Journal of Experimental Psychology: Learning, Memory, and Cognition

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Online First Publication, June 15, 2023. https://dx.doi.org/10.1037/xlm0001264

CITATION

Murphy, D. H., Schwartz, S. T., & Castel, A. D. (2023, June 15). Value-Directed Retrieval: The Effects of Divided Attention at Encoding and Retrieval on Memory Selectivity and Retrieval Dynamics. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. Advance online publication. https://dx.doi.org/10.1037/xlm0001264

AMERICAN PSYCHOLOGICAL ASSOCIATION

Journal of Experimental Psychology: Learning, Memory, and Cognition

ISSN: 0278-7393

https://doi.org/10.1037/xlm0001264

Value-Directed Retrieval: The Effects of Divided Attention at Encoding and Retrieval on Memory Selectivity and Retrieval Dynamics

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Value-directed remembering refers to the tendency to best remember important information at the expense of less valuable information, and this ability may draw on strategic attentional processes. In six experiments, we investigated the role of attention in value-directed remembering by examining memory for important information under conditions of divided attention during encoding and retrieval. We presented participants with lists of words of varying objective or subjective value and compared participants completing the study phase under full or divided attention, in addition to participants completing the testing phase under full or divided attention. Results revealed that certain forms of selectivity were impaired when attention was divided during encoding but not when attention was divided during retrieval. Participants initiated recall (i.e., probability of first recall [PFR]) with high-value words as well as with words they subjectively deemed important; these value-mediated PFR retrieval dynamics resisted influence from reduced attentional resources during encoding and retrieval. Thus, while value-directed remembering involves both strategic encoding and retrieval operations, attentional resources during encoding appear crucial for subsequent recollection of valuable and important information; however, attentional resources during retrieval may be less influential in strategic selective memory.

Keywords: selectivity, attention, retrieval, lag-recency effects, value-directed remembering

People tend to focus on valuable information at the expense of less important information when presented with an abundance of information to remember (Ariel et al., 2009; Castel, 2008; Castel et al., 2002, 2007, 2013; Elliott et al., 2019; McGillivray & Castel, 2017; Schwartz et al., 2020, 2023; Siegel & Castel, 2018a, 2018b; Siegel et al., 2021; Soderstrom & McCabe, 2011; see also Knowlton & Castel, 2022; Madan, 2017 for review). This ability is captured by value-directed remembering paradigms whereby learners employ both bottom-up/automatic and top-down/strategic value-based selectivity processes. In these value-directed remembering tasks, to-be-remembered information is paired with point values which count toward a participant's score if correctly recalled. While selective memory for high-value information is often attributed to strategic attention in the encoding phase (e.g., Ariel et al., 2009, 2015; Castel, 2008; McGillivray & Castel, 2011; Schwartz et al., 2020, 2023), recent work indicates that retrieval dynamics may also play a critical role in memory selectivity (Murphy & Castel, 2022a; Stefanidi et al., 2018).

When participants retrieve items from long-term memory, many systematic trends are observed in their recall (Rohrer & Wixted, 1994). For example, the probability of first recall (PFR) examines the probability that items from each serial position will be recalled first, typically revealing that participants are most likely to initiate recall with either the first or last presented item (Howard & Kahana, 1999; Kahana et al., 2002). In addition to elevated PFR for primacy and recency items, participants are most likely to initiate recall with the most valuable items when words are paired with point values (Murphy & Castel, 2022a; Murphy et al., 2022; Stefanidi et al., 2018). Thus, there are strategic retrieval operations that contribute to memory selectivity.

Following the initiation of retrieval, more systematic tendencies manifest in participants' output, particularly their recall transitions. For example, items studied in close temporal proximity also tend to be recalled in close proximity *and* in the same order with which they were studied. This property is captured by lag conditional-response probabilities (lag-CRPs; Kahana, 1996; see Hintzman, 2015 for a critique, but see Healey et al., 2019 for a response), which illustrate the *lag-recency effect*: The use of just-recalled items to assist the recall of words presented close together in the study phase via the utilization of shared contextual features (Sederberg et al., 2010; Spillers & Unsworth, 2011). Prior research indicates that participants are more likely to retrieve adjacent items compared

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We would like to thank Karina Agadzhanyan and Delaney Falsken for their assistance with managing data collection. Additionally, we thank Drew Murphy for assistance coding the data.

This research was supported in part by the National Institutes of Health (National Institute on Aging; Award Number R01 AG044335 to Alan D. Castel).

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial or nonfinancial interest in the subject matter or materials discussed in this manuscript.

The experiments reported in this article were not formally preregistered, but the stimuli and data have been made available on the Open Science Framework at https://osf.io/hu9xk/?view_only=21f9dff5c28a4406bdf0f369fbb6b7f2.

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to more distant items and that CRPs are greater in the forward direction compared with the backward direction (Kahana, 1996).

Previous work using value-directed remembering paradigms suggests that CRPs are similar in learners completing a value-directed remembering procedure compared with controls where words are not paired with point values (Stefanidi et al., 2018; see also Murphy & Castel, 2022a; Murphy et al., 2022). However, CRPs may be related to selective memory such that processes that disrupt the lag-recency effect may subsequently impact the recall of valuable information. For example, the temporal organization of memory is often related to strategic encoding and retrieval operations (e.g., Unsworth, 2016; Unsworth et al., 2019; Unsworth & Spillers, 2010), potentially implicating the lag-recency effect as a contributor to selective memory. Moreover, the reinstatement of temporal–contextual information during retrieval may also reinstate metacognitive or strategic processes that contribute to selective memory (see Murphy et al., 2021). Thus, combined with evidence that learners initiate retrieval with valuable information (Murphy & Castel, 2022a; Murphy et al., 2022; Stefanidi et al., 2018), there may be important processes occurring during recall that contribute to selective memory, and it is possible that a reduction in CRPs corresponds to a reduction in selective memory.

In addition to items presented closer together in time being recalled in close proximity, items that are semantically related tend to be recalled together (Bousfield et al., 1954; Healey & Kahana, 2014; Howard & Kahana, 2002; Romney et al., 1993). Schematic support (as described by Craik & Bosman, 1992) occurs when prior knowledge in a domain can facilitate memory for other information in that domain. When presented with semantically related information, learners tend to focus on goal-relevant, important information (e.g., Murphy & Castel, 2021a, 2021b, 2022b; Murphy et al., 2023 but it remains unclear how participants organize retrieval of semantically related words according to subjective value.

Selective memory processes are driven by directing attentional resources toward valuable information during encoding, subsequently maximizing the likelihood that this to-be-learned information—which is paired with temporally proximate, associated value information—will be later retrieved (Ariel et al., 2009; Castel et al., 2012). Despite the apparent role that selective attention mechanisms play in the successful encoding and retrieval of high-value information, prior work has demonstrated that under certain circumstances, participants can still be selective for valuable information even when attention at encoding is divided (e.g., Middlebrooks et al., 2017; Siegel & Castel, 2018b). However, other work using various divided attention tasks (e.g., articulatory suppression, random number generation, tone detection) has demonstrated that some divided attention tasks (random number generation, a difficult tone detection task) impair selective memory while selectivity is preserved in other divided attention tasks (articulatory suppression, an easy tone detection task; Elliott & Brewer, 2019; see also Murphy & Castel, 2022c for instances where divided attention at encoding impaired memory selectivity). Thus, the effects of divided attention at encoding on memory selectivity may depend on the degree to which attention is divided.

Memory selectivity can also be attenuated when concurrent primary and secondary tasks rely on overlapping processing resources during encoding (e.g., a visual–spatial primary memory task paired with a concurrent visual–spatial secondary pattern discrimination task). For example, Siegel et al. (2021) investigated memory selectivity for valuable visuospatial information arbitrarily assigned along a gradient of least to most important. Selectivity was preserved when spatial and nonspatial auditory secondary distractor tasks, in addition to a nonspatial visual secondary distractor task, were present during encoding for the primary visual–spatial task. However, when the secondary distractor task was of the same domain (visual) and modality (spatial), participants were no longer selective toward the more valuable visual–spatial information, thus diminishing selectivity effects. Despite these findings, the current state of this intra- versus intermodality research is not necessarily generalizable to other domains (e.g., auditory, verbal) due to a lack of empirical investigation outside of the visuospatial domain. Furthermore, it is unclear what underlying mechanism drives selectivity differences when concurrent memory tasks rely on both encoding and retrieving competing information streams within domains but across modalities.

Similar to when attention is divided at encoding, prior work has shown that there are greater costs of divided attention at retrieval if the primary and secondary tasks overlap (Fernandes & Moscovitch, 2000, 2002, 2003; Skinner & Fernandes, 2008). Yet, in terms of the number of items able to be recalled, early work showed larger effects of divided attention at encoding than at retrieval (Craik et al., 1996; Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000; Naveh-Benjamin et al., 1998; see also Rohrer & Pashler, 2003). However, despite not necessarily causing overall recall deficits, divided attention during retrieval may impair the selective retrieval of more important information. For example, the tendency to initiate recall with valuable or important items and selectivity for this information may be reduced with fewer available resources at retrieval. Thus, a full allotment of attentional resources during both encoding and retrieval may be a critical component of engaging in the effortful processing of important information (see Murphy & Castel, 2022c) such that people struggle to selectively encode high-value items or engage in strategic retrieval operations while completing a secondary task.

A learner's goals and metacognitive strategies to achieve those goals likely lead to focusing on important or valuable information, and we were interested in how these processes are affected by divided attention at encoding and retrieval. Specifically, participants may employ strategic encoding operations, such as engaging in more effective encoding strategies for high-value items (Hennessee et al., 2019), and/or strategic retrieval operations like initiating recall with high-value items or recalling important items before low-value items to reduce potential output interference (Murphy & Castel, 2022a). Thus, there may be important differences in how divided attention at encoding and retrieval impacts selective memory.

The Current Study

In the current study, we used attentional manipulations to (a) elucidate how divided attention at encoding alters previously described effects of value on retrieval dynamics, (b) determine how divided attention at retrieval impacts the dynamics of free recall and memory for valuable information, and (c) examine how divided attention at encoding and retrieval affects the tendency to remember subjectively important information that could have consequences for forgetting in a more applied context. In each experiment, we presented participants with information of varying objective or subjective values to remember for a later test. In Experiment 1, we compared participants completing the *study phase* under full or divided attention while in Experiment 2, we compared participants completing the *testing* *phase* under full or divided attention. In Experiment 3, we directly compared participants completing the study and retrieval phase under divided attention using the same divided attention task.

While participants under divided attention at encoding may show similar selectivity and retrieval tendencies (i.e., PFR, lag-CRPs) as participants with full attention (as shown in Middlebrooks et al., 2017; Murphy & Castel, 2022a), participants under divided attention at retrieval may show reduced selectivity and PFR for highly valued items. Alternatively, prior work suggests that dividing attention during learning may hinder the attentional resources available for effortful item-value encoding (see Yeung & Fernandes, 2021), which may be more detrimental to subsequent value-directed memory performance than dividing attention at retrieval. Furthermore, participants under divided attention at encoding could show detriments in memory selectivity not observed in participants under divided attention at retrieval due to the secondary task demands detracting resources from the effortful associative binding of memoranda and their relative value while retrieval attempts under divided attention may be subjected to more task-based competition and/or interference (see Fernandes & Moscovitch, 2000, 2002, 2003; Skinner & Fernandes, 2008).

Potential differences in memory selectivity and retrieval tendencies when attention is divided at encoding and retrieval may provide evidence that value-directed remembering involves not simply the strategic allocation of attention during encoding, but also strategic retrieval operations which include recalling the most important or valuable items before less important ones. Specifically, selectivity may depend on strategic retrieval operations, such as initiating recall with high-value or important items (as measured by PFR), leading to decreased selectivity if attention is divided during recall. As such, dividing participants' attention at encoding and retrieval may reveal potential underlying behavioral mechanisms contributing to value-directed remembering and may provide a more comprehensive and theoretical approach to understanding how divided attention can influence retrieval dynamics in a value-directed remembering context.

Lastly, the value of information can be objective (experimenter-designated point values) or subjective (intrinsic importance), and these different value assessments could differentially impact memory processes. Specifically, objective point values provide a clear hierarchy of which information should be prioritized while determining subjective value requires learners to consider the benefits of remembering and/or the consequences of forgetting a given item. As such, strategically remembering objectively and subjectively valuable information may involve different memory processes that could be differentially impacted by divided attention at encoding and retrieval.

Experiment 1a

In Experiment 1a, we presented participants with lists of words paired with point values counting toward participants' scores if the word was correctly recalled. Participants either completed the study phase under full or divided attention; participants under divided attention simultaneously completed a digit detection task while studying the words. All participants completed the test phase with full attention.

Method

Participants

In each experiment, participants were undergraduate students recruited from the University of California, Los Angeles (UCLA) Human Subjects Pool. Participants were tested online and received course credit for their participation. Participants were excluded from analysis if they admitted to cheating (e.g., writing down answers) in a posttask questionnaire (they were told they would still receive credit if they cheated). After one exclusion for cheating, our sample included 106 participants ($M_{age} = 20.40$, $SD_{age} = 1.29$). On the divided attention task (details below), participants correctly identified an average of 2.41 out of eight sequences ($SD = 1.07$) on each list. There was an average of 1.69 incorrect detections ($SD = 1.30$) on each list whereby participants pressed the space bar to indicate that three odd digits had been played when they had not. If a participant failed to identify at least one sequence (correctly or incorrectly) during a list, their data for that list was excluded (as was the case in Middlebrooks et al., 2017). This exclusion process resulted in 33 lists being excluded from analysis (out of 330 total lists). A sensitivity analysis based on the observed sample indicated that for a between-subjects analysis of variance (ANOVA) with two groups (attention: *full, divided*) and six measurements (list: *1, 2, …, 6*), assuming $\alpha = .05$, power $= .80$, and an average correlation of $r = .30$ between repeated-measures (selectivity), the smallest effect the design could reliably detect is $\eta_p^2 = .03$.

Materials and Procedure

Participants were presented with a series of to-be-remembered words with each word paired with a unique, randomly assigned value between 1 and 20 indicating how much the word was "worth." Word–value pairs were separated by a colon with the value presented to the right of the word (e.g., twig: 5). Both words and point values were simultaneously displayed for 3 s each and in the same font. Each point value was used only once within each list and the order of the point values within lists was randomized. The stimulus words were nouns that contained between four and seven letters with an everyday occurrence rate of at least 30 times per million (Thorndike & Lorge, 1944). Participants were told that their score would be the sum of the associated values of the words that they recalled and that they should try to maximize their score.

After the presentation of all 20 word–number pairs in each list, participants were given an immediate, 1-min free recall test in which they had to type as many words as they could from the list (they did not need to recall the point values) into an on-screen text box. To account for typographical errors in participants' responses, we employed a real-time textual similarity algorithm where responses with at least 75% similarity to the correct answer were counted as accurate. Immediately following the recall period, participants were informed of their total score for that list but were not given feedback about the items they recalled (or failed to recall). This was repeated for a total of six study-test cycles and participants self-paced their breaks between lists.

In addition to their overall score, participants were scored for efficiency via a selectivity index. For this metric, we calculated each participant's recall score relative to their chance and ideal score. The ideal score was comprised of the sum of only the highest values for the number of words recalled. For example, if a participant only remembered three words, then ideally those words would be paired with the three highest values (e.g., $18 + 19 + 20 = 57$). Chance scores reflected no attention to value and were calculated as the product of the average point value and the number of recalled words. At chance, the score in our example would result in 10.5 (the average value of the points in the list) multiplied by the number of recalled words. If a participant only recalled words paired with the highest values, the resulting selectivity score would be 1 while a participant who only recalled words paired with the lowest values would receive a selectivity score of −1. Scores close to 0 indicate that a subject was not selective (see Castel et al., 2002 for more details).

Participants were randomly assigned to either complete the task with full attention ($n = 51$) or divided attention ($n = 55$). Participants in the divided attention condition studied the to-be-remembered items while completing a digit-detection task. These participants were told that they would hear a series of digits spoken aloud while they studied the words and that they should press the spacebar on the keyboard every time they heard a sequence of three odd digits in a row. One digit (numbers 1–9) was read per second and the digits were randomly generated. For each participant on each list, there were eight instances of three-odd-digit sequences per list (when the spacebar should be pressed), and there was never a sequence of four odd digits in a row.

Results

Analysis Plan

Sample size, mean, variance, skew, and kurtosis for performance on the divided attention task, recall, and selectivity in each experiment are shown in the Table A1. Linear regressions with average divided attention task performance predicting average recall and selectivity in each experiment are shown in Table 1. To examine group differences in recall sensitivity for valuable information, we conducted 2 (attention at encoding: *full, divided*) × 6 (list: *1, 2, …, 6*) mixed ANOVA on selectivity index scores. To examine recall performance and further examine selectivity for valuable information, we computed multilevel models (MLMs) where we treated the data as hierarchical or clustered (i.e., multilevel) with items nested within individual participants; observations were not nested within items. Since recall at the item level was binary (correct or incorrect), we conducted logistic MLMs. In these analyses, the regression coefficients are given as logit units (i.e., the log odds of correct recall). We report exponential betas (e^B), and their 95% confidence intervals (95% CI), which give the coefficient as an odds ratio (i.e., the odds of correctly recalling a word divided by the odds of not recalling a word). Thus, e^B can be interpreted as the extent to which the odds of recalling a word changed. Specifically, values greater than 1 represent an increased likelihood of recall while values less than 1 represent a decreased likelihood of recall. In each MLM, the only random effect was the intercept which varied for each participant; all fixed effects in each model are reported in the analyses. The analysis code for all models is available on OSF (Murphy, 2023).

Table 1
Linear Regressions With Average Recall (Top) and Selectivity (Bottom) Predicted by Average Divided Attention Task Performance in Each Experiment

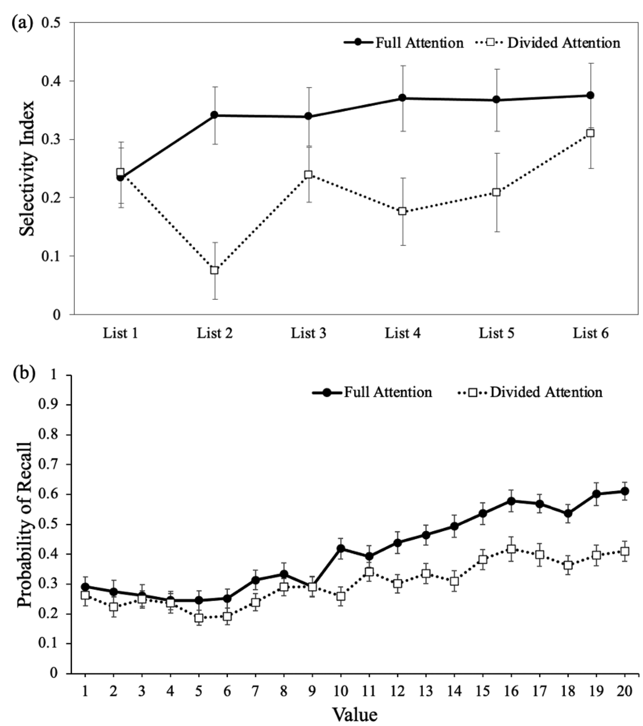
Experiment and measure	B	R^2	p
Experiment 1a—recall	−.04	<.01	.767
Experiment 1b—recall	.29	.08	.061
Experiment 2a—recall	−.01	<.01	.950
Experiment 2b—recall	.46	.21	<.001
Experiment 3a—recall	−.05	<.01	.632
Experiment 3b—recall	.03	<.01	.762
Experiment 1a—selectivity	.09	.01	.526
Experiment 1b—selectivity	.20	.04	.195
Experiment 2a—selectivity	.08	.01	.470
Experiment 2b—selectivity	.02	<.01	.861
Experiment 3a—selectivity	.03	<.01	.734
Experiment 3b—selectivity	.17	.03	.053

Recall Performance and Selectivity

Selectivity as a function of attention at encoding and list is shown in Figure 1a. To determine if participants under full and divided attention were selective, we first conducted one-sample *t*-tests. Results revealed that participants' selectivity scores both with full attention ($M = .34$, $SD = .26$) and divided attention ($M = .20$, $SD = .23$) were different from 0, full: $t(50) = 9.41$, $p < .001$, $d = 1.32$; divided: $t(54) = 6.50$, $p < .001$, $d = .88$. To examine group differences in selectivity, a 2 (attention at encoding: *full, divided*) × 6 (list: *1, 2, …, 6*) mixed ANOVA did not reveal a main effect of list, $F(5, 425) = 2.07$, $p = .068$, $\eta_p^2 = .02$, but list interacted with attention at encoding, $F(5, 425) = 2.90$, $p = .014$, $\eta_p^2 = .03$, such that participants with full attention became more selective with increased task experience. Additionally, results revealed a main effect of attention at encoding, $F(1, 85) = 4.09$, $p = .046$, $\eta_p^2 = .05$, such that participants studying the words with full attention were more selective than participants studying under divided attention.

To examine recall and selectivity with value as a continuous predictor (see Figure 1b), a logistic MLM with item-level recall

Figure 1
Selectivity Index as a Function of Attention at Encoding and List (a) and Probability of Recall as a Function of Attention at Encoding and Word Value (b) in Experiment 1a



Note. Error bars reflect the standard error of the mean.

modeled as a function of value with attention at encoding (full, divided) as a between-subjects factor revealed that value significantly predicted recall, $e^B = 1.08$, 95% CI [1.08, 1.09], $z = 21.98$, $p < .001$, such that high-value words were better recalled than low-value words. Additionally, attention significantly predicted recall, $e^B = 1.60$, [1.27, 2.03], $z = 3.93$, $p < .001$, such that participants studying the words with full attention ($M = .41$, $SD = .14$) recalled more words than participants studying the words under divided attention ($M = .30$, $SD = .12$). Furthermore, value interacted with attention, $e^B = 1.04$, [1.03, 1.06], $z = 5.72$, $p < .001$, such that value was a better predictor of recall for participants with full attention compared with participants under divided attention.

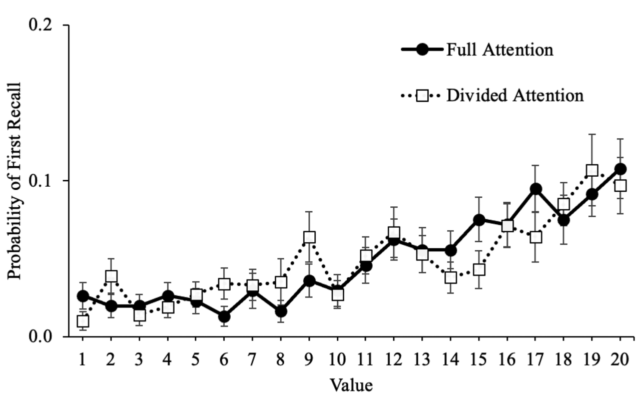
Retrieval Dynamics

To examine the dynamics of participants' recall, we first examined the PFR as a function of word value (see Figure 2). Again, the PFR captures how participants begin recall and in the present analysis, refers to the proportion of the time the word with a given value was the first word recalled. In our analyses of PFR, we do not report the fixed effect for the different conditions as this effect is meaningless. A logistic MLM with PFR modeled as a function of value with attention at encoding (full, divided) as a between-subjects factor revealed that value significantly predicted PFR, $e^B = 1.10$, 95% CI [1.08, 1.12], $z = 11.98$, $p < .001$, such that participants tended to begin recall with the highest valued words. However, value did not interact with attention, $e^B = 1.02$, [.99, 1.05], $z = 1.23$, $p = .220$.

In addition to the PFR, we calculated lag-CRPs to examine how a word's accompanying temporal and contextual information from the study phase impacts recall. In this measure of how participants transition between responses during retrieval, lag is the ordinal distance between successively recalled items (i.e., the lag between Items 1 and 6 would be 5), and the sign of the lag indicates the direction of recall: Positive values indicate a forward transition and negative values indicate a backward transition. The CRP for a recall transition illustrates the likelihood that a word from serial position $i + \text{lag}$ is recalled directly after a word from serial position i. The probability of recalling an item from serial position x followed by the item from position $x + \text{lag}$ is shown in Figure 3a.[1]

Figure 2

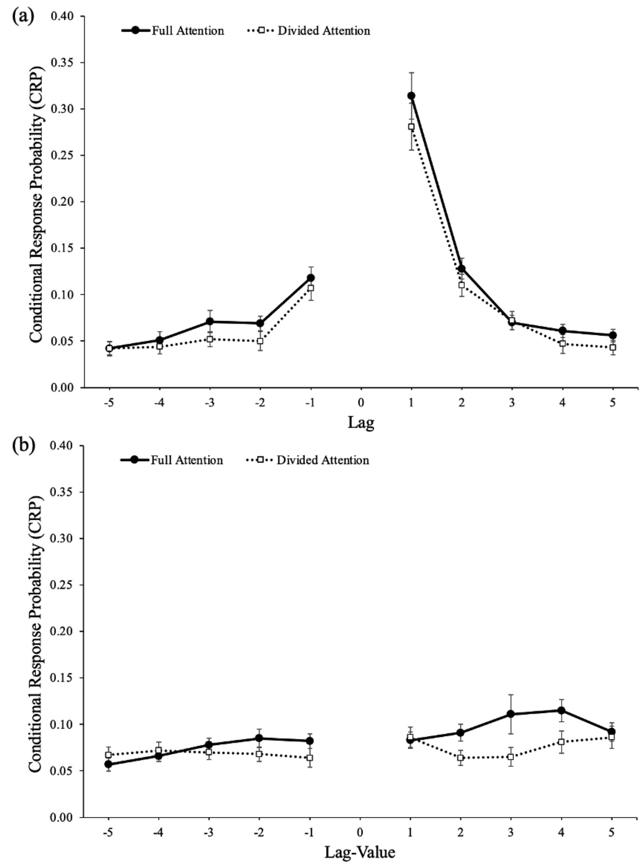
Probability of First Recall (PFR) as a Function of Attention at Encoding and Word Value in Experiment 1a



Note. Error bars reflect the standard error of the mean.

Figure 3

Conditional-Response Probability (a) and Lag-Value Conditional-Response Probability (b) Functions as a Function of Lag and Attention at Encoding in Experiment 1a



Note. Error bars reflect the standard error of the mean.

To examine differences in the lag-recency effect as a function of attention at encoding, we conducted a 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *forward vs. backward*) × 2 (attention at encoding: *full, divided*) mixed ANOVA. Results revealed that participants showed a forward preference for the direction of transitions, $F(1, 104) = 104.23$, $p < .001$, $\eta_p^2 = .50$, but this did not differ as a function of attention, $F(1, 104) = .13$, $p = .719$, $\eta_p^2 < .01$. Additionally, participants showed strong adjacency effects, Mauchly's $W = .32$, $p < .001$; Huynh–Feldt corrected results: $F(2.39, 248.66) = 103.24$, $p < .001$, $\eta_p^2 = .50$, but lag also did not interact with attention, $F(2.39, 248.66) = .27$, $p = .801$, $\eta_p^2 < .01$. There was an interaction between direction and lag, Mauchly's $W = .27$, $p < .001$; Huynh–Feldt corrected results: $F(2.33, 242.15) = 40.68$, $p < .001$, $\eta_p^2 = .28$, such that transitions of lag 1 were more likely in the forward direction but there was not a three-way interaction between direction, lag, and attention at

[1] When calculating the lag-CRPs, incorrect responses were included in participants' output order. For example, if a participant recalled a correct item, then an incorrect item, then another correct item, this last item's output position would be three.

encoding, $F(2.33, 242.15) = .48$, $p = .646$, $\eta_p^2 = .01$. Moreover, there was a main effect of attention, $F(1, 104) = 11.11$, $p = .001$, $\eta_p^2 = .10$, such that, overall, participants with full attention were more likely to organize retrieval based on the temporal proximity in the study phase compared with participants under divided attention.

The probability of recalling an item of value *x* followed by an item of value *x* + lag is shown in Figure 3b. To examine differences in this lag-value effect (i.e., lag-v CRP, see Stefanidi et al., 2018) as a function of attention at encoding, we conducted a 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *increasing vs. decreasing*) × 2 (attention at encoding: *full, divided*) mixed ANOVA. Results revealed that participants showed a decreasing value preference for the direction of transitions, $F(1, 104) = 15.13$, $p < .001$, $\eta_p^2 = .13$, but this did not differ as a function of attention, $F(1, 104) = 3.89$, $p = .051$, $\eta_p^2 = .04$. Participants did not show lag-value effects, $F(3.85, 400.82) = .39$, $p = .810$, $\eta_p^2 < .01$, and lag-value also did not interact with attention, $F(3.85, 400.82) = 1.26$, $p = .288$, $\eta_p^2 = .01$. Moreover, there was not an interaction between direction and lag, $F(3.49, 362.48) = 1.29$, $p = .277$, $\eta_p^2 = .01$, and there was not a three-way interaction between direction, lag, and attention at encoding, $F(3.49, 362.48) = 1.51$, $p = .204$, $\eta_p^2 = .01$. Moreover, there was a main effect of attention, $F(1, 104) = 8.30$, $p = .005$, $\eta_p^2 = .07$, such that, overall, participants with full attention were more likely to organize retrieval according to word value compared with participants under divided attention.

Discussion

In Experiment 1a, participants studied words paired with point values while under full or divided attention. Results revealed that dividing participants' attention during the study phase reduced participants' ability to remember the words, consistent with prior research (see Castel & Craik, 2003; Craik et al., 1996; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000). Additionally, selectivity was reduced in participants under divided attention, consistent with some previous work suggesting that, under certain conditions, selectivity can be impaired when attention is divided at encoding (see Elliott & Brewer, 2019; Murphy & Castel, 2022c; Siegel & Castel, 2018b). However, PFR was preserved when participants' attention was divided during the study phase, although participants with divided attention demonstrated reduced lag-recency effects. Together, Experiment 1a suggests that the strategic remembering of valuable information may depend on strategic encoding processes and these processes can be disrupted by a secondary task.

Experiment 1b

In Experiment 1b, rather than a list of unassociated words paired with objective point values, we presented participants with lists of 20 to-be-remembered items along a theme and of varying subjective value. After a recall test, participants ranked the to-be-remembered items from most important to least important (similar to assigning point values, see McGillivray & Castel, 2017). When words are not paired with arbitrary point values but instead offer schematic support, retrieval dynamics may reveal more about how participants prioritize certain items, initiate recall, and transition between items when considered in terms of their subjective importance or potential consequences for forgetting.

Method

Participants

Participants were 93 undergraduate students ($M_{age} = 20.46$, $SD_{age} = 2.29$); no participants were excluded for cheating. On the divided attention task, participants correctly identified an average of 3.08 out of eight sequences ($SD = 1.50$) on each list and there was an average of 1.61 incorrect detections ($SD = 1.15$) on each list. As in Experiment 1a, if a participant failed to identify at least one sequence (correctly or incorrectly) during a list, their data for that list was excluded. This exclusion process resulted in 37 lists being excluded from analysis (out of 270 total lists). A sensitivity analysis based on the observed sample indicated that for a between-subjects ANOVA with two groups (attention: *full, divided*) and six measurements (list: *1, 2, …, 6*), assuming $\alpha = .05$, power $= .80$, and an average correlation of $r = .16$ between repeated-measures (selectivity), the smallest effect the design could reliably detect is $\eta_p^2 = .03$.

Materials and Procedure

Participants were instructed that they would be presented with six lists of 20 items, with each list containing items along a theme (going camping, going on vacation, child's party, going to class, making lasagna, going on a picnic; stimuli available on OSF). Participants were randomly assigned to either study the word lists with full attention ($n = 48$) or divided attention ($n = 45$; the same digit detection task from Experiment 1a). Each item was presented one at a time, for 3 s each, in a randomized order. After the presentation of all 20 items, participants were given a 1-min free recall test in which they were asked to recall all the items from the just-presented list. Participants were also instructed that after the recall test, they would be presented with all 20 items from that list and asked to rank the items from most important to least important. When ranking the items after recall, participants clicked and dragged items to change their rank order and were required to spend a minimum of 1 min on this portion of the task.

Results

Recall Performance and Selectivity

Although items in this study were not paired with point values counting toward a task score, we still computed selectivity index scores by reverse scoring participants' rankings (i.e., the item ranked most important was given a "point value" of 20).[2] We then calculated each participant's recall "score" (sum of the values of recalled items) relative to their chance and ideal score based on these reversed scored rankings. The ideal score consisted of the sum of only the highest values, or in this case, the items ranked as most important by each participant, for the number of items recalled. Chance scores reflected no attention to rankings and were calculated as the product of the average ranking and the number of recalled items. At chance, the score in our example would be 10.5 multiplied by the number of recalled items. If

[2] This selectivity measure may not capture a pure form of participants' feeling of importance since items were ranked after the memory test. Specifically, items that are more easily accessed and remembered during retrieval may subsequently be ranked as more important.

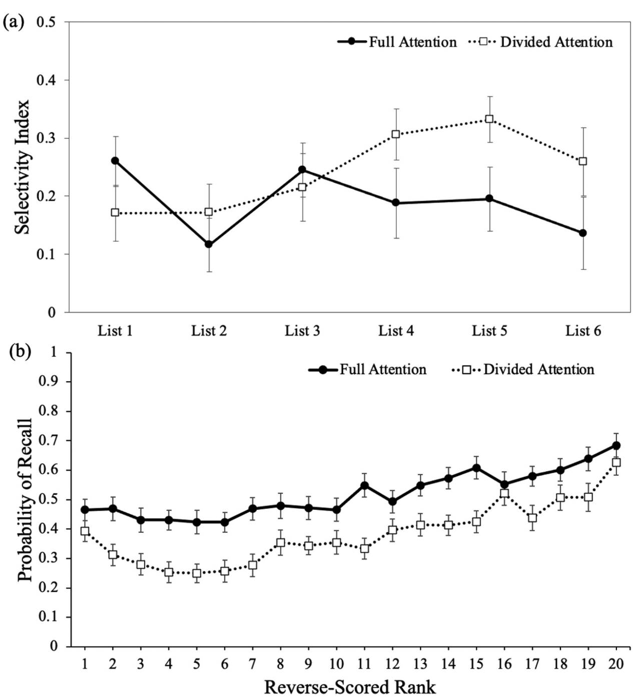
a participant only recalled the items that they ranked the highest, then the resulting selectivity score would be 1 while a participant who only recalled the items that they ranked the lowest would receive a selectivity score of -1. Scores close to 0 indicate that a participant's recall was not sensitive to their rankings.

Selectivity as a function of attention at encoding and list is shown in Figure 4a. To determine if participants under full and divided attention were selective, we first conducted one-sample *t*-tests. Results revealed that both selectivity scores with full attention ($M = .19$, $SD = .21$) and divided attention ($M = .25$, $SD = .14$) were different from 0, full: $t(47) = 6.38$, $p < .001$, $d = .92$; divided: $t(44) = 12.08$, $p < .001$, $d = 1.80$. To examine group differences in selectivity for items participants ranked as important, a 2 (attention at encoding: *full, divided*) × 6 (list: *1, 2, …, 6*) mixed ANOVA did not reveal a main effect of attention, $F(1, 71) = 2.18$, $p = .144$, $\eta_p^2 = .03$, such that participants studying the items with full attention were similarly selective as participants studying the items under divided attention. Additionally, results did not reveal a main effect of list, $F(5, 355) = .97$, $p = .433$, $\eta_p^2 = .01$, and list did not interact with attention, $F(5, 355) = 2.07$, $p = .068$, $\eta_p^2 = .03$.

To examine recall and selectivity with participants' reverse scored rankings as a continuous variable (see Figure 4b), a logistic MLM with item-level recall modeled as a function of participants' rankings with attention at encoding (full, divided) as a between-subjects factor revealed that rank significantly predicted recall, $e^B = 1.06$, 95% CI [1.06, 1.07], $z = 16.92$, $p < .001$, such that items ranked as more important to remember were better remembered than items ranked as less important to remember. Additionally, attention significantly predicted recall, $e^B = 1.77$, [1.30, 2.42], $z = 3.61$, $p < .001$, such that participants studying the items with full attention ($M = .52$, $SD = .19$) recalled more items than participants studying the items under divided attention ($M = .38$, $SD = .13$). Furthermore, rank interacted with attention, $e^B = .97$, [.97, 1.00], $z = -2.08$, $p = .038$, such that rankings were a stronger predictor of recall for participants under divided attention compared with participants with full attention.

Figure 4

Selectivity Index as a Function of Attention at Encoding and List (a) and Probability of Recall as a Function of Attention at Encoding and Participants' Reverse-Scored Rankings (b) in Experiment 1b



Note. Error bars reflect the standard error of the mean.

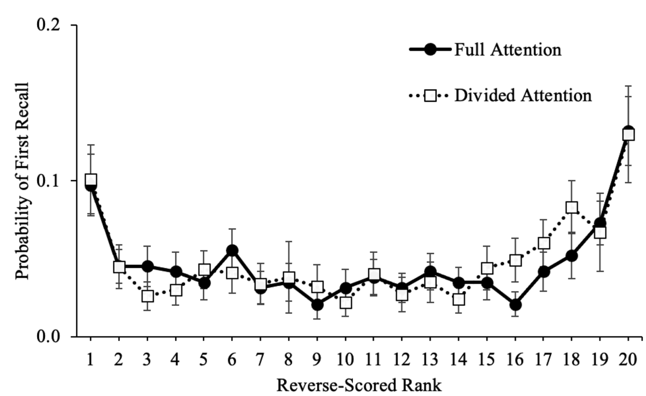
Retrieval Dynamics

To examine the dynamics of participants' recall, we examined the PFR as a function of each participant's rankings (see Figure 5). A logistic MLM with PFR modeled as a function of participants' rankings with attention at encoding (full, divided) as a between-subjects factor revealed that rankings significantly predicted PFR, $e^B = 1.02$, 95% CI [1.01, 1.04], $z = 2.74$, $p = .006$, such that participants tended to begin recall with the top-ranked items as well as the lowest-ranked item. This enhanced PFR for the lowest-ranked item may result from increased distinctiveness (see Neath, 2010) as a result of being considered the least important item or potentially being less consistent with the list theme. However, rank did not interact with attention, $e^B = .99$, [.96, 1.02], $z = -.65$, $p = .514$.

To examine recall transitions, a 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *forward vs. backward*) × 2 (attention at encoding: *full, divided*) mixed ANOVA revealed that participants showed a forward preference for the direction of transitions, $F(1, 91) = 5.24$, $p = .024$, $\eta_p^2 = .05$, and this differed as a function of attention, $F(1, 91) = 12.16$, $p < .001$, $\eta_p^2 = .12$, such that participants with full attention showed a stronger forward preference than participants under divided attention. Additionally, participants showed strong adjacency effects, Mauchly's $W = .65$, $p < .001$; Huynh–Feldt corrected results: $F(3.28, 307.58) = 33.23$, $p < .001$, $\eta_p^2 = .27$, but lag did not interact with attention, $F(3.38, 307.58) = 2.52$, $p = .051$, $\eta_p^2 = .03$. There was also an interaction between direction and lag, Mauchly's $W = .83$, $p = .046$; Huynh–Feldt corrected results: $F(3.86, 351.37) = 3.81$, $p = .005$, $\eta_p^2 = .04$, such that transitions of

Figure 5

Probability of First Recall (PFR) as a Function of Attention at Encoding and Participants' Reverse-Scored Rankings in Experiment 1b



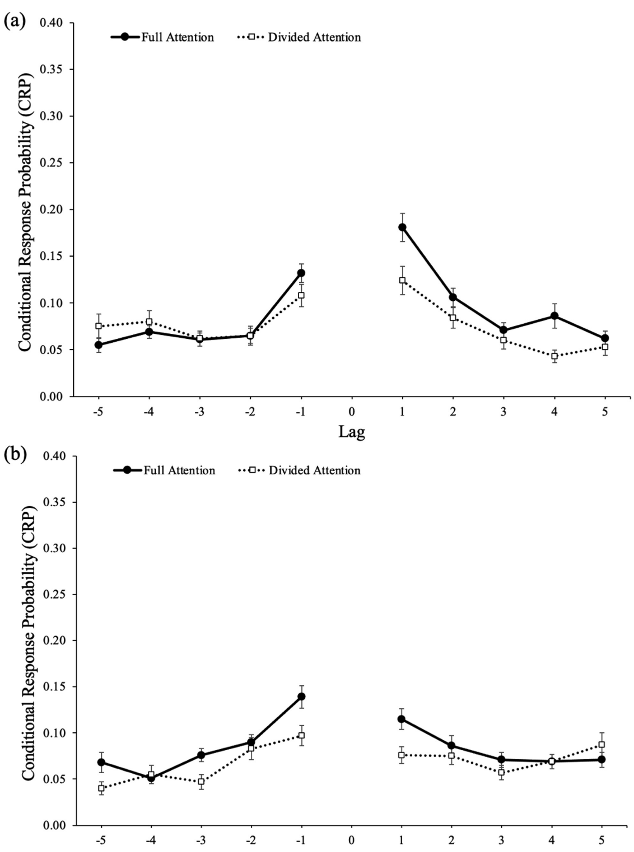
Note. Error bars reflect the standard error of the mean.

lag 1 were more likely in the forward direction but there was not a three-way interaction between direction, lag, and attention, $F(3.86, 351.37) = .55$, $p = .693$, $\eta_p^2 = .01$. However, there was a main effect of attention, $F(1, 91) = 12.84$, $p < .001$, $\eta_p^2 = .12$, such that participants with full attention demonstrated stronger lag-recency effects than participants under divided attention (see Figure 6a).

The probability of recalling an item of rank x followed by an item of rank x + lag is shown in Figure 6b. To examine differences in the lag-rank effect as a function of attention at encoding, we conducted a 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *increasing vs. decreasing*) × 2 (attention at encoding: *full, divided*) mixed ANOVA. Results revealed that participants did not show a preference for the direction of transitions, $F(1, 91) = .44$, $p = .507$, $\eta_p^2 = .01$, and this did not differ as a function of attention, $F(1, 91) = 1.37$, $p = .244$, $\eta_p^2 = .02$. However, participants showed lag-rank effects, Mauchly's $W = .83$, $p = .048$; Huynh–Feldt corrected results: $F(3.85, 350.75) = 17.09$, $p < .001$, $\eta_p^2 = .16$, and lag-rank interacted with attention, $F(3.85, 350.75) = 3.12$, $p = .016$, $\eta_p^2 = .03$, such that participants with full attention showed stronger rank-adjacency effects than participants under divided attention. Furthermore, there was an interaction between direction and lag, Mauchly's $W = .69$, $p < .001$; Huynh–Feldt corrected results: $F(3.67, 334.35) = 4.09$, $p = .004$, $\eta_p^2 = .04$, such that transitions of the lag-rank −1 were more likely than +1, but there was not a three-way interaction between direction, lag, and attention at encoding, $F(3.67, 334.35) = 1.15$, $p = .333$, $\eta_p^2 = .01$. Finally, there was a main effect of attention, $F(1, 91) = 12.13$, $p < .001$, $\eta_p^2 = .12$, such that participants with full attention demonstrated stronger lag-rank effects than participants under divided attention.

Figure 6

Conditional-Response Probability (a) and Lag-Rank Conditional-Response Probability (b) Functions as a Function of Lag and Attention at Encoding in Experiment 1b



Note. Error bars reflect the standard error of the mean.

Discussion

Although the divided attention task successfully reduced participants' ability to remember the items, there was some evidence that selectivity for items ranked as important to remember was impaired (though this effect might be smaller than Experiment 1a). Regardless, PFR was again preserved under divided attention, indicating that reduced attentional resources during encoding may not impact certain strategic retrieval operations. However, CRPs were reduced under divided attention, similar to Experiment 1a.

Since the to-be-remembered words in Experiment 1b were consistent with a semantic theme, participants may have benefitted from schematic support whereby prior knowledge enhances recall (see Castel, 2005; Craik, 2002; Craik & Bosman, 1992; McGillivray & Castel, 2017). Specifically, reduced attentional resources during encoding may hinder one's ability to encode valuable or important words but participants can still engage in value-directed retrieval by harnessing the benefits of schematic support to recall important items, though learners with full attention may be better able to remember important items. Thus, in addition to strategic encoding processes, there are likely strategic retrieval operations that contribute to value-directed remembering.

Experiment 2a

Experiment 1 indicated that sensitivity to the value or importance of to-be-remembered words may be impaired under divided attention during encoding. In Experiment 2a, rather than reducing participants' attentional resources during encoding, we were interested in the effects of divided attention during recall on selective memory and strategic retrieval operations. If the retrieval trends and dynamics like selectivity, PFR, and CRPs are disrupted when under divided attention at retrieval, this would provide evidence that value-directed remembering requires not simply the strategic allocation of attention during encoding, but also strategic retrieval operations.

Although we used a digit detection task to divide participants' attention during encoding in Experiment 1, in Experiment 2, all participants completed the study phase with full attention but simultaneously completed either no task, a tone detection task, or an animacy task during retrieval. We included the animacy task during retrieval as this task may have a greater impact on participants' ability to remember words (i.e., the animacy task taxes the same modality as learning and remembering word lists) but may also impair selective memory; the tone detection task involves a similar discrimination decision as the animacy task and served as a nonverbal comparison to the animacy task. Moreover, we did not use the animacy task to divide participants' attention during encoding as the animacy task may result in recall intrusions. For example, participants may mistakenly recall words from the animacy task which could disrupt retrieval processes. Thus, if we used the animacy task during encoding, both encoding and retrieval processes may be affected rather than just encoding processes.

Method

Participants

After 10 exclusions due to cheating, participants were 130 undergraduate students ($M_{age} = 20.24$, $SD_{age} = 1.61$). Participants were also excluded for failing to complete the divided attention tasks with at least 50% accuracy (as seen in Siegel & Castel, 2018b; Siegel et al., 2021). This exclusion process resulted in the exclusion of 10 participants for poor tone detection performance and 15 participants for poor animacy performance. On the tone discrimination task, participants correctly identified 83.4% of the tones ($SD =$ 15.7%) and on the animacy task, participants correctly identified 74.8% of the items ($SD = 14.3\%$). A sensitivity analysis based on the observed sample indicated that for a between-subjects ANOVA with three groups (attention: *full, divided by tone task, divided by animacy task*) and six measurements (list: *1, 2, …, 6*), assuming $\alpha = .05$, power = .80, and an average correlation of $r = .35$ between repeated-measures (selectivity), the smallest effect the design could reliably detect is $\eta_p^2 = .03$.

Materials and Procedure

The task in Experiment 2a was similar to the task in Experiment 1a. All participants studied the words with full attention but either completed the recall phase with full attention ($n = 52$) or divided attention. Participants under divided attention either completed a tone identification task ($n = 44$) or an animacy task ($n = 34$) during retrieval. In the divided attention conditions, the tone identification and animacy tasks occurred while participants simultaneously tried to recall the to-be-remembered words for 1 min.

Participants recalling the to-be-remembered items while completing a tone identification task were told that they would hear a series of low-pitched (400 Hz) and high-pitched (900 Hz) tones during the test phase. Each tone was played for 1 s with a 3-s interstimulus interval between each tone. Tone sequences were randomly generated for each participant. Participants were instructed to indicate (on the keyboard) whether each pitch they heard was low or high, and the text "awaiting tone response" would appear on the screen if participants did not respond to the tones. Participants completed a short tone discrimination practice session before beginning the task.

In the animacy divided attention task, while participants recalled the to-be-remembered items, they were simultaneously read a list of 15 items (one item was read every 3 s) and had to indicate whether each item was an animal or a manmade object via keyboard clicks (adapted from Fernandes & Moscovitch, 2002). Each recall phase contained a pseudorandomized sequence of 15 animal and manmade objects generated in accordance with the following three conditions: (a) animal and manmade objects appeared at least four times each in the sequence, (b) the longest same-category (i.e., animal or manmade) sequential occurrence did not exceed three-in-a-row, and (c) both animal and manmade objects changed (i.e., animal-to-manmade or manmade-to-animal) at least three times throughout the sequence.

Results

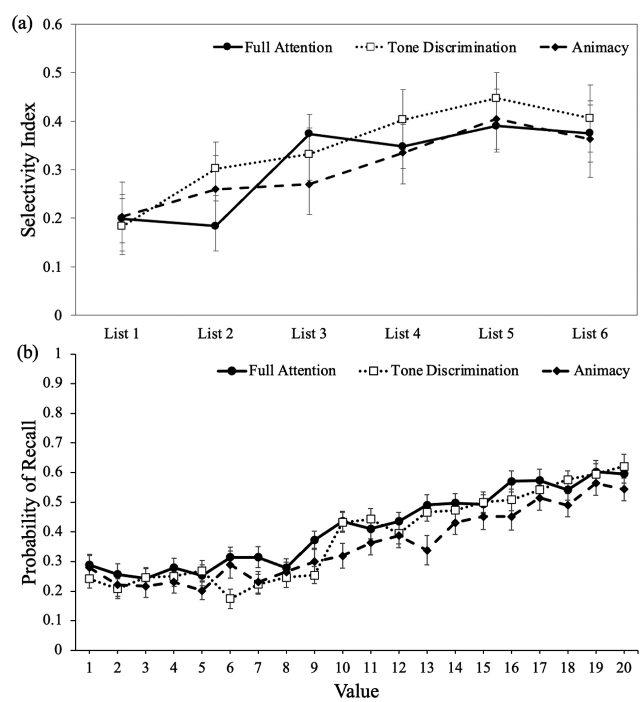
Recall Performance and Selectivity

Selectivity as a function of attention at retrieval and list is shown in Figure 7a. To determine if participants were selective, we first conducted one-sample *t*-tests. Results revealed that participants' selectivity scores with full attention ($M = .31$, $SD = .24$), divided attention via the tone task ($M = .35$, $SD = .28$), and divided attention via the animacy task ($M = .31$, $SD = .27$) were different from 0, full: $t(51) = 9.26$, $p < .001$, $d = 1.28$; tones: $t(43) = 8.30$, $p < .001$, $d =$ 1.25; animacy: $t(33) = 6.80$, $p < .001$, $d = 1.17$. To examine group differences in selectivity, a 3 (Attention at Retrieval: *Full, Divided by Tone Task, Divided by Animacy Task*) × 6 (List: *1, 2, …, 6*) mixed ANOVA revealed a main effect of list, $F(5, 615) = 7.83$, $p < .001$, $\eta_p^2 = .06$, such that participants became more selective with increased task experience but list did not interact with attention at retrieval, $F(10, 615) = .60$, $p = .819$, $\eta_p^2 = .01$. Moreover, results did not reveal a main effect of attention, $F(2, 123) = .24$, $p = .787$, $\eta_p^2 < .01$, such that participants were similarly selective whether recalling words under full or divided attention.

To examine recall and selectivity with value as a continuous predictor (see Figure 7b), we conducted a logistic MLM with item-level recall modeled as a function of value with attention at retrieval (full, divided by tone task, divided by animacy task) as a between-subjects factor. In this model and all subsequent models, participants in the full attention condition served as the reference group. Results revealed that value significantly predicted recall, $e^B = 1.10$, 95%

Figure 7

Selectivity Index as a Function of Attention at Retrieval and List (a) and Probability of Recall as a Function of Attention at Retrieval and Word Value (b) in Experiment 2a



Note. Error bars reflect the standard error of the mean.

CI [1.10, 1.11], $z = 30.81$, $p < .001$, such that high-value words were better recalled than low-value words. Additionally, when comparing the divided attention conditions with participants with full attention, participants completing the tone task during recall ($M = .38$, $SD = .10$) recalled a similar proportion of words as participants with full attention ($M = .41$, $SD = .14$), $e^B = .88$, [.69, 1.11], $z = -1.07$, $p = .283$. However, participants completing the animacy task during recall ($M = .35$, $SD = .13$) recalled fewer words than participants with full attention, $e^B = .77$, [.59, .99], $z = -2.04$, $p = .042$. Furthermore, value was a better predictor of recall for participants completing the tone task during recall than participants with full attention, $e^B = 1.02$, [1.00, 1.03], $z = 1.97$, $p = .049$, but participants completing the animacy task during recall and participants with full attention were similarly selective, $e^B = 1.00$, [.98, 1.01], $z = -.55$, $p = .580$.

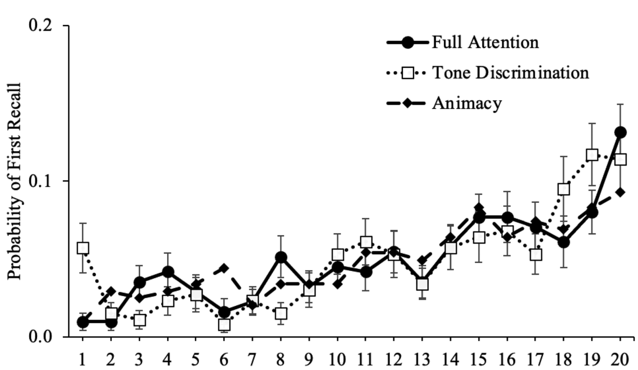
Retrieval Dynamics

To examine the dynamics of participants' recall, we examined the PFR as a function of word value (see Figure 8). A logistic MLM with PFR modeled as a function of value with attention at retrieval (full, divided by tone task, divided by animacy task) as a between-subjects factor revealed that value significantly predicted PFR, $e^B = 1.10$, 95% CI [1.08, 1.11], $z = 13.11$, $p < .001$, such that participants tended to begin recall with the highest valued words. However, there were no significant interactions with value between participants completing the tone task during recall and participants with full attention or participants completing the animacy task during recall and participants with full attention, both $ps > .438$.

To examine differences in the lag-recency effect as a function of attention at retrieval (see Figure 9a), we conducted a 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *forward vs. backward*) × 3 (attention at retrieval: *full, divided by tone task, divided by animacy task*) mixed ANOVA. Results revealed that participants showed a forward preference for the direction of transitions, $F(1, 127) = 118.14$, $p < .001$, $\eta_p^2 = .48$, but this did not differ as a function of attention, $F(2, 127) = .34$, $p = .713$, $\eta_p^2 = .01$. Additionally, participants showed strong adjacency effects, Mauchly's $W = .44$, $p < .001$; Huynh–Feldt corrected results: $F(2.81, 357.22) = 164.25$, $p < .001$, $\eta_p^2 = .56$, and lag interacted with attention, $F(5.63, 357.22) = 4.06$, $p < .001$, $\eta_p^2 = .06$, such that participants whose attention was divided by tones demonstrated a reduced lag-recency effect for lags of 1. There was also an interaction between direction and lag, Mauchly's $W = .52$, $p < .001$; Huynh–Feldt corrected results: $F(3.00, 380.94) = 36.72$, $p < .001$, $\eta_p^2 = .22$, such that transitions of lag 1 were more likely in the forward direction but there was not a three-way interaction between direction, lag, and attention, $F(6.00, 380.94) = 1.08$, $p = .371$, $\eta_p^2 = .02$. Furthermore, there was not a main effect of attention, $F(2, 127) = 1.02$, $p = .363$, $\eta_p^2 = .02$.

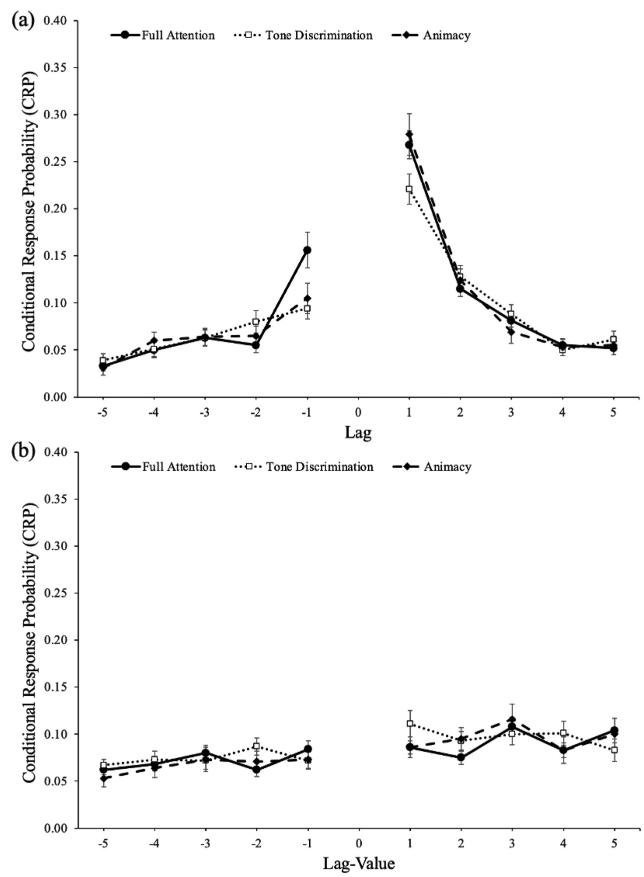
The probability of recalling an item of value x followed by an item of value $x + \text{lag}$ is shown in Figure 9b. To examine differences in the lag-value effect as a function of attention at retrieval, we conducted a 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *increasing vs. decreasing*) × 3 (attention at retrieval: *full, divided by tone task, divided by animacy task*) mixed ANOVA. Results revealed that participants showed a decreasing preference for the direction of transitions, $F(1, 127) = 38.61$, $p < .001$, $\eta_p^2 = .23$, but this did not differ as a function of attention, $F(2, 127) = .48$, $p = .621$, $\eta_p^2 = .01$. Additionally, participants did not show lag-value effects,

Figure 8
Probability of First Recall (PFR) as a Function of Attention at Retrieval and Word Value in Experiment 2a



Note. Error bars reflect the standard error of the mean.

Figure 9
Conditional-Response Probability (a) and Lag-Value Conditional-Response Probability (b) Functions as a Function of Lag and Attention at Encoding in Experiment 2a



Note. Error bars reflect the standard error of the mean.

$F(4, 508) = 1.77$, $p = .134$, $\eta_p^2 = .01$, and lag-value also did not interact with attention, $F(8, 508) = 1.14$, $p = .332$, $\eta_p^2 = .02$. Furthermore, there was not an interaction between direction and lag, $F(4, 508) = 1.34$, $p = .254$, $\eta_p^2 = .01$, and there was not a three-way interaction between direction, lag, and attention at retrieval, $F(8, 508) = 1.04$, $p = .403$, $\eta_p^2 = .02$. Moreover, there was not a main effect of attention, $F(2, 127) = .49$, $p = .613$, $\eta_p^2 = .01$, indicating that divided attention during recall did not influence the organization of recall according to value.

Discussion

In Experiment 2a, we again presented participants with words paired with point values, but participants either recalled the words under full or divided attention (tone discrimination or animacy task). Results revealed that the animacy task, but not the tone discrimination task, impaired overall recall performance, consistent with prior work indicating that there are greater costs of divided attention at retrieval if the tasks overlap (Craik et al., 1996; Fernandes & Moscovitch, 2000, 2002, 2003; Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000; Naveh-Benjamin et al., 1998; Siegel et al., 2021; Skinner & Fernandes, 2008) as well as research suggesting that a secondary task during recall often has minimal effects on retrieval (e.g., Rohrer & Pashler, 2003). However, despite some recall impairments, there were no differences in selectivity for valuable information as a function of attention at retrieval (although there was some evidence that selectivity was enhanced for participants completing the tone task). Moreover, there were no group differences in PFR, and the lag-recency effect was preserved when under divided attention during retrieval. Thus, the ability to selectively remember valuable information, and the retrieval operations contributing to selective memory, appear to be preserved under divided attention during retrieval.

Experiment 2b

In Experiment 2b, we presented participants with lists of to-be-remembered words along a theme (similar to Experiment 1b) rather than unassociated words. Similar to Experiment 2a, all participants completed the study phase with full attention but the retrieval phase under either full or divided attention (via a tone detection or animacy task). Consistent with Experiment 2a, we expected participants to demonstrate preserved selectivity and strategic retrieval operations when under divided attention during retrieval.

Method

Participants

After exclusions, participants were 128 undergraduate students ($M_{age} = 20.02$, $SD_{age} = 1.42$); no participants were excluded for cheating. Participants were also excluded for failing to complete the divided attention tasks with at least 50% accuracy. This exclusion process resulted in the exclusion of seven participants for poor tone detection performance and 21 participants for poor animacy performance. On the tone discrimination task, participants correctly identified 88.3% of the tones ($SD = 12.3\%$) and on the animacy task, participants correctly identified 79.6% of the items ($SD = 10.1\%$). A sensitivity analysis based on the observed sample indicated that for a between-subjects ANOVA with three groups (attention: *full, divided by tone task, divided by animacy task*) and six measurements (list: *1, 2, …, 6*), assuming $\alpha = .05$, power $= .80$, and an average correlation of $r = .05$ between repeated-measures (selectivity), the smallest effect the design could reliably detect is $\eta_p^2 = .02$.

Materials and Procedure

The task in Experiment 2b was similar to the task in Experiment 1b. All participants studied the words with full attention but either completed the recall phase with full attention ($n = 49$) or divided attention. Similar to Experiment 2a, participants under divided attention either completed a tone detection task ($n = 46$) or an animacy task ($n = 33$) during retrieval.

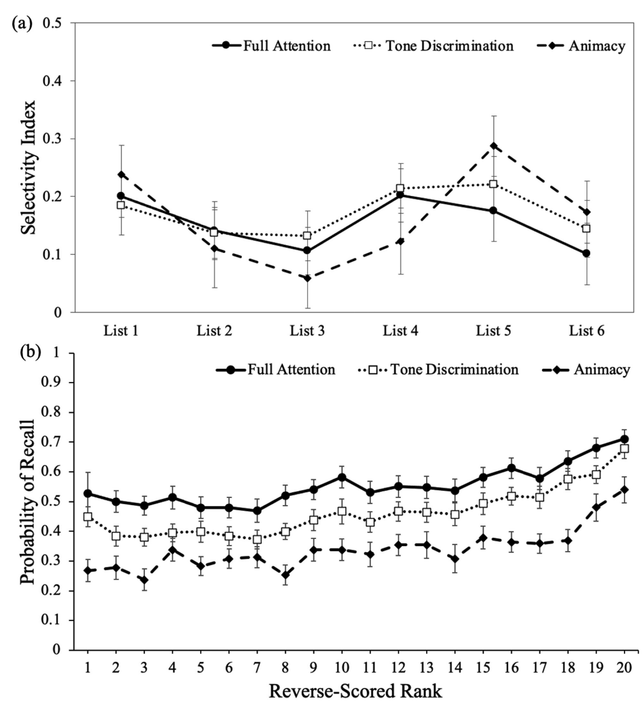
Results

Recall Performance and Selectivity

Selectivity as a function of attention at retrieval and list is shown in Figure 10a. To determine if participants under full and divided attention were selective, we again scored participants for recall efficiency using their reverse-scored rankings. One-sample *t*-tests revealed that participants' selectivity scores with full attention ($M = .17$, $SD = .19$), divided attention via the tone task ($M = .17$, $SD = .14$), and divided attention via the animacy task ($M = .16$, $SD = .12$) were different from 0, full: $t(48) = 6.03$, $p < .001$, $d = .86$; tones: $t(45) = 8.62$, $p < .001$, $d = 1.27$; animacy:

Figure 10

Selectivity Index as a Function of Attention at Retrieval and List (a) and Probability of Recall as a Function of Attention at Retrieval and Participants' Reverse-Scored Rankings (b) in Experiment 2b



Note. Error bars reflect the standard error of the mean.

$t(32) = 7.71$, $p < .001$, $d = 1.34$. To examine group differences in selectivity for items participants ranked as important, a 3 (attention at retrieval: *full, divided by tone task, divided by animacy task*) × 6 (list: *1, 2, …, 6*) mixed ANOVA revealed a main effect of list, $F(5, 570) = 3.06$, $p = .010$, $\eta_p^2 = .03$, such that selectivity decreased with task experience but list did not interact with attention at retrieval, $F(10, 570) = 1.02$, $p = .424$, $\eta_p^2 = .02$. Additionally, results did not reveal a main effect of attention, $F(2, 114) = .17$, $p = .846$, $\eta_p^2 < .01$.

To examine recall and selectivity with participants' reverse scored rankings as a continuous measure (see Figure 10b), a logistic MLM with item-level recall modeled as a function of participants' rankings with attention at retrieval (full, divided by tone task, divided by animacy task) as a between-subjects factor revealed that participants' rankings (reverse scored) significantly predicted recall, $e^B = 1.05$, 95% CI [1.04, 1.05], $z = 15.18$, $p < .001$, such that items ranked as important to remember were better remembered than items ranked as less important to remember. Additionally, when comparing the divided attention conditions and participants with full attention, participants completing the tone task during recall ($M = .46$, $SD = .12$) recalled fewer items than participants with full attention ($M = .55$, $SD = .16$), $e^B = .68$, [.53, .89], $z = -2.86$, $p = .004$. Furthermore, participants completing the animacy task during recall ($M = .34$, $SD = .13$) recalled fewer items than participants with full attention, $e^B = .39$, [.29, .52], $z = -6.45$, $p < .001$. However, there were no significant interactions with rankings between participants completing the tone task during recall and participants with full attention or participants completing the animacy task during recall and participants with full attention, both $ps > .249$.

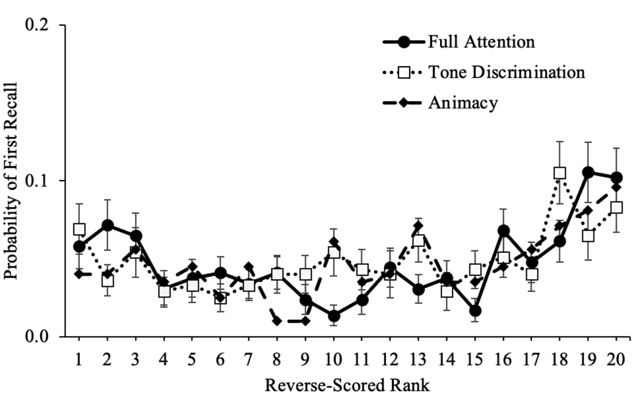
Retrieval Dynamics

To examine the dynamics of participants' recall, we first examined the PFR as a function of each participant's reverse-scored rankings (see Figure 11). A logistic MLM with PFR modeled as a function of participants' rankings with attention at retrieval (full, divided by tone task, divided by animacy task) as a between-subjects factor revealed that rankings significantly predicted PFR, $e^B = 1.04$, 95% CI [1.02, 1.04], $z = 5.34$, $p < .001$, such that participants tended to begin recall with the top-ranked items as well as the lowest-ranked items. Similar to Experiment 1b, this increased tendency to initiate recall with items ranked as least important to remember may be attributable to the potentially increased distinctiveness of these items. However, there were no significant interactions with rankings between participants completing the tone task during recall and participants with full attention or participants completing the animacy task during recall and participants with full attention, both $ps > .362$.

CRPs as a function of direction, lag, and attention at retrieval are shown in Figure 12a. A 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *forward vs. backward*) × 3 (attention at retrieval: *full, divided by tone task, divided by animacy task*) mixed ANOVA revealed that participants showed a forward preference for the direction of transitions, $F(1, 125) = 28.33$, $p < .001$, $\eta_p^2 = .19$, but this did not differ as a function of attention, $F(2, 125) = .54$, $p = .585$, $\eta_p^2 = .01$. However, participants showed strong adjacency effects, Mauchly's $W = .62$, $p < .001$; Huynh–Feldt corrected results: $F(3.32, 415.54) = 76.97$, $p < .001$, $\eta_p^2 = .38$, and lag interacted with attention, $F(6.65, 415.54) = 1.50$, $p = .170$, $\eta_p^2 = .02$, such that participants with full attention showed the strongest adjacency

Figure 11

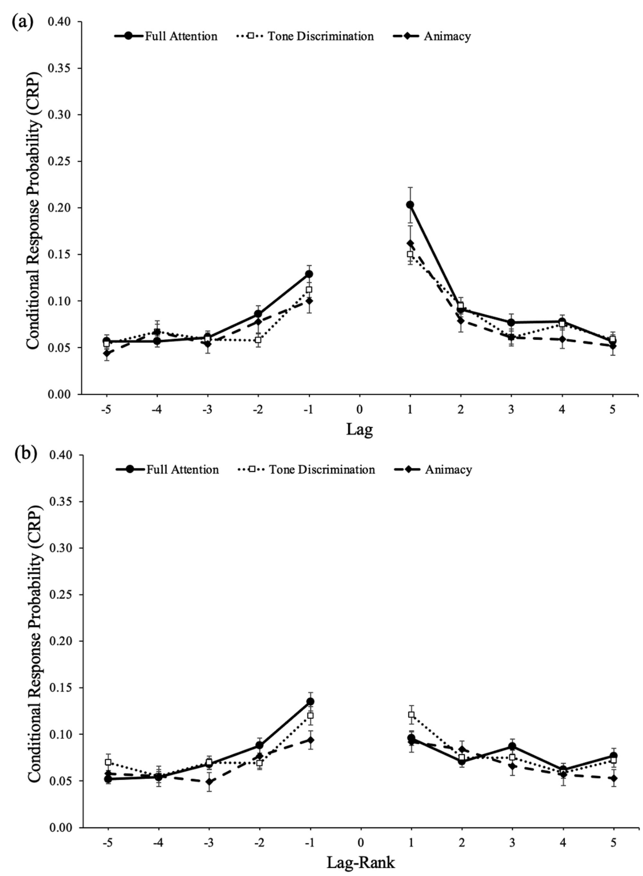
Probability of First Recall (PFR) as a Function of Attention at Retrieval and Participants' Reverse-Scored Rankings in Experiment 2b



Note. Error bars reflect the standard error of the mean.

Figure 12

Conditional-Response Probability (a) and Lag-Rank Conditional-Response Probability (b) Functions as a Function of Lag and Attention at Encoding in Experiment 2b



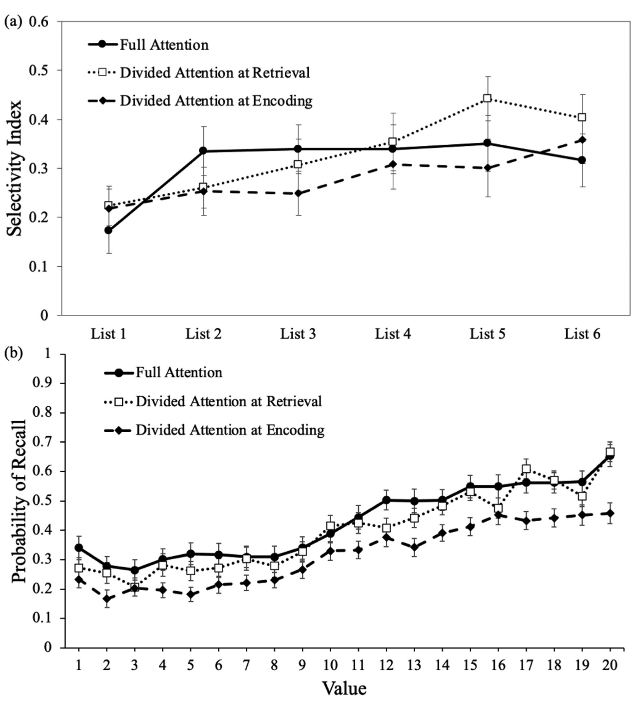
Note. Error bars reflect the standard error of the mean.

effects for lag 1. There was also an interaction between direction and lag, Mauchly's $W = .66$, $p < .001$; Huynh–Feldt corrected results: $F(3.33, 415.61) = 8.06$, $p < .001$, $\eta_p^2 = .06$, such that participants were most likely to transition forward one lag, but there was not a three-way interaction between direction, lag, and attention, $F(6.65, 415.61) = 1.26$, $p = .269$, $\eta_p^2 = .02$. Moreover, there was a main effect of attention, $F(2, 125) = 6.45$, $p = .002$, $\eta_p^2 = .09$, such that participants with full attention demonstrated stronger lag-recency effects than participants completing the animacy task during recall, $p_{holm} = .004$, $d = .29$, and participants completing the tone task during recall, $p_{holm} = .014$, $d = .24$; however, there were no differences in the lag-recency effect between the divided attention conditions, $p_{holm} = .439$, $d = .07$.

The probability of recalling an item of rank x followed by an item of rank $x + \text{lag}$ is shown in Figure 12b. To examine differences in the lag-rank effect as a function of attention at retrieval, we conducted a 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *increasing vs. decreasing*) 3 (attention at retrieval: *full, divided by tone task, divided by animacy task*) mixed ANOVA. Results revealed that participants did not show a preference for the direction of transitions, $F(1, 125) = .54$, $p = .465$, $\eta_p^2 < .01$, and this did not differ as a function of attention, $F(2, 125) = .22$, $p = .803$, $\eta_p^2 < .01$. However, participants showed lag-rank effects, Mauchly's $W = .83$, $p = .008$; Huynh–Feldt corrected results: $F(3.75, 469.05) = 32.04$, $p < .001$, $\eta_p^2 = .20$, but lag-rank did not interact with attention, $F(7.51, 469.05) = 1.35$, $p = .223$, $\eta_p^2 = .02$. Moreover, there was an interaction between direction and lag, $F(4, 500) = 2.40$, $p = .049$, $\eta_p^2 = .02$, such that participants were most likely to transition decreasing by one rank, but there was not a three-way interaction between direction, lag, and attention at retrieval, $F(8, 500) = 1.96$, $p = .050$, $\eta_p^2 = .03$. Additionally, there was a main effect of attention, $F(2, 125) = 5.17$, $p = .007$, $\eta_p^2 = .08$, such that participants with full attention demonstrated stronger lag-rank effects than participants completing the animacy task during recall, $p_{holm} = .013$, $d = .25$, but not participants completing the tone task during recall, $p_{holm} = .946$, $d = .01$; moreover, participants completing the tone task during recall demonstrated stronger lag-rank effects than participants completing the animacy task during recall, $p_{holm} = .013$, $d = .26$.

Figure 13

Selectivity Index for Each Group as a Function of List (a) and Probability of Recall for Each Group as a Function of Word Value (b) in Experiment 3a



Note. Error bars reflect the standard error of the mean.

Discussion

In Experiment 2b, both divided attention tasks impaired recall but there were no group differences in selectivity for important information or PFR. However, the lag-recency effect was impaired in participants under divided attention during recall, indicating that reduced attentional resources during retrieval can impair one's ability to recruit a recalled item's accompanying temporal–contextual information to recall additional words.

Experiment 3a

Since we used different divided attention tasks in Experiments 1 and 2, we cannot directly compare the effects of divided attention at encoding and retrieval as any observed differences between encoding and retrieval could potentially be explained by the divided attention task used. As such, in Experiment 3, we directly compared divided attention at encoding and retrieval using the same task (tone discrimination in Experiment 3a and digit detection in Experiment 3b). Generally, we expected to replicate the effects observed in Experiments 1 and 2 such that selectivity is impaired when attention is divided at encoding but not when attention is divided at retrieval.

Method

Participants

After exclusions, participants were 155 undergraduate students ($M_{age} = 19.86$, $SD_{age} = 1.19$); three participants were excluded for cheating. Participants were also excluded for failing to complete the divided attention tasks with at least 50% accuracy. This exclusion process resulted in the exclusion of 11 participants for poor performance during encoding and 19 participants for poor performance during retrieval. When the tone discrimination task occurred during encoding, participants correctly identified 89.0% of the tones ($SD = 9.4\%$). When the tone discrimination task occurred during retrieval, participants correctly identified 81.4% of the tones ($SD = 12.0\%$)—this difference was significant, $t(102) = 3.59$, $p < .001$, $d = .71$. A sensitivity analysis based on the observed sample indicated that for a between-subjects ANOVA with three groups (attention: *full, divided attention during encoding, divided attention during retrieval*) and six measurements (list: *1, 2, …, 6*), assuming $\alpha = .05$, power = .80, and an average correlation of $r = .33$ between repeated-measures (selectivity), the smallest effect the design could reliably detect is $\eta_p^2 = .03$.

Materials and Procedure

The task in Experiment 3a was similar to the task in Experiment 2a. One group completed both the study and test phases with full attention ($n = 51$), one group completed the study phase under divided attention but the test phase with full attention ($n = 55$), and one group completed the study phase with full attention but the test phase under divided attention ($n = 49$). The divided attention task required participants to identify tones as either low- or high-pitched (similar to the procedure used in Experiment 2). Specifically, during the study or test phase (each 60 s long), participants heard 20 tones played for 1 s each with 2 s between each tone. Participants' task was to indicate whether the tone they heard was low- or high-pitched.

Results

Recall Performance and Selectivity

Selectivity for each group as a function of list is shown in Figure 13a. To determine if participants were selective, we first conducted one-sample *t*-tests. Results revealed that participants' selectivity scores with full attention ($M = .31$, $SD = .26$), divided attention during encoding ($M = .28$, $SD = .24$), and divided attention during retrieval ($M = .33$, $SD = .22$) were different from 0, full: $t(50) = 8.59$, $p < .001$, $d = 1.20$; divided attention during encoding: $t(54) = 8.60$, $p < .001$, $d = 1.16$; divided attention during retrieval: $t(48) = 10.54$, $p < .001$, $d = 1.51$. To examine group differences in selectivity, a 3 (Attention: *full, divided attention during encoding, divided attention during retrieval*) × 6 (list: *1, 2, …, 6*) mixed ANOVA revealed a main effect of list, $F(5, 740) = 6.61$, $p < .001$, $\eta_p^2 = .04$, such that participants became more selective with increased task experience but list did not interact with attention, $F(10, 740) = .97$, $p = .467$, $\eta_p^2 = .01$. Moreover, results did not reveal a main effect of attention, $F(2, 148) = .56$, $p = .571$, $\eta_p^2 = .01$, such that participants were similarly selective whether recalling words under full or divided attention.

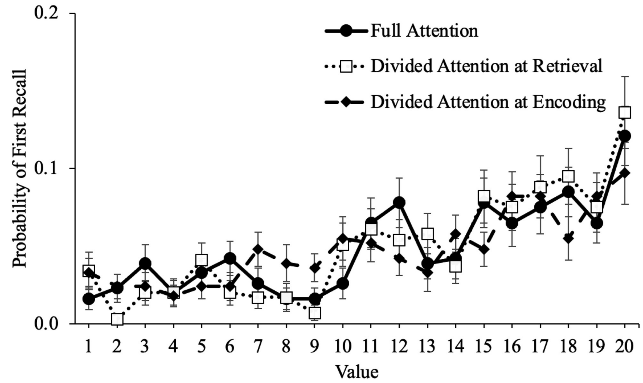
To examine recall and selectivity with value as a continuous predictor (see Figure 13b), a logistic MLM with item-level recall modeled as a function of value with attention (full, divided attention during encoding, divided attention during retrieval) as a between-subjects factor revealed that value significantly predicted recall, $e^B = 1.10$, 95% CI [1.09, 1.10], $z = 31.99$, $p < .001$, such that high-value words were better recalled than low-value words. Additionally, when comparing the divided attention conditions with participants with full attention, participants under divided attention during encoding ($M = .32$, $SD = .10$) recalled a smaller proportion of words than participants with full attention ($M = .43$, $SD = .16$), $e^B = .58$, [.45, .75], $z = -4.21$, $p < .001$. However, participants under divided attention during recall ($M = .40$, $SD = .14$) recalled a similar proportion of words as participants with full attention, $e^B = .87$, [.67, 1.12], $z = -1.08$, $p = .281$. Neither comparison interacted with value, both *p*s > .177.

Retrieval Dynamics

To examine the dynamics of participants' recall, we examined the PFR as a function of word value (see Figure 14). A logistic MLM with PFR modeled as a function of value with attention (full, divided attention during encoding, divided attention during retrieval) as a between-subjects factor revealed that value significantly predicted PFR, $e^B = 1.10$, 95% CI [1.08, 1.11], $z = 14.42$, $p < .001$, such that participants tended to begin recall with the highest valued words. However, there were no significant interactions with value

Figure 14

Probability of First Recall (PFR) for Each Group as a Function of Value in Experiment 3a



Note. Error bars reflect the standard error of the mean.

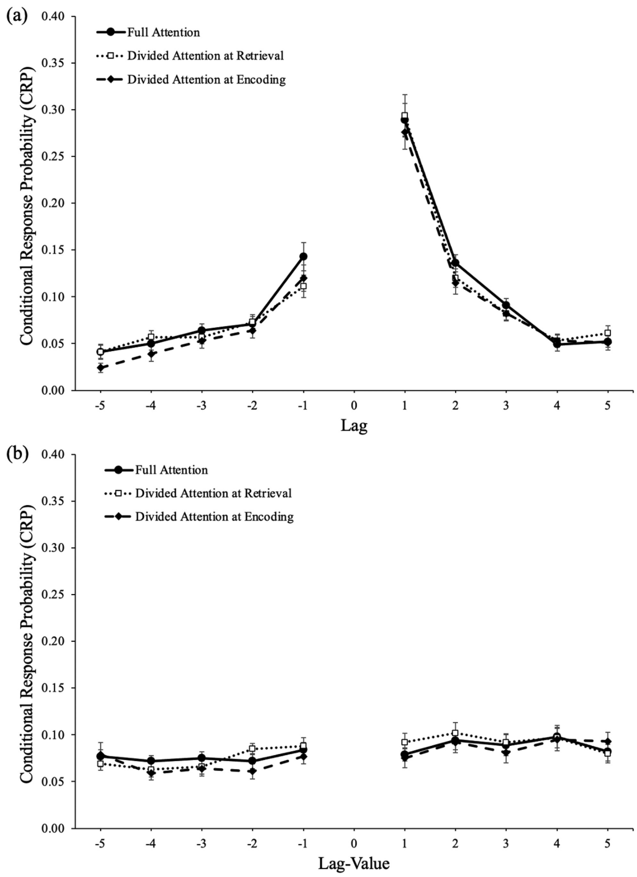
between participants completing the tone task during recall and participants with full attention or participants completing the animacy task during recall and participants with full attention, both *p*s > .142.

To examine differences in the lag-recency effect as a function of attention at retrieval (see Figure 15a), we conducted a 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *forward vs. backward*) × 3 (attention: *full, divided attention during encoding, divided attention during retrieval*) mixed ANOVA. Results revealed that participants showed a forward preference for the direction of transitions, $F(1, 152) = 163.91$, $p < .001$, $\eta_p^2 = .52$, but this did not differ as a function of attention, $F(2, 152) = .16$, $p = .851$, $\eta_p^2 < .01$. Additionally, participants showed strong adjacency effects, Mauchly's $W = .35$, $p < .001$; Huynh–Feldt corrected results: $F(2.47, 375.50) = 236.56$, $p < .001$, $\eta_p^2 = .61$, but lag did not interact with attention, $F(4.94, 375.50) = .37$, $p = .869$, $\eta_p^2 = .01$. There was an interaction between direction and lag, Mauchly's $W = .46$, $p < .001$; Huynh–Feldt corrected results: $F(2.78, 422.99) = 58.03$, $p < .001$, $\eta_p^2 = .28$, such that transitions of lag 1 were more likely in the forward direction, but there was not a three-way interaction between direction, lag, and attention, $F(5.57, 422.99) = .63$, $p = .691$, $\eta_p^2 = .01$. However, there was a main effect of attention, $F(2, 152) = 4.20$, $p = .017$, $\eta_p^2 = .05$, such that the lag recency effect was greater with full attention than divided attention at encoding, $p_{holm} = .015$, $d = .15$, but there were no other significant comparisons, both *p*s > .129.

The probability of recalling an item of value *x* followed by an item of value *x* + lag is shown in Figure 15b. To examine differences in the lag-value effect as a function of attention at retrieval, we conducted a 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *increasing vs. decreasing*) × 3 (attention: *full, divided attention during encoding, divided attention during retrieval*) mixed ANOVA. Results revealed that participants showed an increasing preference for the direction of transitions, $F(1, 152) = 27.78$, $p < .001$, $\eta_p^2 = .16$, but this did not differ as a function of attention, $F(2, 152) = .46$, $p = .635$, $\eta_p^2 = .01$. Additionally, participants did not show lag-value effects, $F(4, 608) = .48$, $p = .752$, $\eta_p^2 < .01$, and lag-value also did not interact with attention, $F(8, 608) = .92$, $p = .499$, $\eta_p^2 = .01$. There was an interaction between direction and

Figure 15

Conditional-Response Probability (a) and Lag-Value Conditional-Response Probability (b) Functions for Each Group as a Function of Lag in Experiment 3a



Note. Error bars reflect the standard error of the mean.

lag, $F(4, 608) = 2.67$, $p = .031$, $\eta_p^2 = .02$, such that transitions greater than one lag value were more likely in the increasing direction, but there was not a three-way interaction between direction, lag, and attention at retrieval, $F(8, 608) = .13$, $p = .998$, $\eta_p^2 < .01$. Moreover, there was not a main effect of attention, $F(2, 152) = .85$, $p = .428$, $\eta_p^2 = .01$, indicating that divided attention during recall did not influence the organization of recall according to value.

Discussion

In Experiment 3a, results revealed that divided attention reduced memory when occurring at encoding but divided attention at retrieval did not impair recall performance. Additionally, neither divided attention at encoding nor retrieval impaired selective memory or altered strategic retrieval operations. However, the divided attention task in Experiment 3a may not have been particularly difficult for participants. Prior work has indicated that an easy divided attention task may not impair selectivity but a more difficult one can (see Elliott & Brewer, 2019). Thus, in Experiment 3b, we examined memory selectivity when attention is either divided at encoding or retrieval using a more difficult secondary task.

Experiment 3b

If the secondary task used to divide a participant's attention does not impress enough cognitive load on the learner, they may still be able to engage in selective memory processes. As such, if the divided attention task significantly increases cognitive load, divided attention at encoding and/or retrieval may reduce memory selectivity. In Experiment 3b, rather than asking participants to discriminate between low- and high-pitched tones (which may be relatively easy), participants completed the digit detection task used in Experiment 1 (which is likely more difficult). Specifically, participants heard a series of digits read aloud and were asked to press the spacebar every time they heard three odd digits in a row. Again, we expected divided attention during encoding, but not divided attention at retrieval, to reduce selectivity.

Method

Participants

After exclusions, participants were 182 undergraduate students ($M_{age} = 20.96$, $SD_{age} = 3.74$); five participants were excluded for cheating. On the divided attention task, participants correctly identified an average of 1.48 out of eight sequences ($SD = 1.10$) on each list. There was an average of 2.49 incorrect detections ($SD = 2.05$) on each list whereby participants pressed the space bar to indicate that three odd digits had been played when they had not. As in Experiment 1, if a participant failed to identify at least one sequence (correctly or incorrectly) during a list, their data for that list was excluded (see Middlebrooks et al., 2017). This exclusion process resulted in 60 lists being excluded from analysis (out of 385 total lists) from participants under divided attention at encoding and 65 lists being excluded from analysis (out of 378 total lists) from participants under divided attention at retrieval. When the digit detection task occurred during encoding, participants correctly identified 1.34 out of eight sequences ($SD = .89$) and when the digit detection task occurred during retrieval, participants correctly identified 1.63 out of eight sequences ($SD = 1.27$)—this difference was not significant, $t(125) = 1.49$, $p = .139$, $d = .26$. A sensitivity analysis based on the observed sample indicated that for a between-subjects ANOVA with three groups (attention: *full, divided attention during encoding, divided attention during retrieval*) and six measurements (list: *1, 2, …, 6*), assuming $\alpha = .05$, power $= .80$, and an average correlation of $r = .29$ between repeated-measures (selectivity), the smallest effect the design could reliably detect is $\eta_p^2 = .02$.

Materials and Procedure

The task in Experiment 3b was similar to the task in Experiment 3a. One group completed both the study and test phases with full attention ($n = 55$), one group completed the study phase under divided attention but the test phase with full attention ($n = 64$), and one group completed the study phase with full attention but the test phase under divided attention ($n = 63$). The divided attention task was similar to Experiment 1. Participants were told that they would hear a series of digits spoken aloud and that they were to press the spacebar on the keyboard every time they heard a sequence of three odd digits in a row. One digit (numbers 1–9) was read per second and the digits were randomly generated. For each participant on each list, there were eight instances of three-odd-digit sequences per list (when the spacebar should be pressed), and there was never a sequence of four odd digits in a row.

Results

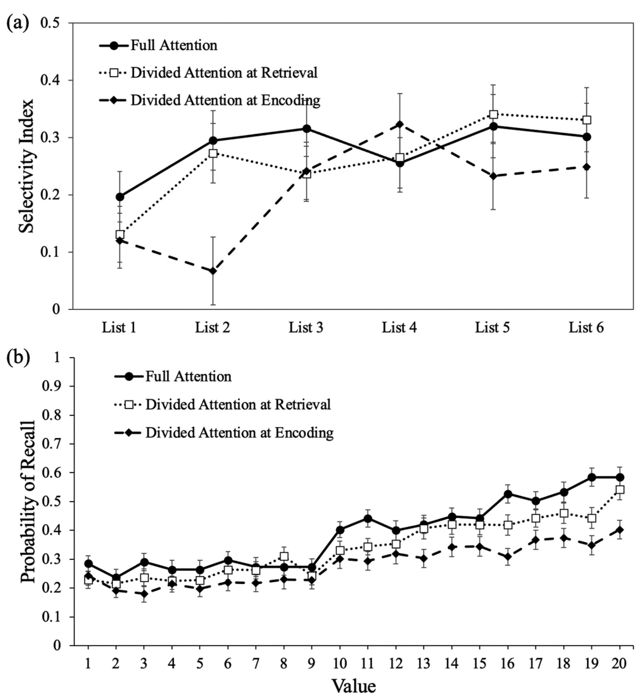
Recall Performance and Selectivity

Selectivity for each group as a function of list is shown in Figure 16a. To determine if participants were selective, we first conducted one-sample *t*-tests. Results revealed that participants' selectivity scores with full attention ($M = .28$, $SD = .25$), divided attention during encoding ($M = .19$, $SD = .26$), and divided attention during retrieval ($M = .25$, $SD = .28$) were different from 0, full: $t(54) = 8.45$, $p < .001$, $d = 1.14$; divided attention during encoding: $t(63) = 6.01$, $p < .001$, $d = .75$; divided attention during retrieval: $t(62) = 7.03$, $p < .001$, $d = .89$. To examine group differences in selectivity, a 3 (attention: *full, divided attention during encoding, divided attention during retrieval*) × 6 (list: *1, 2, …, 6*) mixed ANOVA revealed a main effect of list, $F(5, 635) = 3.03$, $p = .010$, $\eta_p^2 = .02$, such that participants became more selective with increased task experience but list did not interact with attention, $F(10, 635) = 1.34$, $p = .208$, $\eta_p^2 = .02$. Moreover, results did not reveal a main effect of attention, $F(2, 127) = 1.19$, $p = .309$, $\eta_p^2 = .02$, such that participants had similar selectivity index scores whether recalling words under full or divided attention.

To examine recall and selectivity with value as a continuous predictor (see Figure 16b), a logistic MLM with item-level recall modeled as a function of value with attention (full, divided attention during encoding, divided attention during retrieval) as a between-subjects factor revealed that value significantly predicted recall, $e^B = 1.08$, 95% CI [1.07, 1.08], $z = 26.45$, $p < .001$, such that high-value words were better recalled than low-value words. Additionally, when comparing the divided attention conditions with participants with full attention, participants under divided attention during encoding ($M = .28$, $SD = .13$) recalled a smaller proportion of words than participants with full attention ($M = .39$, $SD = .12$), $e^B = .60$, [.49, .75], $z = -4.65$, $p < .001$. Participants under divided attention during recall ($M = .34$, $SD = .12$) also recalled fewer words than participants with full attention, $e^B = .80$, [.65, .99], $z = -2.06$, $p = .040$. The comparison between participants under divided attention at recall and participants with full attention did not interact with value, $e^B = .99$, [.98, 1.00], $z = -1.24$, $p = .214$, but the comparison between participants under divided attention at encoding and participants with full attention interacted with value, $e^B = .97$, [.96, .99], $z = -3.72$, $p < .001$, such that value was a better predictor of recall for participants with full attention than participants under divided attention during encoding.

Figure 16

Selectivity Index for Each Group as a Function of List (a) and Probability of Recall for Each Group as a Function of Word Value (b) in Experiment 3b



Note. Error bars reflect the standard error of the mean.

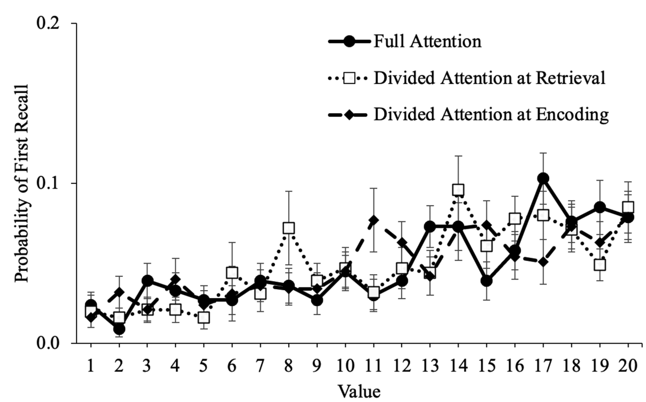
Retrieval Dynamics

To examine the dynamics of participants' recall, we examined the PFR as a function of word value (see Figure 17). A logistic MLM with PFR modeled as a function of value with attention (full, divided attention during encoding, divided attention during retrieval) as a between-subjects factor revealed that value significantly predicted PFR, $e^B = 1.08$, 95% CI [1.07, 1.09], $z = 12.57$, $p < .001$, such that participants tended to begin recall with the highest valued words. However, there were no significant interactions with value between participants completing the tone task during recall and participants with full attention or participants completing the animacy task during recall and participants with full attention, both $ps > .404$.

To examine differences in the lag-recency effect as a function of attention at retrieval (see Figure 18a), we conducted a 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *forward vs. backward*) × 3 (attention: *full, divided attention during encoding, divided attention during retrieval*) mixed ANOVA. Results revealed that participants showed a forward preference for the direction of transitions,

Figure 17

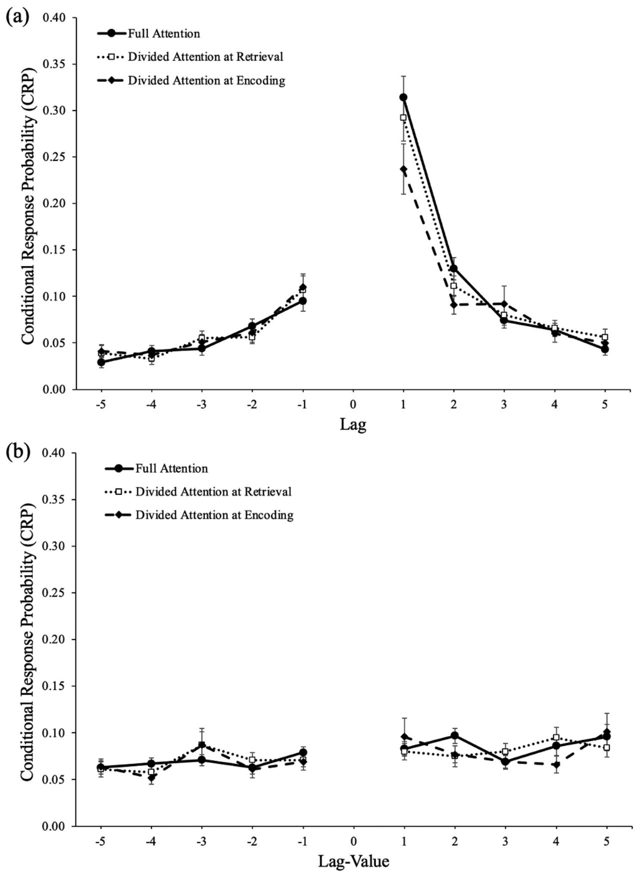
Probability of First Recall (PFR) for Each Group as a Function of Value in Experiment 3b



Note. Error bars reflect the standard error of the mean.

Figure 18

Conditional-Response Probability (a) and Lag-Value Conditional-Response Probability (b) Functions for Each Group as a Function of Lag in Experiment 3b



Note. Error bars reflect the standard error of the mean.

$F(1,\ 179) = 162.82$, $p < .001$, $\eta_p^2 = .48$, but this did not differ as a function of attention, $F(2, 179) = 2.20$, $p = .114$, $\eta_p^2 = .02$. Additionally, participants showed strong adjacency effects, Mauchly's $W = .26$, $p < .001$; Huynh–Feldt corrected results: $F(2.27, 405.54) = 129.05$, $p < .001$, $\eta_p^2 = .42$, but lag did not interact with attention, $F(4.53, 405.54) = 1.19$, $p = .316$, $\eta_p^2 = .01$. There was an interaction between direction and lag, Mauchly's $W = .37$, $p < .001$; Huynh–Feldt corrected results: $F(2.61, 467.60) = 46.71$, $p < .001$, $\eta_p^2 = .21$, such that participants were most likely to transition in the forward direction by one lag, but there was not a three-way interaction between direction, lag, and attention, $F(5.23, 467.60) = 1.56$, $p = .168$, $\eta_p^2 = .02$. There was a not a main effect of attention, $F(2,\ 179) = 1.96$, $p = .145$, $\eta_p^2 = .02$.

The probability of recalling an item of value x followed by an item of value $x + \text{lag}$ is shown in Figure 18b. To examine differences in the lag-value effect as a function of attention at retrieval, we conducted a 5 (lag: *1–5*; within-subjects factor) × 2 (direction: *increasing vs. decreasing*) × 3 (attention: *full, divided attention during encoding, divided attention during retrieval*) mixed ANOVA. Results revealed that participants showed an increasing preference for the direction of transitions, $F(1, 179) = 15.58$, $p < .001$, $\eta_p^2 = .08$, but this did not differ as a function of attention, $F(2, 179) = .13$, $p = .878$, $\eta_p^2 < .01$. Additionally, participants did not show lag-value effects, Mauchly's $W = .86$, $p = .001$; Huynh–Feldt corrected results: $F(3.82, 683.98) = .69$, $p = .590$, $\eta_p^2 < .01$, and lag-value also did not interact with attention, $F(7.64, 683.98) = .89$, $p = .518$, $\eta_p^2 = .01$. There was an interaction between direction and lag, $F(3.77, 675.48) = 2.93$, $p = .023$, $\eta_p^2 = .02$, such that decreasing transitions were less likely for shorter lags, but there was not a three-way interaction between direction, lag, and attention at retrieval, $F(7.55,\ 675.48) = .66$, $p = .719$, $\eta_p^2 = .01$. Moreover, there was not a main effect of attention, $F(2, 179) = .32$, $p = .726$, $\eta_p^2 < .01$, indicating that divided attention during recall did not influence the organization of recall according to value.

Discussion

In Experiment 3b, we employed a secondary task (digit detection) that is likely more difficult than that used in Experiment 3a (tone discrimination). There was evidence that divided attention at encoding—but not retrieval—impaired participants' ability to selectively recall high-value words at the expense of low-value words, though this effect may be small. Thus, if attentional resources are sufficiently increased during encoding, this can impair selective memory but divided attention during recall does not impede selectivity.

General Discussion

In everyday life, we are frequently presented with more information than we can remember. Additionally, when presented with information to remember, we are often distracted and/or operating under divided attention. Checking your email while in a class or a meeting, watching TV while working on homework, or talking on the phone while driving all exemplify situations in which we divide our attentional resources. Memory is often a byproduct of attention, but attention can be allocated in different ways during encoding and retrieval, ideally giving rise to the recall of important information. Specifically, prior work has illustrated the negative effects of divided attention on encoding and subsequent remembering (Castel & Craik, 2003; Craik et al., 1996; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000), but some recent work has indicated that one's ability to selectively remember valuable information is preserved under divided attention (e.g., Middlebrooks et al., 2017) while other work indicates that divided attention at encoding can impair selective memory (e.g., Elliott & Brewer, 2019; Murphy & Castel, 2022c). In the present work, we expand on the memory mechanisms that contribute to value-based remembering by demonstrating that the strategic retrieval mechanisms that contribute to value-directed remembering are impaired when attention is divided at encoding but not when attention is divided at retrieval.

In Experiment 1, we investigated the impact of reduced attentional resources during encoding on participants' ability to remember valuable information. Specifically, we were interested in how the dynamics of participants' retrieval differed when encoding information with full or divided attention. Results generally suggested that divided attention during encoding resulted in impaired selectivity. Additionally, although divided attention did not affect PFR (participants tended to initiate recall with valuable information regardless of attention at encoding), CRPs were reduced under divided attention; we did not find any lag-value effects of interest, consistent with prior work (Stefanidi et al., 2018). Collectively, Experiment 1 indicates that engaging in value-directed remembering requires strategic encoding operations, but strategic retrieval operations may also play a role.

Again, some prior work has found that divided attention during encoding does not impede selective memory under some conditions (e.g., Middlebrooks et al., 2017) while other work has shown that more difficult divided attention tasks—but not easier ones—reduce learners' ability to prioritize valuable items in memory (e.g., Elliott & Brewer, 2019; see also Murphy & Castel, 2022c). Additionally, prior work suggests that divided attention tasks that span the same modality as the learning task tend to impair selectivity (e.g., Siegel et al., 2021). The present work favors the latter studies suggesting that reduced attentional resources during encoding can reduce value-directed remembering, although it is not clear why the results of Experiment 1a, which used the same divided attention task, did not corroborate the results of Middlebrooks et al. (2017). It may be that participants in the present studies were allocating attentional resources in a different manner across trials, and future research could examine how the emphasis on accuracy in competing tasks (e.g., the type and measures of accuracy used in the primary and secondary task, familiarity with the task, and which task may be potentially prioritized by certain participants), relevant individual differences in attentional control (e.g., age, working memory span, ADHD), and possibly other factors (e.g., circadian rhythms, level of education, fatigue/distraction, use of stimulants) that may play a moderating role.

In addition to often studying information with fewer available attentional resources, people also frequently retrieve information while distracted. For instance, taking an exam in a noisy lecture hall, trying to remember someone's name during a conversation at a party, or writing while watching TV all exemplify situations in which you may need to retrieve information when fewer attentional resources are available. While divided attention during retrieval can have small costs in terms of the quantity of recall (Craik et al., 1996; Fernandes & Moscovitch, 2000, 2002, 2003; Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000; Naveh-Benjamin et al., 1998; Skinner & Fernandes, 2008; but see Rohrer & Pashler, 2003), the reduction of attentional resources during retrieval may also hinder one's ability to engage in value-directed retrieval. Specifically, we were interested in whether divided attention during retrieval could disrupt the ability to selectively recall information, suggesting an effortful form of retrieval guides the strategic process of outputting valuable information from memory.

Value- or importance-based remembering involves determining what information is most important or would have the biggest consequences if forgotten and best remembering that information (see Murphy & Castel, 2020, 2021a, 2021b, 2022b; Murphy et al., 2023; see also Murphy & Knowlton, 2022). While this metacognitive process may be driven by strategic encoding operations, value-directed remembering may also involve strategic retrieval operations (see Murphy & Castel, 2022a; Murphy et al., 2022). For example, initiating retrieval with important items can be a strategy to ensure that these important items are not interfered with (i.e., output interference—the decreased probability of retrieval as a function of later serial position in one's output, see Bäuml, 1998; Roediger, 1974; Roediger & Schmidt, 1980) and increase their probability of recall as a result of retrieval operations, rather than encoding operations. Thus, in Experiment 2, we examined whether memory selectivity is affected by divided attention during recall.

In Experiment 2, we again presented participants with to-be-remembered words of both objective and subjective value. However, all participants studied the information with full attention but either completed the retrieval phase under full or divided attention. If value-directed remembering depends on strategic retrieval operations, selectivity for valuable or important information should be impaired when under divided attention during recall. Though, if participants demonstrate preserved selectivity—even with fewer attentional resources available during recall—this would indicate that value-directed remembering depends largely on strategic encoding operations more so than strategic retrieval operations. Consistent with the latter hypothesis, selectivity for valuable and important information was preserved under divided attention during retrieval. Thus, although strategic retrieval operations like the PFR or the use of an item's accompanying temporal–contextual information to recall additional items likely contribute to value-directed remembering, strategically encoding valuable information may play a larger (albeit qualitative different) role in successfully engaging in value-based memory.

In Experiment 3, we further compared memory selectivity when attention is divided at encoding or divided at retrieval. Consistent with Experiments 1 and 2, results generally indicated that the costs of divided attention on memory selectivity are greater when attention is divided at encoding than at retrieval. However, this was only the case in Experiment 3b when a more difficult divided attention task was employed (digit detection); Experiment 3a did not reveal significant impairments in memory selectivity when attention was divided at either encoding or retrieval using a tone discrimination task. These results are in line with prior work suggesting that divided attention reduces the number of cognitive resources available for effortful processing (see Yeung & Fernandes, 2021) which here, need to be used to selectively encode high-value items. At retrieval, although divided attention could increase interference, selective memory was preserved. Thus, the present study indicates that the memory processes occurring during encoding likely contribute more to selective memory than the memory processes occurring during retrieval, although future work should directly compare memory selectivity when attention is divided at encoding and retrieval using secondary tasks that differentially tax participants' cognitive resources or involve greater overlap and/or competition between the materials and task demands in each task.

In the present study, we also manipulated the type of word lists participants studied (i.e., unassociated words or semantically related lists). When to-be-remembered words are related, participants can use schematic support to recall additional words, and the words benefiting most from schematic support were generally considered most important (e.g., "tent" may highly fit the schema for a camping trip and greatly benefit from schematic support while also being ranked as highly important). Moreover, the lag-rank effect observed in Experiments 1b and 2b, and the absence of a lag-value effect in Experiments 1a and 2a, illustrates the propensity to make transitions between semantically associated items often observed in prior work (e.g., Healey & Kahana, 2014). Thus, participants better recalled items offering schematic support but also generally considered these items to be important and used importance to guide recall. Together, participants' better memory for items ranked as important, although this may be slightly impaired under divided attention at encoding, suggests that considering words that are highly semantically related to a category as important may be an adaptive memory mechanism to increase the semantic associations between items of importance and the function they serve. However, we note that participants' posttest rankings could be contaminated by the recall test and not reflect the intrinsic value of the item; future work could address this limitation by determining item importance in a way that does not influence recall or is not influenced by recall.

Overall, participants in the current study were sensitive to objective value as well as the subjective value of the to-be-remembered information. However, future work may benefit from implementing more salient rewards for remembering (see Madan et al., 2012) and consequences for forgetting as these may have been taken less into account in the present experiments. Specifically, we examined behavior in a learning and remembering context rather than a situation where importance has consequences (i.e., forgetting a passport while on a trip has practical and often anxiety-provoking implications). Additionally, when remembering words paired with point values, there are not exactly consequences for forgetting a high-value word (but see Elliott et al., 2019; McGillivray & Castel, 2011). However, in a more applied setting, there can be both value in remembering but also costs for forgetting. For example, when remembering a list of items to pack for a camping trip, remembering to pack water is crucially important but also has severe consequences if forgotten. Furthermore, future work could increase the cognitive demands of secondary tasks during situations demanding selective memory to further elucidate value-directed remembering when competing tasks more severely limit learners' memory capacity.

In sum, we were interested in how divided attention at encoding and retrieval impacts memory selectivity as well as the retrieval dynamics potentially contributing to selective memory. Results revealed that attentional resources during encoding are crucial for remembering valuable or important information while attentional resources during retrieval are less critical to selective memory. Specifically, divided attention during encoding can impair some forms of selectivity but divided attention during retrieval did not impair memory for valuable or important information. Additionally, whether recalling unassociated words paired with point values or a list of words along a theme, participants initiated recall with high-value words or items they considered to be important, and this tendency was resistant to reduced attentional resources during encoding or retrieval. Thus, successfully engaging in value-directed remembering appears to involve both effective encoding and retrieval operations but these encoding operations can be disrupted when under divided attention, but many strategic retrieval operations are preserved when attention is divided during recall.

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(*Appendix follows*)

Appendix

Table A1

Sample Size, Mean, Variance, Skew, and Kurtosis for Divided Attention Task Performance, Recall, and Selectivity in Each Experiment

Experiment and measure	*n*	*M*	Variance	Skew	Kurtosis
Experiment 1a—distractor performance	52	2.41 (.15)	1.15	1.31 (.33)	1.93 (.65)
Experiment 1a—recall	106	.35 (.01)	.02	.77 (.24)	.82 (.47)
Experiment 1a—selectivity	106	.27 (.03)	.06	.55 (24)	−.39 (.47)
Experiment 1b—distractor performance	44	3.08 (.23)	2.25	.56 (.36)	−.24 (.70)
Experiment 1b—recall	93	.45 (.02)	.03	−.20 (.25)	−.33 (.50)
Experiment 1b—selectivity	93	.25 (.02)	.03	.38 (.25)	1.20 (.50)
Experiment 2a—distractor performance	78	.80 (.02)	.02	−.58 (.27)	−.92 (.54)
Experiment 2a—recall	130	.39 (.01)	.02	.29 (.21)	−.10 (.42)
Experiment 2a—selectivity	130	.32 (.02)	.07	−.24 (.42)	−.32 (.42)
Experiment 2b—distractor performance	79	.85 (.01)	.02	−.74 (.27)	−.41 (.54)
Experiment 2b—recall	128	.47 (.01)	.03	−.26 (.21)	−.29 (.43)
Experiment 2b—selectivity	128	.17 (.01)	.02	.48 (.21)	4.29 (.43)
Experiment 3a—distractor performance	104	.85 (.01)	.01	−.81 (.24)	−.36 (.47)
Experiment 3a—recall	155	.38 (.01)	.02	1.02 (.20)	1.39 (.39)
Experiment 3a—selectivity	155	.31 (.02)	.06	.22 (.20)	−.82 (.39)
Experiment 3b—distractor performance	127	1.48 (.10)	1.20	.83 (.22)	.96 (.43)
Experiment 3b—recall	182	.33 (.01)	.02	.86 (.18)	1.29 (.36)
Experiment 3b—selectivity	182	.24 (.02)	.07	−.03 (.18)	−.50 (.36)

Note. The standard error for each variable is listed in parentheses.

Received April 14, 2021
Revision received January 24, 2023
Accepted April 18, 2023 ■