drawn from clusters 7 and 8 of the Toglia and Battig (1978) word norms, as these clusters were high in imagability. Words were selected to have similar imagability (*M* = 5.66, *SD* = 0.40, range: 4.75-6.61), concreteness (*M* = 5.75, *SD* = 0.37, range: 4.50-6.48), and number of letters (*M* = 5.78, *SD* = 0.73, range: 5-7). During encoding, 48 of these words were randomly presented and paired with a point-value of 1, 2, 3, 10, 11, or 12 to the right of the word. These values were chosen to maintain a large difference between low-value (1-3 pts.) and high-value (10-12 pts.) items and yet to provide a larger range of values than Experiment 1. This wider selection of point-values was also used to make the work more comparable to recent examinations of value and memory (Cohen et al., 2016; Hennessee, Knowlton, & Castel, 2018). Whether an item was assigned to be low-value, high-value, or a new item at test was counterbalanced across participants. During the recognition test all 96 words (half new) were presented in random order in black on a white background screen without a point-value. All materials were presented on a desktop computer with the E-prime 2.0 software (Psychology Software Tools Inc., Pittsburgh, PA; https://www.psnet.com). All words were presented in 32 pt. Arial font.

Procedure

Participants completed the study individually in a private computer lab. They were told they would view a large selection of words, each paired with a point-value they would earn if they could remember the item, and that their goal was to earn a high score. Instructions regarding how they should learn items were varied between-subjects. The No Instruction condition was not provided instruction as to which strategy to use, the Mental Rehearsal condition was instructed to think of the word repeatedly (e.g., “Knight, Knight, Knight, . . .”), and the Mental Imagery condition was asked to picture in mind what the item looks like. During the encoding phase, participants were presented with 48 words that were each on screen for 2 s and with a 1 s fixation cross between words. After encoding, participants completed seven multiplication and division problems as a distractor task. Afterwards, they were instructed regarding the meaning of Remembering, Knowing, and Guessing with instructions adapted from Gardiner and Java (1990; see Appendix A). Participants were asked to explain what Remembering meant in the context of this study, and corrected if their response was deemed unsatisfactory.

Finally, participants completed a self-paced recognition test including 96 words (half new). Participants were told they would lose 2 points for incorrect responses to discourage labeling all items as old. Participants first rated how confident they were that each item was presented before on the 6-point scale described in Experiment 1 (1 “Definitely New” to 6 “Definitely Old”). For items rated as old (4-6), they reported whether they recognized the item due to Remembering, Knowing, or Guessing. For items rated as new (1-3), they completed a filler question where they rated the pleasantness of the word. This filler question was added to prevent participants from rating items as new to reduce the duration of the experiment. At the end, participants were asked to rate the proportion of time (0-100% in 10-percent increments) they used the following strategies: (a) mental imagery, (b) mental rehearsal, (c), putting items into a sentence. These three ratings were made independently, so the proportion of time spent using these strategies was not required to sum to 100%. These strategies were targeted because Ariel, Price, and Hertzog (2015) found that they were commonly used.

Results

Strategy Use

First, the reported proportion of time participants used each strategy was examined to determine how well they followed instructions (Figure 4). The relationship between the encoding condition and use of the three strategies was examined using a 3 x 3 repeated measures ANOVA. A significant Condition x Strategy interaction was observed, $F(4, 145) = 6.86$, $p < .001$, $\eta_p^2 = .15$. In the Rehearsal condition, using rehearsal was significantly more common than the other two strategies (all p's ≤ .002). Likewise, in the Mental Imagery condition, using imagery was significantly more common than the other two strategies (all p's ≤ .005). Finally, the No Instruction condition was examined to better understand normal strategy use on this value-directed remembering task. In this condition, rehearsal was the most common strategy (all

p's ≤ .034), though mental imagery was also quite common and was used more frequently than putting items into a sentence, $t(34) = 3.03$, $p = .005$, $d = 0.51$.

Memory Performance

The influences of encoding condition and item-value on recognition sensitivity (A_z) were examined using a 3 x 2 repeated measures ANOVA (Figure 5; Table 1). The Condition x Value interaction only showed a trend, $F(2, 77) = 2.54$, $p = .085$, $\eta_p^2 = .06$. However, a follow-up ANOVA comparing sensitivity between the No Instruction and Mental Imagery condition did show a significant Condition x Value interaction, $F(1, 58) = 4.41$, $p = .040$, $\eta_p^2 = .07$. In the No Instruction condition, sensitivity was considerably higher for high-value items than low-value items, $t(35) = 4.38$, $p < .001$, $d = 0.74$. In the Rehearsal condition, sensitivity was also significantly higher for high-value items than low-value items, $t(19) = 3.61$, $p = .002$, $d = 0.82$. In the Mental Imagery condition, the value effect on sensitivity was smaller though still significant, $t(23) = 2.11$, $p = .046$, $d = 0.47$. Differences in sensitivity by value were considerably reduced in the Mental Imagery condition largely because although the sensitivity to low-value items significantly improved compared with the No Instruction condition, $t(58) = 3.43$, $p = .001$, $d = 0.91$, high-value items only showed a trend for improvement, $t(58) = 1.93$, $p = .058$, $d = 0.51$.

We then examined influences of encoding condition and item-value on the proportion of items given the highest confidence response (‘Definitely Old’). The 3 x 2 repeated measures ANOVA showed a significant interaction of value and condition, $F(2, 77) = 4.31$, $p = .017$, $\eta_p^2 = .10$. In the No Instruction condition, ‘Definitely Old’ responses were given to a significantly higher proportion of high-value items ($M = .54$, $SD = .21$) than low-value items (*M* = .34, *SD* = .20), $t(35) = 5.17$, $p < .001$, $d = 0.86$. Likewise, in the Rehearsal condition, ‘Definitely Old’ responses were more common for high-value items (*M* = .55, *SD* = .23) than low-value items (*M* = .34, *SD* = .17), $t(19) = 3.72$, $p = .001$, $d = 0.84$. However, in the Mental Imagery condition, the proportion of items given a ‘Definitely Old’ response did not significantly differ between high-value (*M* = .67, *SD* = .20) and low-value items (*M* = .62, *SD* = .19), $t(23) = 1.47$, $p = .156$, $d = 0.30$. Unlike recognition sensitivity, the highest confidence responses increased in frequency in the imagery condition both for low-value items $t(58) = 5.53$, $p < .001$, $d = 1.46$, and valuable items, $t(58) = 2.43$, $p = .018$, $d = 0.65$.

Experiences of Remembering, Knowing, and Guessing

To examine whether the proportion of correctly recognized old items given a Remember, Know, or Guess response differed as a function of item-value and encoding condition (Figure 6; Table 1), a 3 x 2 x 3 repeated measures ANOVA was computed. The Memory type (R-K-G) x Condition x Value interaction was not found to be significant, $F(2, 77) = 1.54$, $p = .221$, $\eta_p^2 = .04$. A significant Memory type x Condition interaction was observed, $F(2, 77) = 11.01$, $p < .001$, $\eta_p^2 = .22$. Additionally, a significant Memory Type x Value interaction was observed, $F(1, 77) = 7.32$, $p = .008$, $\eta_p^2 = .09$. Posthoc analyses revealed that valuable items were more likely than low-value items to receive a Remember response at test, $t(79) = 3.85$, $p < .001$, $d = 0.43$, and less likely to receive a Guess response, $t(79) = -3.92$, $p < .001$, *d* = -0.46. The proportion of recognized items that received a Know response did not significantly differ by value, $t(79) = 1.31$, $p = .193$, $d = 0.15$.

Next, we examined how the proportion of items given a Remember response in the Mental Imagery condition compared with the No Instruction condition. We observed a significant Value x Condition interaction, $F(1, 58) = 4.15$, $p = .046$, $\eta_p^2 = .07$. More specifically, in the No Instruction condition, recognized high-value items were more likely to receive a Remember response than low-value items, $t(35) = 3.71$, $p = .001$, $d = 0.62$. But, the frequency of Remember responses did not significantly differ by value in the Mental Imagery condition, $t(23) = 0.74$, $p = .467$, $d = 0.15$. Interestingly, the Mental Imagery condition showed higher rates of remembering than the No Instruction condition both for high-value items, $t(58) = 3.52$, $p = .001$, $d = 0.96$ and low-value items, $t(58) = 5.53$, $p < .001$, $d = 1.47$.

Discussion

A key finding was that instructing participants to learn all items using mental imagery mitigated value’s enhancement of recognition. In contrast, valuable items were recognized and recollected at significantly higher levels than less valuable words when participants primarily used a less effective mental rehearsal strategy. Value-based differences in recognition sensitivity were substantially reduced in the Mental Imagery condition, and the frequency of highest confidence responses and recollection did not differ significantly by item-value because performance was sharply enhanced for low-value items. These results support the idea that participants are engaging in more elaborative encoding of high-value words, as the value effect was nearly eliminated when participants were instructed to engage in elaborative encoding of low-value words as well. The small effect of value that remained may have resulted from automatic effects of value as described in Experiment 1. In the other conditions, subjects reported primarily using a less effective rehearsal strategy, and recognition was significantly better for high-value words, and this effect of value was much greater than for the mental imagery condition. It is possible that in these conditions, an automatic enhancement of encoding occurred for high-value words. It is also possible that participants did engage in some elaborative encoding for high-value words, as they reported using deeper encoding strategies for some of the time. This interpretation is consistent with our prior neuroimaging work showing that participants with high value-related selectivity in memory show increased activity in left hemisphere semantic processing regions when encoding valuable items (Cohen et al., 2014).

Experiment 3

To further examine the role of differential encoding in value-directed remembering, we replicated Experiment 2 using a new encoding manipulation. Our primary goal was to determine whether using another type of deep encoding, such as putting all items into sentences, would also mitigate value's effect on recognition. Additionally, one limitation of Experiment 2 was that there was some ambiguity as to how well participants followed their encoding instructions, so we incorporated a more easily monitored encoding strategy manipulation. To examine value effects when all items are shallowly encoding, we replaced the Mental Rehearsal condition with a Consonant Counting condition where participants had to report out loud whether each word at encoding had an even or odd number of consonants. To examine value effects during deep encoding, the Mental Imagery condition was replaced with a Sentence Generation condition where participants had to generate and say aloud a sentence incorporating the current word. Consonant counting and sentence generation were selected as manipulations as they have previously been shown to encourage shallow and deep encoding, respectively, as evident by recognition performance (Smith, MacLeod, Bain, & Hoppe, 1989). Importantly, experimenters can easily monitor participant engagement in these two encoding methods.

Method

Participants

Data from 108 UCLA undergraduate students were collected for this experiment. Seven participants were excluded for failing to count consonants or generate sentences out loud for at least 80% of encoding trials, resulting in a final sample size of 101. There were 36 participants in the No Instruction condition, 31 in the Consonant Counting condition, and 34 in the Sentence Generation Condition. This sample included 78 females and 23 males with an age range of 18-36 (*M* = 20.85, *SD* = 2.36). Participants gave informed consent and completed the study for course credit.

Materials and Procedure

Experiment 3 was designed using the same materials and procedure as Experiment 2 but with new encoding instructions. As in Experiment 2, participants viewed 48 words at encoding and 96 words at test (half old). At encoding, items were paired with either a low-value (1-3 pts.) or high-value (10-12 pts.). Item-value and whether each word was presented at encoding or as a new item during testing was counterbalanced across participants. Participants were told that they would view a large series of words and to remember words with the goal of earning a high score. Stimulus presentation time was increased from 2 s per word to 3 s per word in order to provide sufficient time to complete the assigned encoding task. As before, we collected confidence judgments and Remember, Know, and Guess responses at test.

Prior to encoding, participants were given one of three sets of encoding instructions that were manipulated between-subjects. In the No Instruction group, participants received no further instruction after being told their goal was to earn a high score. In the Counting Consonants group, participants were told to mentally tally how many consonants were in a word and say out loud whether that number was odd or even (e.g., rivers, “four”). In the Sentence Generation group, participants were asked to use the word in a short sentence. For these last two conditions, participants were given a single practice trial to ensure they understood the instructions. The experimenter reminded participants to follow this encoding procedure when necessary and recorded instances of participants not saying their answers aloud for at least 80% of encoding trials.

Results

Memory Performance

A 3 x 2 ANOVA indicated that there was a Condition x Value interaction in predicting recognition sensitivity (Az; Figure 7; Table 2), $F(2, 98) = 5.55$, $p = .005$, $\eta_p^2 = .10$. In the No Instruction condition, sensitivity was significantly higher for high-value items relative to low-value items, $t(35) = 3.45$, $p = .001$, $d = 0.58$. However, sensitivity did not significantly differ between high-value and low-value items for the Consonant Counting condition, $t(30) = 0.08$, $p = .937$, $d = 0.01$, nor for the Sentence Generation condition, $t(33) = 0.73$, $p = .471$, $d = 0.13$. Compared with the No Instruction condition, Consonant Counting produced worse memory for high-value items, $t(65) = -4.06$, $p < .001$, $d = -0.99$, but not low-value items, $t(65) = -1.37$, $p = .176$, $d = -0.33$. Compared with the No Instruction condition, Sentence Generation produced both better sensitivity for high-value items, $t(68) = 3.54$, $p = .001$, $d = 0.87$, and low-value items, $t(68) = 5.03$, $p < .001$, $d = 1.23$.

Next, we examined influences of encoding condition and value on the proportion of items recognized with highest confidence (‘Definitely Old’). A 3 x 2 repeated measures ANOVA indicated that there was a significant Condition x Value interaction, $F(2, 98) = 11.39$, $p < .001$, $\eta_p^2 = .19$. In the No Instruction condition, ‘Definitely Old’ responses were given to a significantly greater proportion of high-value items ($M = .56$, $SD = .24$) than low-value items (*M* = .38, *SD* = .24), *t*(35) = 4.09, $p < .001$, *d* = 0.68. In the Consonant Counting condition, the proportion of ‘Definitely Old’ responses did not differ between high-value (*M* = .29, *SD* = .21) and low-value items (*M* = .29, *SD* = .23), *t*(30) = -0.29, *p* = .772, *d* = -0.03. Lastly, in the Sentence Generation condition, the proportion of ‘Definitely Old’ responses also did not differ between high-value (*M* = .89, *SD* = .16) and low-value items (*M* = .88, *SD* = .16), *t*(33) = 0.58, *p* = .567, *d* = 0.10. As with recognition sensitivity, the highest confidence responses became much more frequent in the Sentence Generation condition, both for low-value items, *t*(68) = 10.06, $p < .001$, *d* = 2.47, and valuable items, *t*(68) = 6.66, $p < .001$, *d* = 1.63.

Experiences of Remembering, Knowing, and Guessing

A 3 x 2 x 3 repeated measures ANOVA was computed to determine how the proportion of correctly recognized old items given a Remember, Know, or Guess response was affected by item-value and encoding condition (Figure 8; Table 2). The Memory Type (R-K-G) x Condition x Value interaction was significant, *F*(2, 98) = 4.86, *p* = .001, $\eta_p^2 = .09$. Significant two-way interactions were observed for Memory Type x Condition, *F*(2, 98) = 31.12, $p < .001$, $\eta_p^2 = .39$, and Memory Type x Value, *F*(2, 98) = 7.68, *p* = .001, $\eta_p^2 = .07$. As was observed in Experiment 2, high-value items were more likely to receive a Remember response than low-value items, *t*(100) = 3.26, *p* = .002, *d* = 0.33, and less likely to receive a Guess response, *t*(100) = -3.08, *p* = .003, *d* = -0.31. The frequency of Know responses did not significantly differ by item-value, *t*(100) = 0.55, *p* = .587, *d* = 0.05.

The proportion of items given a Remember response was then compared between the Sentence Generation and No Instruction conditions. A significant Value x Condition interaction was observed, $F(1, 68) = 8.47$, $p = .005$, $\eta_p^2 = .11$. In the No Instruction condition, recognized high-value items were more likely to receive a Remember response than low-value items, $t(35) = 3.50$, $p = .001$, $d = 0.59$. In contrast, in the Sentence Generation condition rates of Remember responses did not significantly differ between the two item values, $t(33) = 0.79$, $p = .434$, $d = 0.14$. The Sentence Generation condition showed higher rates of Remember responses than the No Instruction condition both for high-value items, $t(68) = 5.87$, $p < .001$, $d = 1.42$ and low-value items, $t(68) = 7.78$, $p < .001$, $d = 1.89$.

Discussion

The primary goal of Experiment 3 was to determine whether a different deep encoding strategy (sentence generation) would also mitigate value’s effect on recognition, as mental imagery was found to do in Experiment 2. Recognition sensitivity, frequency of highest confidence responses, and frequency of recollection did not differ significantly by item-value when participants were instructed to generate sentences for both low- and high-value items, supporting the idea that differences in recognition accuracy based on value are likely due to differences in depth of encoding. The results from the Counting Consonants condition support this idea as well. In this condition, participants had limited ability to employ deep encoding strategies for high-value items, and their recognition memory for high-value items was not significantly better than their recognition memory for low-value items. Recognition memory for both high- and low-value items in the Consonant Counting condition was similar to recognition memory for low-value items in the No Instruction condition, suggesting this level of performance is supported by simply reading the words without engaging with them on a deeper semantic level. In contrast, the level of performance for both high- and low-value items in the sentence generation condition was markedly higher than the level of performance for the high-value items in the No Instruction condition. This suggests that sentence generation is a more effective encoding strategy than participants typically use for learning high-value items, consistent with the relatively low levels of self-reported use of this strategy in the No Instruction condition in Experiment 2.

General Discussion

Relatively Automatic Contributions to Value-Directed Remembering

Across three experiments, the contributions of relatively automatic and elaborative encoding processes to value–directed remembering were examined. A key result of this study was that value can enhance recognition in a relatively automatic fashion, even when subjects are immediately told that the item is irrelevant. In Experiment 1, when items were paired with an immediate forget cue, participants showed stronger recognition sensitivity for valuable items than low-value items. The large directed-forgetting effect observed in this study suggests that an immediate forget cue effectively reduced intentional encoding of items; thus, the most plausible explanation for these results is that a less deliberate and relatively automatic process is enhancing the learning of valuable items.

One plausible mechanism by which valuable items may be automatically strengthened in memory is that these items activate midbrain dopaminergic circuitry that can enhance hippocampal activity (Bethus, Tse, & Morris, 2010; Rossato et al., 2009). High-value cues elicit activity in dopaminergic regions and this dopamine release appears to signal the anticipation of rewards (Adcock et al., 2006; Carter et al., 2009). Furthermore, this dopaminergic signaling has been shown to act directly on the hippocampus to upregulate the storage of information in long-term memory (Lisman & Grace, 2005; Otmakhova, Duzel, Deutsch, & Lisman, 2013; Rossato et al., 2009). Neuroimaging of value-directed remembering has revealed that activation of bilateral nucleus accumbens, a component of the midbrain dopaminergic reward system, does coincide with high point-value cues (Cohen et al., 2014). In a previous study, the presentation of rewards strengthened subsequent memory for information that was proximal to these rewards, consistent with the idea that value can automatically enhance memory independent of motivation to remember (Murayama & Kitagami, 2014). In a similar vein, Cohen et al. (2017) showed that effects of value were present on a free recall task, even when subjects reported that they did not attend to value and attempted to encode all items in a similar fashion.

One difference between the current study and much of previous work showing activation of the midbrain dopamine system is that these previous effects were mainly apparent after a delay of at least 12 hours, suggesting that the effect of dopamine is to enhance memory consolidation (Bethus, Tse, & Morris, 2010; Rossato et al., 2009; Spaniol, Schain, & Bowen, 2013). In the present study, small effects of value were seen on a recognition test that occurred shortly after study, and these immediate effects of value have been observed in previous research (Hennessee, Castel, & Knowlton, 2017; Hennessee, Knowlton, & Castel, 2018). In the current study, we used a fairly sensitive measure of recognition, and thus it is possible that we were able to detect relatively subtle value effects on memory strength. It may be that there would be larger value effects with a long delay due to enhanced consolidation of these items. Thus, relatively small differences in memory strength due to value may become magnified if there is differential consolidation of higher-strength items.

Contributions of Elaborative Encoding

Other work has suggested that high-value cues promoted increased elaborative semantic processing of items which leads to better subsequent memory. Research by Cohen et al. (2016) suggests that value-directed remembering promotes increased activity in left VLPFC, pre-supplementary motor area, and posterior lateral temporal cortex, and these regions have been implicated in deep semantic processing (Binder et al., 2009; Binder and Desai, 2011). In Experiment 1, we did not observe a significant effect of prolonged elaborative encoding on recognition for high- or low-value words. More specifically, when the learn cue was presented immediately, participants had the maximal amount of time (6 s) to use any encoding strategy they preferred, but this was not shown to improve performance relative to seeing the cue only 1 s before the next item. At first glance, this seems at odds with prior research showing that people selectively use effective strategies for valuable word-pairs (Ariel, Price, & Hertzog, 2015) and they alter their strategy use based on item-value (Cohen et al., 2017). Likewise, this seems to go against the agenda-based regulation model (Ariel, Dunlosky, & Bailey, 2009), as the longer study time should allow for larger differences in allocating time, resources, and effort based on item-value. However, as shown in Cohen et al. (2017), participants often require multiple study-test lists with feedback on their performance to fully develop this value-related selectivity in encoding. Ariel, Price, and Hertzog (2015) and Cohen et al. (2017) used multiple lists with feedback, whereas the present study did not. Thus it is possible that our participants did not have sufficient feedback on performance to develop selective encoding strategies observed in studies with multiple study-test lists. The contribution of elaborative encoding strategies on value-directed remembering may be relatively small when studying a single recognition list without intermittent feedback.

Nevertheless, in Experiment 2, there was evidence of differential encoding strategies for valuable items. Unlike in Experiment 1, participants in Experiment 2 did not have to engage in directed-forgetting, and thus it may have been easier to adopt different encoding strategies depending on value. A strong value effect on recognition was observed in the maintenance rehearsal condition, and this value effect was not significantly different than when no instruction was present. In these conditions, valuable items may have been automatically encoded more effectively, or participants may have strategically engaged in more effective encoding of these items. Even when participants were instructed to engage in rehearsal, it is possible that they were able to also engage in more semantic encoding of some items, as participants generally reported using more than one strategy during the encoding session. In support of the idea that participants engage in more semantic encoding strategies for high-value items, instructing participants to encode all learned items using a mental imagery strategy improved memory for low-value items to the point that value-based differences in sensitivity were reduced and differences in the rates of highest confidence response and Remember responses were eliminated. In a recent study, item-value was associated with increased experiences of recollection but the frequency of high confidence responses was not significantly affected by value (Hennessee, Castel, & Knowlton, 2017). The current findings suggest that value can alter the frequency of these high confidence responses and that mental imagery during encoding may increase both confidence and recollection similarly at test.

The results of Experiment 3 support and extend the results of Experiment 2. A limitation of Experiment 2 was that use of the instructed encoding strategy was reported by participants at the end of the experiment rather than monitored directly. Therefore, in Experiment 3, we required participants in the Sentence Generation and Counting Consonants conditions to respond aloud, which allowed us to monitor whether they were following the encoding instructions they had been assigned. Under these circumstances, we did not observe any effects of value on recognition, supporting the idea that differential encoding makes a strong contribution to value effects. It is possible that we were not able to detect automatic effects of value in the Sentence Generation condition because recognition sensitivity was near ceiling; however, we observed a similar pattern of results when looking at the proportion of items rated as Remembered, which was quite high but not at ceiling. It is also possible that the numerical task of counting consonants interfered with processing of word values. Replication of this result with a non-numerical task that similarly limits differential strategy use would provide additional support for our findings.

In Cohen et al. (2014), neuroimaging data indicated differences in activation in semantic processing regions between high-value and low-value items, and we observed that differences in performance were mitigated when participants increase their semantic processing of low-value items through mental imagery and sentence generation. Taken together, these two studies suggest that differences in semantic processing based on item-value contribute to value-directed remembering, though this contribution is likely greater when participants receive feedback through multiple lists.

Conclusions

Across three experiments we demonstrated that value can improve recognition in both a relatively automatic fashion as well as by inducing participants to engage in more effective encoding. The current findings, together with prior research, suggest that valuable items receive increased semantic processing. Further research may determine how learners adjust and apply encoding strategies to maximize memory efficiency.

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Appendix A

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. For words you recognize, you will also be asked whether you recognized it due to remembering, knowing, or guessing. Now, I will describe what we mean by remembering and knowing:

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, if someone asks you what a hammer is, and you are certain you know what hammers are, but you can't remember any specific experiences with a hammer, you would call that *knowing*. The key distinction, again, 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.