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ORIGINAL RESEARCH REPORT

Divided Attention Selectively Impairs Value-Directed Encoding

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In the present study, we examined the effect of value-directed encoding on recognition memory and how various divided attention tasks at encoding alter value-directed remembering. In the first experiment, participants encoded words that were assigned either high or low point values in multiple study-test phases. The points corresponded to the value the participants could earn by successfully recognizing the words in an upcoming recognition memory task. Importantly, participants were instructed that their goal was to maximize their score in this memory task. The second experiment was modified such that while studying the words participants simultaneously completed a divided attention task (either articulatory suppression or random number generation). The third experiment used a non-verbal tone detection divided attention task (easy or difficult versions). Subjective states of recollection (i.e., "Remember") and familiarity (i.e., "Know") were assessed at retrieval in all experiments. In Experiment 1, high value words were recognized more effectively than low value words, and this difference was primarily driven by increases in "Remember" responses with no difference in "Know" responses. In Experiment 2, the pattern of subjective judgment results from the articulatory suppression condition replicated Experiment 1. However, in the random number generation condition, the effect of value on recognition memory was lost. This same pattern of results was found in Experiment 3 which implemented a different variant of the divided attention task. Overall, these data suggest that executive processes are used when encoding valuable information and that value-directed improvements to memory are not merely the result of differential rehearsal.

Keywords: Recognition Memory; Value-Directed Remembering; Dual-Process Theory; Divided Attention

The central nervous system encounters a seemingly limitless amount of information daily. Capacity limits of the system demand that important information be selected, prioritized, and remembered over unimportant information (Broadbent, 1958; Cowan, 2000). The selection and prioritization of content potentiates encoding into long-term memory, but the mechanisms underlying this effect remain unclear. These processes have been examined with value-directed remembering (VDR) paradigms where participants encode information that differs in its future value for a subsequent memory task (Watkins & Bloom, 1999; Castel, Benjamin, Craik, & Watkins, 2002). Not surprisingly, participants are sensitive to value and the typical finding from this paradigm is that high-valued information is remembered better than low-value information. In the current study we aimed to evaluate the memorial basis for improved memory for high- value information. On the one hand, perhaps differential rehearsal processes are responsible for this effect (Rundus, 1971). On the other hand, perhaps executive processes support elaborative encoding of important information (Robison & Unsworth, 2017; Cohen, Rissman, Hovhannisyan, Castel, & Knowlton, 2017). We argue here that these two alternatives lead to specific predictions regarding the relative amounts of subjective recollection versus familiarity that support improved memory for high-valued information. Moreover, the process of encoding valuable information into memory can become even more difficult when busily engaged with unrelated demanding activities. Thus, a secondary aim of the current study is to further examine value- directed encoding while participants simultaneously complete various divided attention tasks meant to inhibit articulatory versus executive processes.

In a typical VDR experiment, a list of words is presented to the participant and these words vary in value. For example, value can be operationalized by assigning a number next to the word (i.e., "CAR 4"; Watkins & Bloom, 1999). Participants are instructed that they will be awarded the point value corresponding to the number presented with the word if they are able to remember the word in an upcoming memory test. The participants are instructed that their goal is to maximize the number of points they achieve in the upcoming memory test. Previous findings from VDR experiments show that participants recall

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more words associated with higher point values than words with lower point values (Castel et al., 2002; Castel, 2008). Additionally, participants tend to exhibit accurate associative memory for values associated with the words (Stefanidi, Ellis, & Brewer 2018). Finally, this finding holds true for both younger and older healthy adults (Castel, Murayama, Friedman, McGillivray, & Link, 2013). Overall, these effects support the hypothesis that special processes are recruited during encoding that enhance memories for higher-valued information in VDR paradigms.

In order to further understand the effect that value has on guiding encoding, researchers have applied the VDR paradigm in the context of recognition memory. Recognition memory tasks are similar to free recall tasks in that a list of words is studied with the knowledge that there will be an upcoming test. However, instead of recalling the words at test, participants are provided with old and new words and they must discriminate between the previously encountered words (i.e., targets) and new words (i.e., lures). To account for a wide range of dissociations that have been discovered during recognition memory testing, it has been hypothesized that dual processes contribute to the discrimination process (Mandler, 1980; Wixted, 2007; Yonelinas, 2002). This dual-process model suggests that recognition memory decisions are driven by two distinct processes, recollection and familiarity. Recollection affords conscious access to associations and qualitative information from the study episode. Familiarity- based judgments are more automatic, and do not cue previous associations or provide qualitative information about the study episode (for review, see Yonelinas, 2002). One method for measuring these processes requires participants to make a subjective evaluation for each item that they discriminate in terms of the phenomenological state of awareness accompanying their decision (e.g., "I remember this item" versus "I know this item occured"; Tulving, 1985).

When VDR paradigms are applied in the context of recognition memory tasks, it is generally found that the typical enhancement to memory for higher-valued information is localized to strongest memories (or recollection in dual-process frameworks). One of the first studies to examine VDR in the context of a remember-know procedure was reported by Adcock, Thangavel, Whitfield-Gabrieli, Knutson, and Gabrieli (2006). Adcock and colleagues collected behavioral and event-related fMRI data while participants performed a recognition memory task that was monetarily incentivized. Participants were presented either a high value ($5) or low value (10¢) cue followed by a scenic picture. Recognition memory test data was collected 24 hours post scan in the form of a "remember"- "know" recognition test. Scenes that were previously paired with higher value cues were better recognized compared to scenes previously paired with lower value cues. The value-driven gain in recognition was between pooled "remember" and high confidence "know" responses, whereas pooled low confidence responses showed no effect of value. The result that value preferentially affects strongest memories (or recollection) has been repeated in both incidental (Wittmann et al., 2005) and intentional encoding paradigms (Gruber & Otten, 2010; Wolosin, Zeithamova, & Preston, 2012; Cohen et al., 2017; Hennessee, Castel, & Knowlton, 2017), and also for encoded stimuli where, rather than earning reward for correct recognition judgments, a punishment is avoided (Shigemune, Tsukiura, Kambara, & Kawashima, 2014). These studies suggest that the value establishes an encoding context that selectively enhances strong recollective memories, with no consistent effect on weaker memories.

Within the recognition memory literature, various other encoding manipulations have been shown to selectively enhance later states of recollection over familiarity. Some of these manipulations include: deep versus shallow processing, generation versus word reading, benzodiazepine versus placebo administration, and full versus divided attention (Yonelinas 2002). Overall, the similarity between these prior effects on recollective processes and those found in VDR paradigms suggest that one possible mechanism for value-based encoding reflects executive processes used to encode information. That is, perhaps participants in these paradigms engage in a more elaborative, frontally-mediated encoding of higher-valued information compared with lower-valued information and this leads to more enduring and distinctive representations in memory. This view predicts that divided attention manipulations that disrupt executive processes necessary for encoding information into memory should attenuate value- based effects on recognition memory.

An alternative account for these effects is that VDR paradigms promote differential rehearsal of high versus low value information. This view makes two important predictions, one not fully supported by existing data. First, differential rehearsal typically effects "know" responses more than "remember" responses in remember-know paradigms (Gardiner, Gawlik, & Richardson-Klavehn, 1994). Importantly, VDR effects are typically found for "remember" responses instead of "know" responses. Second, this view predicts that divided attention manipulations that disrupt articulatory processes should attenuate value-based effects on recognition memory. These alternative predictions are tested across 3 experiments in the current study.

Theoretically, the effects of divided attention on word learning can be motivated in terms of Baddeley's original model of working memory (Baddeley & Hitch, 1974). The components of this model include an attentional control system, labelled the "central executive" and two slave systems labelled the "phonological loop" and the "visuospatial sketchpad". The phonological loop is proposed as an articulatory storage and rehearsal system. Baddeley supported the existence of these different systems in his working memory model by reviewing data from divided attention manipulations on list learning. Specifically, executive resources can be taxed by having participants complete a secondary task during list learning where they randomly generate integers (random number generation; Baddeley, Emslie, Kolodny, & Duncan, 1998). In contrast, having participants recite an irrelevant sound or word has been shown to disrupt articulatory rehearsal mechanisms ascribed to the phonological loop, while leaving more executive resources available (articulatory suppression; Baddeley, Thomson, & Buchanan, 1975).

The Current Study

The current study used a VDR recognition memory paradigm to examine the subjective states of awareness underpinning value-directed encoding processes. Moreover, we also examined the extent to which executive resources are required for the effect of value on recognition memory using various divided attention manipulations at encoding. In Experiment 1, we administered a value-based remember – know recognition memory test. Given previous literature, we expected the effect that value had on recognition memory (measured with hit rates) to be localized to remember responses, with no difference in know responses. Increased memory for higher-valued items could be due to increased rehearsal, or to the use of executive resources.

Therefore, in Experiment 2 we administered the same value-based remember – know recognition memory test. However, participants in this experiment completed either an articulatory suppression or random number generation divided attention task during encoding. If the effect of value on memory is ascribed to increased rehearsal of the higher-valued information, one would expect articulatory suppression to impair the effect of value. If executive resources are required for value-based encoding, then only the random number generation condition should impair the effect of value on recognition memory performance.

Because both our articulatory suppression and random number generation tasks used numbers as the spoken distractions, we replicated Experiment 2 using non-verbal divided attention tasks at encoding (sequential and random tone detection; Mangels, Picton, & Craik, 2001). Additionally, using this divided attention manipulation allowed us to more directly vary the executive demands of the secondary task while holding all other features constant. All together, these experiments were designed to understand the effect of value on recognition memory processes and how these processes are affected by dividing attention at encoded.

Experiment 1 Methods

Participants

Forty participants were recruited from the Arizona State University research participation pool and took part in a study on recognition memory. All participants were compensated with course credit upon completion of the experiment. One participant failed to make any "remember" responses, and was excluded from the "remember" – "know" analyses.

Materials and Design

Stimuli consisted of 200 nouns from the Toronto noun pool (Friendly, Franklin, Hoffman & Rubin, 1982). Participants completed multiple study-test blocks. The study phases consisted of 40 words each randomly assigned either a high (7, 9) or low (1, 3) point value (i.e., 20 high value and 20 low value, 10 of each specific value). The test phases consisted of 80 words (40 from the most recent list and 40 new nouns, randomly intermixed) presented one at a time without point values. Participants classified these old and new items at test along with making judgments on subjective states of recollection (i.e., "remember") and familiarity (i.e., "know"). Each study- test phase was considered 1 block and 5 blocks were completed by each participant.

Procedure

All experiments followed a study protocol that was approved by Arizona State University's Institutional Review Board. Written informed consent was obtained from each participant before beginning the study. Participants were instructed that they would be completing multiple study-test blocks in a recognition memory task. The participants were told that their objective was to remember as many words as possible, with the goal of maximizing their score on each recognition memory test. They studied lists of 40 randomly selected nouns presented to them for a duration of 2s at a time, with a randomly jittered interstimulus interval from 300 to 500ms in 17 ms increments. The nouns were randomly paired with an integer indicating that it was either a low (1, 3) or high (7, 9) value item with a total of 20 low and 20 high values in each study block, ten of each value. Participants were told they would earn the point value previously paired with the word if correctly recognized, regardless of confidence rating, and that they would lose 1 point for incorrectly identifying a new word as old.

Each word appeared in the center of the computer screen below a central fixation cross, with the paired value appearing simultaneously above the central fixation cross in the center of the screen. After studying each list of 40 words, a test phase followed with 80 words (with no point values presented) that included all 40 of the words from the previous list and 40 new words randomly intermixed. Test words were presented one at a time and participants judged whether they thought the word was old or new. Participants responded using a standard computer keyboard with the following response option assignments: Z "Definitely New"—left pinky, X "Maybe New"—left ring finger, C "Maybe Know"—left middle finger, V "Definitely Know"—left index finger, and M "Remember"—right index finger. The participants were told to respond with their first instinct, but the test was untimed.

Before the experiment began, participants were briefed on the difference between remembering and knowing with the following instructions (adapted from Herzmann & Curran, 2011):

> "Make a remember judgment if you not only remember the word, but also consciously remember the experience of studying the word. For example, perhaps you remember the specific value of the word, something else that happened in the room while you were studying it (like a cough or sneeze), an association that came to mind, or what came just before or after the word in the study phase. To give you a real world example, imagine you are walking across campus and recognize someone, but cannot recall their name or where you have met them. You are certain you have seen this person before, but do not remember anything

> specifically about them or where you met them. This is would be “knowing”. If you recognize this person and remember that it is John whom you met in Biology class, this would be “remembering”.

Data Analysis

The effect of value on memory performance was analyzed using 3 paired-sample t-tests. Importantly, words were assigned value during encoding only and that means there is a common false alarm rate for both high and low value words (M = .23, SE = .02; analyses using a false-alarm correction procedure are reported in the supplemental material.). Memory performance was calculated as the mean proportion of old words successfully recognized regardless of dual- process judgment (total hits) and for remember and know (pooling over low and high confidence) judgments separately.

Results and Discussion

Memory performance as a function of value and judgment type is summarized in **Table 1**. 87.5% of participants in the sample (35/40) exhibited the typical VDR effect of better memory for higher- compared with lower-valued words in their overall hit rates. Accordingly, higher recognition accuracy was found for high- compared with low-value words in overall hit rates ($t_{(39)} = 5.163$, $p < 0.001$, Cohen’s $d = 0.90$). When hit rates were conditionalized on the subjective state of awareness supporting those decisions, the value-driven gain in memory performance was due to an increase in “remember” responses ($t_{(38)} = 6.447$, $p < 0.001$, Cohen’s $d = 1.03$). Importantly, no effect of value was observed for “know” responses ($t_{(38)} = -1.886$, $p = 0.067$, **Figure 1A**).

These data show that value affects encoding processes leading to enhanced “remember” responses, supporting the executive encoding view of VDR effects. Therefore, in Experiment 2 we aimed to divide attention using either an executive-demanding secondary task (random number generation) or an articulatory-demanding task (articulatory suppression). We reasoned that dividing attention at encoding could be used to further dissociate encoding mechanisms that may be differentially affected by value in support of the executive view. Specifically, if executive processes are necessary for value-directed encoding then simultaneously completing the random number generation should attenuate the VDR effect, and this attenuation should be most prevalent in the “remember” responses.

Experiment 2 Methods

To examine the underlying encoding mechanisms that value may affect to achieve greater rates of remember responses at test, in Experiment 2 we asked participants to perform either an articulatory suppression or random number generation task while studying the to-be remembered stimuli. Given articulatory suppression has been shown to disrupt articulatory rehearsal, while random number generation also taxes executive resources, we can use these manipulations to determine cognitive processes affected by value at encoding. If value at encoding leads to increased articulatory rehearsal, we would expect that articulatory suppression at encoding would reduce or eliminate the effect of value on later memory. To the extent that value at encoding affects executive resources, we would expect random number generation at encoding to reduce or eliminate the effect of value on memory. Besides the divided attention manipulations at encoding, this experiment was identical to Experiment 1.

Participants

Forty participants were recruited from the Arizona State University research participation pool and they took part in a study on recognition memory. All participants were compensated with course credit upon completion of the experiment.

Table 1: Descriptive Statistics (Means and Standard Errors) for Raw Hits, “Remember”, and “Know” Responses Across All 3 Experiments as a Function of Value.

Experiment and condition	Hit rates			“Remember”			“Know”		
	High value	Low value	Difference (HV-LV)	High value	Low value	Difference (HV-LV)	High value	Low value	Difference (HV-LV)
	M (SE)	M (SE)	M (SE)	M (SE)	M (SE)	M (SE)	M (SE)	M (SE)	M (SE)
Experiment 1									
Full attention	.79 (.02)	.67 (.03)	.12 (.02)*	.50 (.04)	.34 (.04)	.16 (.03)*	.30 (.03)	.33 (.03)	.03 (.02)
Experiment 2									
AS	.70 (.02)	.62 (.03)	.08 (.02)*	.28 (.03)	.21 (.03)	.07 (.02)*	.42 (.03)	.40 (.03)	.02 (.02)
RNG	.53 (.02)	.51 (.02)	.02 (.02)	.12 (.02)	.11 (.02)	.01 (.01)	.42 (.03)	.40 (.03)	.02 (.02)
Experiment 3									
Easy	.66 (.02)	.57 (.03)	.09 (.02)*	.19 (.03)	.13 (.02)	.06 (.02)*	.47 (.03)	.45 (.03)	.02 (.02)
Hard	.56 (.02)	.53 (.03)	.03 (.01)*	.10 (.02)	.08 (.01)	.02 (.01)	.46 (.03)	.45 (.02)	.01 (.01)

Note: AS = Articulatory Suppresion, RNG = Random Number Generation, Easy = Easy Divided Attention, and Hard = Hard Divided Attention * denotes significance $p < .05$.

Materials and Design

The materials were identical to that of Experiment 1 with two exceptions. First, participants in Experiment 2 completed 4 study-test blocks instead of 5 study-test blocks. Second, during the encoding period participants completed either an articulatory suppression or random number generation divided attention task in each study-test block creating a 2 (Value: High versus Low) × 2 (Divided Attention: Random Number Generation versus Articulatory Suppression) fully within-subjects design.

Procedure

Upon arrival, participants were instructed that they were to complete a memory task, but while studying the to-be remembered stimuli, they would also be completing one of two other secondary tasks. In the articulatory suppression condition, participants repeated the number "five" aloud on beat to a metronome at a pace of one response per second. In the random number generation condition, participants were asked to generate a random integer from one to nine aloud on beat to a metronome at a pace of one response per second. The participants were instructed that they should not use any patterns, and that their responses should be like "picking numbers out of a hat". Participants were given one minute to practice each divided attention task before beginning the study. Otherwise, the memory task was identical to Experiment 1, except that four study-test blocks were completed (two with articulatory suppression at encoding, two with random number generation at encoding). The order in which participants completed each divided attention task at encoding was selected randomly.

Data Analysis

The effects of value and divided attention on memory performance were analyzed using 3 repeated measures Analyses of Variance (ANOVAs) with the following within-subject factors, Value (High versus Low) and Divided Attention (Articulatory Suppression versus Random Number Generation). These analyses were conducted on the following dependent measures: proportion correctly recognized (hit rate), proportion given a "remember" response, and proportion given a "know" response. Importantly, words were assigned value during encoding only and that means there is a common false alarm rate for both high and low value words (M = .30, SE = .02). Analyses using a false-alarm correction procedure are reported in the supplemental material.

Results and Discussion

Memory performance as a function of value and judgment type is summarized in **Table 1**. A 2 (Value: High versus Low) × 2 (Divided Attention: Random Number Generation versus Articulatory Suppression) repeated measures ANOVA on hit rates revealed a main effect of value, $F(1,39) = 12.96$, $p = .001$, $\eta^2_{partial} = .249$, a main effect of divided attention condition, $F(1,39) = 42.54$, $p < .001$, $\eta^2_{partial} = .522$, and an interaction, $F(1,39) = 6.81$, $p < .05$, $\eta^2_{partial} = .149$. Thus, we rejected the null hypothesis that the effect of value was similar across divided attention conditions. Post-hoc t-tests revealed that this interaction was driven by a difference between high and low value in the articulatory suppression condition ($t_{(39)} = 4.211$, $p < 0.001$, Cohen's $d = 0.67$) with no difference in the random number generation condition ($t_{(39)} = 1.158$, $p = .254$; **Figure 1B**).

When hit rates were conditionalized on the subjective state of awareness supporting those decisions, we find similar results for "remember" responses. A 2 (Value: High versus Low) × 2 (Divided Attention: Random Number Generation versus Articulatory Suppression) repeated measures ANOVA on "remember" responses revealed a main effect of value, $F(1,39) = 5.25$, $p < .05$, $\eta^2_{partial} = .119$, a main effect of divided attention condition, $F(1,39) = 33.05$, $p < .001$, $\eta^2_{partial} = .459$, and an interaction, $F(1,39) = 6.50$, $p < .05$, $\eta^2_{partial} = .143$. Post-hoc t-tests revealed that this interaction was driven by a difference between high and low value in the articulatory suppression condition ($t_{(39)} = 2.794$, $p < 0.01$, Cohen's $d = 0.45$) with no difference in the random number generation condition ($t_{(39)} = .361$, $p = .720$).

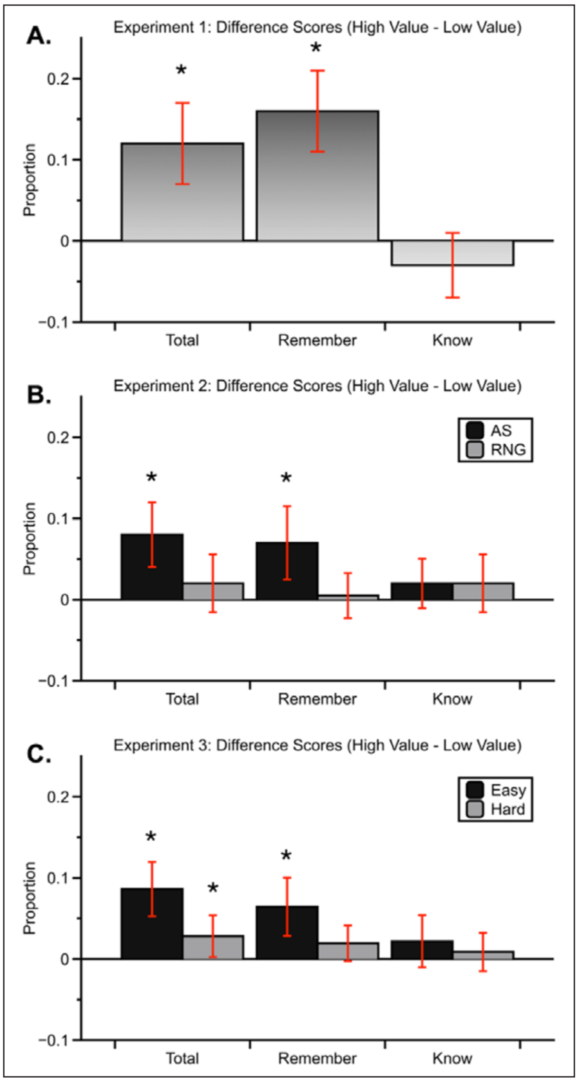

Figure 1: Effect of value (difference score: high value – low value) for raw hits, "remember", and "know" responses across all 3 experiments as a function of value. * denotes significance $p < .05$.

A 2 (Value: High versus Low) × 2 (Divided Attention: Random Number Generation versus Articulatory Suppression) repeated measures ANOVA on "know" responses revealed no main effect of value, $F(1,39) = 2.06$, $p = .159$, no main effect of divided attention condition, $F(1,39) = .055$, $p = .816$, and no interaction, $F(1,39) = .054$, $p = .817$. Together, these data again show that value affects encoding processes leading to enhanced states of subjective recollection. In addition, random number generation at encoding eliminated this effect, while articulatory suppression at encoding did not. This result supports the view that executive resources are necessary for value-directed encoding effects on memory. One alternative explanation with the current experiment is that dividing attention via verbally spoken integers could have impaired encoding the value of the stimuli due to the conceptual overlap of the integers used to represent value, rather than disrupting executive resources. To this end, Experiment 3 was conducted using a non-verbal tone detection divided attention manipulation that lacked the conceptual overlap of integer values.

Experiment 3 Methods

In Experiment 3 we asked participants to perform either an easy or difficult secondary task while studying the to-be remembered stimuli. The logic here was to use divided attention tasks that placed relative demands on executive processes but no obvious demands on articulatory processes. To the extent that value-based encoding places demands on executive resources, we would expect the more difficult secondary task to reduce or eliminate the effect of value on recollection. Besides the change in divided attention tasks at encoding, this experiment was identical to Experiment 2.

Participants

Forty participants were recruited from the Arizona State University research participation pool and they took part in a study on recognition memory. All participants were compensated with course credit upon completion of the experiment.

Materials and Design

The materials were identical to that of Experiment 2 except instead of articulatory suppression and random number generation during encoding, participants completed either an easy or difficult tone detection secondary task in each study-test block creating a 2 (Value: High versus Low) × 2 (Divided Attention: easy tone detection versus difficult tone detection) fully within-subjects design. The tone detection task was adapted from Mangels et al. (2001). The stimuli were low (250 Hz), medium (750 Hz) and high (2250 Hz) tones played over standard computer speakers. The 750 Hz was presented at 55 dB sound pressure level with the other tones being adjusted to be equally loud. All the tones were created using Audacity.

Procedure

Upon arrival, participants were instructed that they were to complete a memory task, but while studying the to-be remembered stimuli, they would also be completing one of two other ongoing tasks. In both secondary tasks, participants were instructed that they would need to recognize low, medium, and high tones by pressing the corresponding key (1, 2, and 3 on a standard keyboard number pad). The tones were presented at a pace of one per second. In the easy tone detection condition, tones occurred in a fixed order of low, medium, high. In the difficult tone detection condition, tones occurred in a random order. Otherwise, the memory task was identical to Experiment 2. Participants were given one minute to practice each divided attention task before beginning the study. The order in which participants completed each divided attention task at encoding was selected randomly.

Data Analysis

The effects of value and divided attention on memory performance were analyzed using 3 repeated measures Analyses of Variance (ANOVAs) with the following within-subject factors, Value (High versus Low) and Divided Attention (Easy versus Difficult). These analyses were conducted on the following dependent measures: proportion correctly recognized (hit rate), proportion given a remember response, and proportion given a know response. Importantly, words were assigned value during encoding only and that means there is a common false alarm rate for both high and low value words (M = .29, SE = .02).

Results and Discussion

Memory performance as a function of value and judgment type is summarized in **Table 1**. A 2 (Value: High versus Low) × 2 (Divided Attention: easy tone detection versus difficult tone detection) repeated measures ANOVA on hit rates revealed a main effect of value, $F(1,39) = 24.05$, $p < .001$, $\eta^2_{partial} = .381$, a main effect of divided attention condition, $F(1,39) = 19.00$, $p < .001$, $\eta^2_{partial} = .328$, and an interaction, $F(1,39) = 9.64$, $p < .01$, $\eta^2_{partial} = .198$. Thus, we rejected the null hypothesis that the effect of value was similar across divided attention conditions. Post-hoc t-tests revealed that this interaction was driven by a difference between high and low value in the easy tone detection condition ($t_{(39)} = 5.136$, $p < 0.001$, Cohen's $d = 0.85$) with a markedly smaller difference in the difficult tone detection condition ($t_{(39)} = 2.188$, $p = .035$, Cohen's $d = 0.36$, **Figure 1C**).

When hit rates were conditionalized on the subjective state of awareness supporting those decisions, we find similar results for "remember" responses. A 2 (Value: High versus Low) × 2 (Divided Attention: easy tone detection versus difficult tone detection) repeated measures ANOVA on "remember" responses revealed a main effect of value, $F(1,39) = 12.35$, $p = .001$, $\eta^2_{partial} = .241$, a main effect of divided attention condition, $F(1,39) = 13.60$, $p = .001$, $\eta^2_{partial} = 259$, and an interaction, $F(1,39) = 6.35$, $p < .05$, $\eta^2_{partial} = .140$. Post-hoc t-tests revealed that this interaction was driven by a difference between high and low value in the easy tone detection condition ($t_{(39)} = 3.583$, $p = 0.001$, Cohen's $d = 0.63$) with no difference in the difficult tone detection condition ($t_{(39)} = 1.764$, $p = .085$).

A 2 (Value: High versus Low) × 2 (Divided Attention: easy tone detection versus difficult tone detection) repeated measures ANOVA on "know" responses revealed no main effect of value, *F*(1,39) = 2.22, *p* = .145, no main effect of divided attention condition, *F*(1,39) = .004, *p* = .949, and no interaction, *F*(1,39) = .464, *p* = .500. Together, these data again show that value affects encoding processes leading to enhanced states of subjective recollection. In addition, a difficult secondary task at encoding eliminated this effect, while an easy secondary task at encoding did not. This pattern of results replicates Experiments 1 and 2 while further supporting the view that executive resources are necessary for value-directed encoding effects on memory.

General Discussion

Across the current study, three primary findings emerged. First, the effects of value-based encoding consistently increased recognition memory performance for high compared with low-value information. Second, this improvement in recognition memory for high-value information was consistently localized to enhancement of subjective states of "remembering" (i.e., recollection) with no significant changes in subjective states of "knowing" (i.e., familiarity). Third, difficult divided attention tasks (random number generation and random tone detection) administered during value-based encoding mitigated these effects. However, easy divided attention tasks (articulatory suppression and sequential tone detection) had relatively little impact on the enhancement in remembering high-value information.

These VDR effects in recognition memory contribute to a growing body of literature examining how value-based encoding positively influences subsequent memory in a broad range of tasks including delayed free recall (Castel et al., 2002; Castel et al., 2008; Stefanidi et al., 2018), cued recall (Wolosin et al., 2012) recognition memory (Adcock et al., 2006; Hennessee et al., 2017; Cohen et al., 2017; Gruber & Otten, 2010; Gruber, Ritchey, Wang, Doss, & Ranganath, 2016), and source memory (Shigemune, Tsukiura, Kambara, & Kawashima, 2014). Across these studies, value-directed encoding leads to improved memory for high-value information. The current study aimed to evaluate two aspects of the nature of this improvement by evaluating subjective states of awareness accompanying recognition memory decisions and dividing attention while participants encoded high versus low-value information.

The current results are broadly consistent with previous research indicating that the effect of value at encoding selectively increases strong memories (whether they be recollective or simply highest memory strength). Replicating prior studies (Gruber & Otten, 2010; Gruber, et al., 2016; Hennessee et al., 2017; Cohen et al., 2017), value-directed encoding in the current study consistently led to more recollective experiences being reported at test with little influence on familiarity-based experiences. Recollection is generally influenced by depth of processing manipulations (deep > shallow), generation effects (generation > reading), pharmacological intervention (benzodiazepine > placebo), and attention at encoding (full > divided). VDR effects in recognition memory contribute to this growing list of manipulations that selectively enhance recollection (or remember responses in a remember-know paradigm).

However, it is still inconclusive whether two distinct processes contribute to recognition memory decisions, or a single-process based on memory strength. Given prior research showing VDR effects localized to strong/recollective memories, this data may prove useful for testing between contemporary models of recognition memory. Specifically, it is an interesting question how single process models of recognition memory can capture the effects found in prior research and the current research.

In Experiments 2 and 3, we aimed to evaluate the role of attention in encoding high-value information. In Experiment 2 we found that a divided attention task intended to block articulatory processes had relatively smaller effects on VDR than a divided attention task intended to block executive processes. Given prior work examining the role of executive processes in establishing more recollective experiences (Unsworth & Brewer, 2009), we predicted that random number generation would attenuate or even eliminate the VDR effect in recollection, which it did. In addition, we failed to find support in Experiment 2 that articulatory rehearsal processes were influenced by value-directed encoding. It is important to note, however, that the articulatory suppression condition in the current study was less difficult than the random number generation condition. Therefore, the interpretation that the effect of value on memory relies more on executive functions than articulatory process could be confounded by task difficulty. Future studies should address this concern.

In Experiment 3 we conceptually replicated Experiment 2 by examining how more difficult executive tasks attenuate value-based encoding effects in recollection relative to less difficult executive tasks. We found that a more difficult executive demanding task attenuated the effect of value on memory, while a less difficult task did not. Together, the data suggest that executive resources are necessary for the effect of value on memory. Executive functions are thought to arise from a network of regions in the brain that include the dorsolateral prefrontal cortex (dlPFC; Kane & Engle, 2002). Similarly, neuroimaging and neurostimulation studies have shown that the dlPFC is necessary for random number generation (Jahanshahi & Dirnberger, 1999; Jahanshahi, Dirnberger, Fuller, & Frith. 2000). Therefore, given evidence from the current study that executive resources are necessary for the effect of value on memory, the current study may provide indirect evidence for the role of the dlPFC in value-directed encoding.

Although this study revealed the importance of executive resources for value at encoding to improve "remember" responses, it does not provide direct evidence for the specific neural or cognitive processes utilized when encoding higher-valued information. Previous literature has revealed at least two possible systems that are activated during value-directed memory encoding, the mesolimbic reward system (via dopaminergic midbrain-hippocampal projections, Lisman & Grace, 2005; Shohamy & Adcock, 2010) and fronto-temporal strategy driven processes (Cohen, Rissman, Suthana, Castel, & Knowlton, 2014; Cohen, Rissman, Suthana, Castel, & Knowlton, 2016). In addition, higher-valued information has been shown to affect selective attention and working memory processes (Anderson, 2013; Ariel & Castel, 2014; Krawczyk, Gazzaley, & D'Esposito, 2007), which could also have an effect on later memory (Blumenfeld & Ranganath, 2007). Importantly, the reward system and selective strategy use at encoding typically lead to different effects on later states of awareness, with the former leading to enhanced states of recollection alone and the latter to enhanced states of recollection and familiarity (Cohen et al., 2017).

Our data clearly showed an effect of value on "remember" responses alone across all three experiments. According to previous literature, this result would be consistent with memory enhancement via the mesolimbic dopamine system. However, across Experiments 2 and 3 we found that disrupting executive resources mitigated the effect of value on recollection. One way to interpret this finding is that disrupting executive resources prevented the use of engaging deep semantic strategies, and that this lead to the modulation of value-driven enhancement of recollection. Under this interpretation one would expect that we would have found value related improvements to both remember and know responses, which we did not. Another interpretation is the more difficult divided conditions had an effect on executive resources that may be necessary for activation of phasic dopaminergic responses. There is evidence that the prefrontal cortex (an underlying structure crucial for executive resources) drives the midbrain to initiate motivated behavior (Ballard et al., 2011; Murty, Ballard, & Adcock, 2016). It is not possible from this study to dissociate if one or both these systems are responsible for the benefit of value at encoding to later memory, as disrupting executive resources could prevent selective attention, PFC driven midbrain activation, and later metacognitive strategy selection. Further, individual differences likely exist amongst the use of these systems. Future studies should address these concerns.

Contrary to our results, a study conducted by Middlebrooks, Kerr, and Castel (2017) investigating the effects of value on delayed free recall under various divided attention conditions did not find divided attention to influence the effect of value on memory performance. Although conceptually similar, the current study utilized a recognition memory paradigm, while Middlebrooks and colleagues utilized a free recall paradigm. The contrasting results may indicate different encoding processes or strategies used to selectively remember higher-valued stimuli in free recall versus recognition memory paradigms. Future studies should address this contradiction.

It is well observed that capacity limits of our memory systems necessitate the attenuation of most of the information we encounter daily. Given these capacity limits, important or highly- valued information must be selected and prioritized over less important information, although the underlying mechanisms remain unclear. Across three experiments we demonstrate that value at encoding enhances memory for higher-valued items. Specifically, this effect is localized to subjective states of recollection with no effect on familiarity. Additionally, disrupting executive resources by dividing attention at encoding eliminated the effect of value on recollection, while disrupting articulatory rehearsal processes at encoding had little effect. Our results suggest that executive resources at encoding are necessary for the prioritization and selective encoding of important information, expanding our knowledge of mechanisms that influence selection and prioritization of items for later remembering. These results dovetail with recent research aimed at clarifying the relation between motivational and cognitive processes at play when people study and recognize important information.

Data Accessibility Statement

Data can be found on OSF at osf.io/3dh5w.

Additional File

The additional file for this article can be found as follows:

- **Text S1.** Supplemental Analyses: Analysis with false-alarm correction, Signal Detection measures (D-prime and C), and memory performance across time (study-test block) for Experiment 1. DOI: https://doi.org/10.1525/collabra.156.s1

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Competing Interests

The authors have no competing interests to declare.

Author Contributions

B.L. Elliott and G.A. Brewer developed the study concept and implemented the design. B.L. Elliott analyzed, interpreted the data, and drafted the manuscript. Both authors approved the final version of the manuscript for submission.

Author Information

Portions of this research were presented in Blake Elliott's Masters Thesis at Arizona State University.

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