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Serial and strategic memory processes in goal-directed selective remembering☆

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ABSTRACT

People often rely on habitual, serial processing when presented with to-be-learned information. We tested how strategic processing can override more bottom-up, serial processes when remembering information by having participants study a list of word triads (e.g., "dollar phone pizza"). Participants' goal was manipulated by maximizing either (i) their recall for each of the studied words or (ii) their total score associated with recalling certain words in each triad that were more valuable (worth more points) to engage either serial or strategic processing and retrieval mechanisms. Results revealed that when learners were told to maximize their total recall, they frequently engaged in serial remembering—remembering guided by an item's location within the study phase (i.e., words were retrieved according to a habitual reading bias). However, when words were paired with point values that counted towards participants' scores if recalled, participants were not only selective for high-value words but also attempted to overcome the tendency to engage in serial remembering; instead, they appeared to engage in strategic remembering whereby retrieval is guided by value. Thus, to maximize memory utility, it may be beneficial to override habitual processes and initiate retrieval with high-value words, and when making recall transitions, to recall high-value words together. Importantly, when certain to-be-remembered words were more valuable than their neighbors, participants still demonstrated some serial processing of the to-be-remembered words, indicating that even when engaging in strategic memory, some habitual processes can persist.

People often rely on habitually driven cognitive processes when parsing information, such as when reading a book or dialing a phone number. For example, when simultaneously presented with several words to remember for a later test, learners' prior experiences with processing simultaneously presented words (i.e., reading) can trigger the habitual response of reading the words in serial order (i.e., from left-to-right or top-to-bottom) rather than strategically focusing on words to achieve a learning goal (e.g., Ariel, Al-Harthy, Was, & Dunlosky, 2011; Dunlosky & Ariel, 2011a). As a result, people may sometimes forget information that can be important, such as trying to remember items from a misplaced shopping list. Ideally, important items are recalled even if they are lower on the list, suggesting that people can engage in strategic processing to remember important information. Thus, there may be instances where processing information habitually or serially could result in the forgetting of valuable or important information, but more strategic processing can help one to prioritize what to remember.

The organization of a visual display frequently influences behavior like economic decision making (Kwak & Huettel, 2018) and study decisions (e.g., Ariel et al., 2011), often according to the habitual reading bias (e.g., Ariel & Dunlosky, 2013; see also Dunlosky & Ariel, 2011b). Specifically, in visual-spatial tasks where learners are presented with information on a screen, there is substantial evidence illustrating a left-gaze bias such that the left-most information is processed first relative to information that is presented on the right (e.g., Kwak & Huettel, 2018). As such, the scanning of visual space generally starts on the left and travels to the right (e.g., Durgin, Doyle, & Egan, 2008; Guo, Meints, Hall, Hall, & Mills, 2009; Kazandjian & Chokron, 2008; Speedie et al., 2002; see also Román, El Fathi, & Santiago, 2013; Román, Flumini, Lizano, Escobar, & Santiago, 2015). This habitual reading bias can influence many aspects of cognition (e.g., Chokron & De Agostini, 1995, 2000;

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Eviator, 1995; Shaki, Fischer, & Petrusic, 2009; Spalek & Hammad, 2005; Van der Henst & Schaeken, 2005; see Ouellet, Santiago, Israeli, & Gabay, 2010 for a review), and memory is sometimes predicted by this serial processing of information. For example, left- and top-most information on a screen when studying is often better recalled than right- or bottom-most information (e.g., Ariel et al., 2011; Ariel & Dunlosky, 2013; Murphy & Castel, 2021; Murphy, Hoover, & Castel, 2022).

Although learners sometimes engage in serial remembering such that recall is predicted by where information was presented in a simultaneous-presentation study phase (i.e., when to-be-learned information is presented *all at once* on a sheet of paper or computer screen; see Murdock, 1962; Murphy, Friedman, & Castel, 2022 for analyses of serial position effects in study time and memory of sequentially presented items), learners can overcome this habitual reading bias to maximize the recall of valuable or important information (Ariel & Dunlosky, 2013). Thus, if learners execute a goal-based agenda to maximize memory utility, they can overcome bottom-up habitual or serial processing biases with top-down, strategic processes.

To examine strategic memory processes, previous work has employed value-directed remembering tasks whereby to-be-remembered words are paired with point values counting towards participants' scores if recalled (with participants' goal being to maximize their point scores). In these value-directed remembering tasks, learners generally prioritize high-value items at the expense of low-value items (Castel, Benjamin, Craik, & Watkins, 2002; Elliott, McClure, & Brewer, 2020; see Knowlton & Castel, 2022; Madan, 2017 for reviews; see also Rangel, Camerer, & Montague, 2008) and are generally metacognitively aware of this selectivity (Murphy, Agadzhanyan, Whatley, & Castel, 2021). Moreover, compared with instances where to-be-remembered information is presented sequentially, when learners study information of varying value simultaneously, they are generally more selective for high-value information (Middlebrooks & Castel, 2018; see also Ariel, Dunlosky, & Bailey, 2009; Dunlosky & Thiede, 2004; Robison & Unsworth, 2017; Schwartz, Siegel, & Castel, 2020; Siegel & Castel, 2018a, 2018b; Siegel, Schwartz, & Castel, 2021).

Learners' increased selectivity in situations involving simultaneous presentation indicates that the creation and execution of strategic agendas may be easier under simultaneous presentation than sequential presentation. Specifically, when studying words sequentially, learners need to maintain their agenda, previously studied items, the anticipation of future items, and awareness of word value or importance (see Ariel et al., 2009; Dunlosky & Ariel, 2011b; Thiede & Dunlosky, 1999). In contrast, when studying words simultaneously, learners only need to maintain their agenda and awareness of word value or importance; they do not need to maintain previous items (they can return to those items for restudy) or anticipate future items (they already have access to all items) when processing the to-be-remembered information.

Furthermore, the sequential presentation of information seemingly limits a learner's ability to implement selective strategies at encoding; the top-down, strategic allocation of attentional resources towards incoming information is dampened by not knowing when upcoming to-be-prioritized (as directed by an individual's strategic agenda) information will appear during the serial presentation session (although if the timing of the prioritized information is predictable, people can allocate their attention at preferential times, see Denison, Carrasco, & Heeger, 2021). For instance, a learner aiming to remember only sequentially presented words paired with 7's, 8′, 9's, or 10's (for a task where 10 is the *maximum* associated point-value and 1 in the *minimum* value) cannot implement their attentional strategy as easily as someone presented with all competing information at once since these high-value items may appear in any random order interleaved amongst competing low-value information that cannot be anticipated on a trial-by-trial basis throughout the task.

In contrast, simultaneous presentation may pose less of a tax on a learners' cognitive resources as all items and their value or importance do not need to be maintained in working memory to execute a goal-based agenda. As such, high working memory participants tend to be less impacted by presentation format than low working memory participants (e.g., Ariel et al., 2009; Dunlosky & Thiede, 2004). Similarly, low working memory individuals are less likely to use effective, value-based study strategies than high working memory individuals (Robison & Unsworth, 2017). Thus, it appears that engaging in bottom-up habitual or serial processing, rather than more top-down, strategic processing, likely occurs because it is less cognitively demanding than creating, maintaining, and executing a goal-based agenda. However, there may be boundary conditions to this effect like circumstances where value-item pairs are simultaneously presented in a large array under a short time restriction. Such conditions could make it more difficult to strategically locate and encode high-value items compared with serial presentation.

Strategic processing may be cognitively demanding but strategic encoding operations also critically contribute to selective memory for valuable items (e.g., Hennessee, Patterson, Castel, & Knowlton, 2019). Additionally, prior work has demonstrated that the retrieval process contributes to memory selectivity (e.g., Halamish & Stern, 2022; Murphy & Castel, 2022; Stefanidi, Ellis, & Brewer, 2018). Specifically, participants generally initiate recall with high-value items and recall valuable information before low-value items, a strategy potentially employed to reduce output interference: the lower likelihood of retrieval for a given item when other items are recalled (Bäuml, 1998; Roediger III, 1974; Roediger III & Schmidt, 1980). However, it remains unclear how value influences the retrieval process when information is presented simultaneously during encoding.

Furthermore, when remembering information, in addition to strategic retrieval operations, learners often demonstrate a *lag-recency effect* whereby items studied in close temporal proximity (when presented sequentially) tend to be recalled in close temporal proximity (Kahana, 1996; Sederberg, Miller, Howard, & Kahana, 2010; Spillers & Unsworth, 2011). Specifically, the contextual features or temporal context of a given item can facilitate the retrieval of items presented nearby in the encoding phase, a pattern illustrated by lag conditional-response probabilities (lag-CRPs). This analysis generally reveals that learners recall items that were presented in close temporal proximity together, and items are recalled in the order that they were presented (i.e., in the forward direction; see Kahana, 1996). However, it is also unclear whether the lag-recency effect influences recall when items are presented simultaneously during encoding.

1. The current study

In the current study, we presented participants with lists of words to remember for a later test. However, rather than presenting words one at a time (sequentially) or all at once (simultaneously), we presented three words at a time (i.e., word triads like "dollar phone pizza") with each word triad followed by the next triad such that the entire list was presented "semi-simultaneously". Critically, some participants were told that each word was worth a particular point value counting towards their score if recalled and that the point value depended on its position within the triad. When not given any value instructions, we expected participants to engage in serial remembering such that the left-most words would be best remembered. Importantly, when words were paired with point values, we expected learners to be selective for these high-value words, as has been seen in prior work with simultaneously presented information (e.g., Middlebrooks & Castel, 2018).

Concerning participants' retrieval dynamics, when learners are not given any value instructions, we expected participants to initiate recall serially by beginning retrieval with words presented in the left-most position. However, when words are paired with point values and the goal is to maximize their task scores (the sum of the point values of recalled words), we expected participants to initiate recall with high-value items since the binding of temporal-contextual information within each triad of words could impede strategic retrieval operations. Specifically, binding may occur for each triad of words and enhance the lag-recency effect, potentially at the expense of selectivity. To optimize task performance, we expected learners to engage in some form of strategic processing at encoding and subsequent retrieval by focusing attention on high-value items and prioritizing the output of high-value words from each triad before recalling low-value words, respectively.

2. Experiment 1a

In Experiment 1a, we presented participants with lists of 15 to-be-remembered words in sets of three. However, one group of participants was told to recall as many words as they could while another group was also told that the words in the middle of each triad were worth 5 points but the words on the left and right were worth 1 point each (with these participants' goal being to maximize their point score). When not given any value instructions, we expected participants to demonstrate a habitual reading bias whereby they best recall words on the left, followed by words in the middle, and recall for the words on the right to be the worst. Additionally, we expected these participants to recall words in a similar serial order according to where they were presented in the study phase. However, when the words varied in value, we expected participants to be selective for high-value words in the middle of the triad. Moreover, we expected these participants to recall high-value words before low-value words rather than using the temporal proximity of items in the study phase to guide retrieval. Specifically, we expect a decreased lag-recency effect in strategic processers compared with serial processers.

2.1. Method

2.1.1. Participants

Participants were 100 undergraduate students (M_{age} = 20.52 years, SD_{age} = 2.76) 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 post-task questionnaire (they were told they would still receive credit if they cheated). This exclusion process resulted in one exclusion. In each experiment, we aimed to collect around 50 participants in each condition (following our preregistration). The sample size was selected based on prior exploratory research and the expectation of detecting a medium effect size. A sensitivity analysis based on the observed sample indicated that for a 2 (condition: control, values) × 3 (triad position: left, middle, right) mixed-subjects ANOVA, assuming alpha = 0.05, power = 0.80, and a correlation of $r = 0.33$ between repeated measures (recall of left, middle, and right words), the smallest effect the design could reliably detect is $\eta_p^2 = 0.04$.

2.1.2. Materials and procedure

Participants were presented with six lists of words with each list containing 15 words. Words were presented in triads formed by randomly sampling sets of three words from a pool of 280 (e.g., "twig crumb noodle", "skillet dresser lotion", "buckle spoon freight", etc.), and each triad was presented for 5 s. For example, while one participant may have seen "skillet dresser lotion" as the fourth triad on the second list of words, another participant may have seen "spoon skillet crumb" as the first triad on the fifth list of words. One group of participants ($n = 50$) was informed that each word was worth a point value counting towards their score if correctly recalled. Specifically, they were told that the middle word in the triad was worth 5 points while the left and right words were worth 1 point each; these participants were informed that their goal was to maximize their score. After the presentation of all 15 words, participants were given an immediate free recall test where they had 1 min to recall the words on that list. Immediately following the recall test, participants were told their score for that list (their point score out of 35 possible points) but were not given feedback about specific items. The other group of participants ($n = 50$) was not given any instructions regarding the values of the words or any kind of task feedback (i.e., they were not told how many words they recalled correctly); their goal was only to recall as many words as possible. The experiments reported in this article were formally preregistered, and the stimuli and data for each experiment have been made available on the Open Science Framework here.

2.2. Results

Recall as a function of position within each triad in the study phase and the presence of values is shown in Fig. 1. To examine potential differences, we conducted a 2 (condition: control, values) × 3 (triad position: left, middle, right) mixed-subjects ANOVA. However, Mauchly's test of sphericity indicated violations for triad position [Mauchly's $W = 0.57$, $p < .001$]. Huynh-Feldt corrected results revealed a main effect of triad position [$F(1.41, 138.61) = 51.52$, $p < .001$, $\eta_p^2 = 0.35$] such that the middle words ($M = 0.56$, $SD = 0.22$) were better remembered than the left ($M = 0.40$, $SD = 0.20$), [$t = 8.46$, $p_{holm} < 0.001$, $d = 0.86$] and right words ($M = 0.39$, $SD = 0.19$), [$t = 9.09$, $p_{holm} < 0.001$, $d = 0.93$]; however, the left and right words were similarly recalled [$t = 0.63$, $p_{holm} = 0.527$, $d = 0.07$]. Results did not reveal a main effect of the presence of values [$F(1, 98) = 0.75$, $p = .388$, $\eta_p^2 = 0.01$] such that participants studying words without values ($M = 0.46$, $SD = 0.17$) recalled a similar proportion of words as participants studying words supplied with a point value structure ($M = 0.43$, $SD = 0.12$). Moreover, triad position significantly interacted with the presence of values [$F(1.41, 138.61) = 60.97$, $p < .001$, $\eta_p^2 = 0.38$] such that when the middle word was given a high point value, it was recalled better than the left [$t = 5.80$, $p_{holm} < 0.001$, $d = 1.16$] and right words [$t = 12.96$, $p_{holm} < 0.001$, $d = 1.87$] but in the absence of point values, the middle word was recalled at a similar rate as left [$t = 1.00$, $p_{holm} > 0.999$, $d = 0.14$] and right words [$t = 0.10$, $p_{holm} > 0.999$, $d = 0.01$]; additionally, the enhanced recall of the middle word in the value condition came at the expense of recall for the left [$t = 4.27$, $p_{holm} < 0.001$, $d = 0.85$] and right words [$t = 3.63$, $p_{holm} = 0.003$, $d = 0.73$].

Next, we examined the probability of first recall (PFR) as a function of position within each triad in the study phase (see Fig. 2). The PFR measures how participants initiate recall and refers to the number of times the first recalled word comes from each position within each triad in the study phase divided by the number of times the first word recalled could have come from that position (see Howard & Kahana, 1999). A 2 (condition: control, values) × 3 (triad position: left, middle, right) mixed-subjects ANOVA revealed a main effect of triad position [Mauchly's $W = 0.45$, $p < .001$; Huynh-Feldt corrected results: $F(1.30, 127.17) = 90.61$, $p < .001$, $\eta_p^2 = 0.48$] such that the left words were more likely to be recalled first than the middle [$t = 7.70$, $p_{holm} < 0.001$, $d = 1.32$] and right words [$t = 13.41$, $p_{holm} < 0.001$, $d = 2.30$]; additionally, the middle words were more likely to be recalled first than the right words [$t = 5.71$, $p_{holm} < 0.001$, $d = 0.98$]. Moreover, triad position significantly interacted with the presence of values [$F(1.30, 127.17) = 52.23$, $p < .001$, $\eta_p^2 = 0.35$] such that, in the absence of point values, participants tended to initiate recall with the left word more than the middle [$t = 12.67$, $p_{holm} < 0.001$, $d = 3.07$] or right words [$t = 12.84$, $p_{holm} < 0.001$, $d = 3.11$]; however, when the middle word was worth more points than its neighbors, participants were still less likely to initiate recall with the right compared with the left [$t = 6.13$, $p_{holm} < 0.001$, $d = 1.49$] and middle words [$t = 7.91$, $p_{holm} < 0.001$, $d = 1.92$]

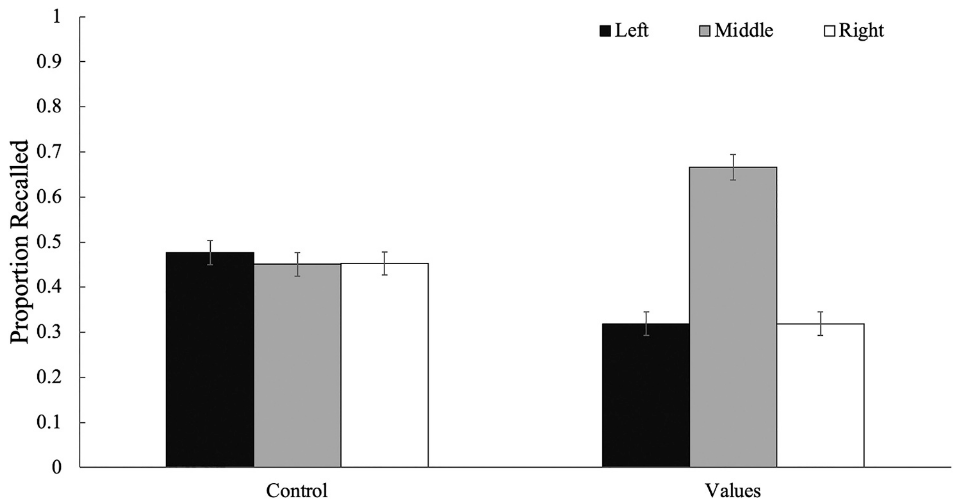

Fig. 1. Probability of recall as a function of position within each triad in the study phase and the presence of values in Experiment 1a. Error bars reflect the standard error of the mean.

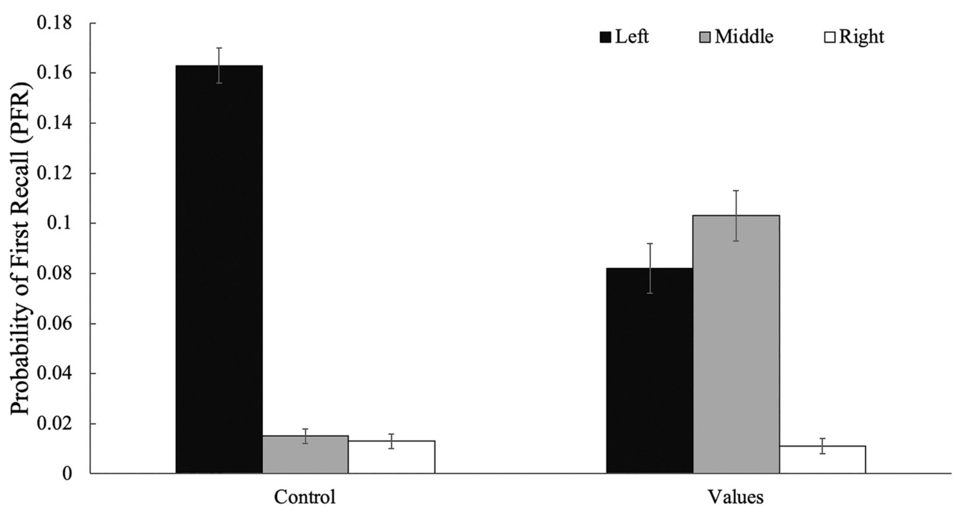

Fig. 2. Probability of first recall (PFR) as a function of position within each triad in the study phase and the presence of values in Experiment 1a. Error bars reflect the standard error of the mean.

but the left bias was reduced such that the likelihood of initiating recall with the left and middle words was similar [$t = 1.78$, $p_{holm} = 0.309$, $d = 0.43$].

The probability of recalling an item from serial position *x* followed by an item from serial position *y* for different lags is shown in Fig. 3.[1] To examine CRPs, a 5 (lag: 1–5; within-subjects factor) × 2 (direction: forward vs backward) × 2 (presence of values: control, values) mixed-subjects ANOVA did not reveal a main effect of the presence of values [$F(1, 95) = 3.54$, $p = .063$, $\eta_p^2 = 0.04$]. However, participants showed a forward preference for the direction of transitions [$F(1, 95) = 413.99$, $p < .001$, $\eta_p^2 = 0.81$] but this did not differ as a function of the presence of values [$F(1, 95) = 0.99$, $p = .323$, $\eta_p^2 = 0.01$]. Additionally, participants showed strong adjacency effects [Mauchly's $W = 0.06$, $p < .001$; Huynh-Feldt corrected results: $F(1.68, 159.21) = 129.44$, $p < .001$, $\eta_p^2 = 0.58$] and lag significantly interacted with the presence of values [$F(1.68, 159.21) = 33.27$, $p < .001$, $\eta_p^2 = 0.26$] such that participants studying words without point values were more likely to make transitions of lag 1 than participants studying words given values [$t = 8.85$, $p_{holm} < 0.001$, $d = 1.30$]; participants studying words given values were more likely to make transitions of lag 3 (the distance between successive high-value words) than participants studying words without point values [$t = 8.88$, $p_{holm} < 0.001$, $d = 1.30$]. Furthermore, there was an interaction between direction and lag [Mauchly's $W = 0.14$, $p < .001$; Huynh-Feldt corrected results: $F(2.06, 195.19) = 72.13$, $p < .001$, $\eta_p^2 = 0.43$] such that recall transitions of lags 1 and 3 in the forward direction were most likely [all $ps < 0.001$]. Finally, there was a significant three-way interaction between direction, lag, and the presence of values [$F(2.06, 195.19) = 22.70$, $p < .001$, $\eta_p^2 = 0.19$] such that participants studying words without point values demonstrated a classic lag-recency effect whereby they were most likely to transition in the forward direction of 1 lag [all $ps < 0.001$] while participants studying words given point values also demonstrated a similar lag-recency effect [all $ps < 0.001$], but were similarly likely to make transitions of lag +1 as lag +3 [$t = 0.11$, $p_{holm} > 0.999$, $d = 0.03$]; there was not a significant difference between value conditions at lag −3 [$t = 0.94$, $p_{holm} > 0.999$, $d = 0.19$].

[1] We only considered 5 lags in each direction for our analyses and other transitions did not differ between attention groups in Experiment 1. Although it has been common to limit lag CRP analyses to 5 lags, see Farrell and Lewandowsky (2008) for the limitations of this approach.

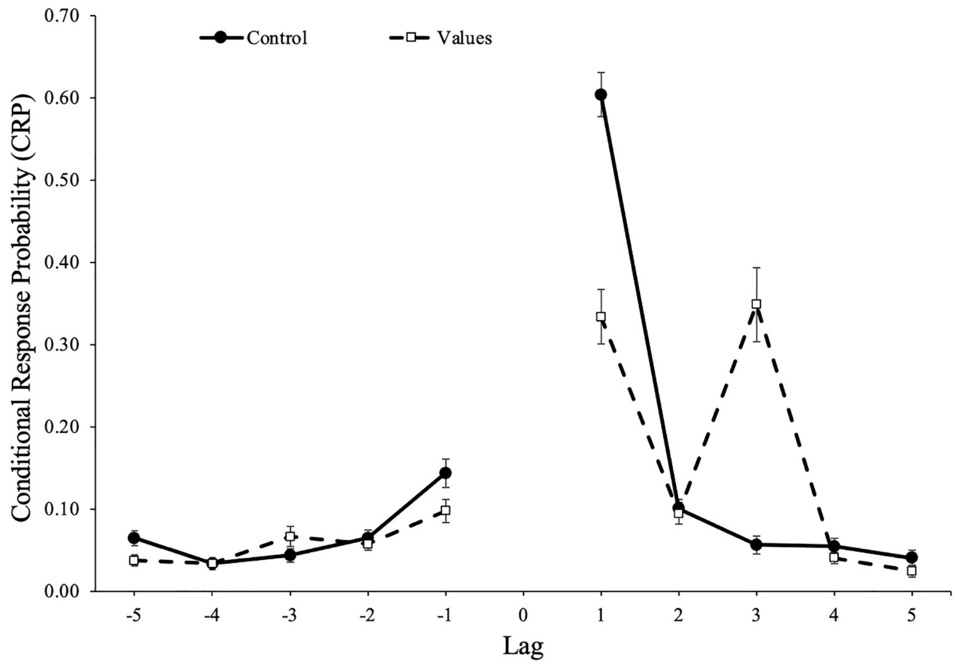

Fig. 3. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag and the presence of values in Experiment 1a. Error bars reflect the standard error of the mean.

2.3. Discussion

In Experiment 1a, when words were not paired with point values, participants demonstrated similar recall of each word, regardless of its position within each triad. Additionally, these participants demonstrated a strong tendency to initiate recall with words presented in the left position while also demonstrating a classic conditional-response probability curve whereby words presented adjacently in the study phase were recalled adjacently and in the forward direction, illustrating serial remembering. However, when the middle word was worth more than its neighbors, participants demonstrated enhanced recall of the middle word. Furthermore, these learners mitigated the tendency to engage in serial retrieval by frequently initiating recall with high-value items. Finally, conditional-response probability curves illustrated that these participants engaged in strategic processing throughout the retrieval process. Specifically, participants studying words of varying value frequently made forward transitions of both lags 1 and 3. Recalling words serially is illustrated by the tendency to recall words in the forward direction of 1 lag; however, the tendency to engage in strategic processing is illustrated by the tendency to recall words of lag 3 (since words were presented in triads and high-value words were three lags apart). Thus, in the absence of point values, location within the study phase primarily influenced retrieval but when the middle word in each triad was more valuable than its neighbors, these participants engaged in strategic processing by using value to guide the retrieval process.

3. Experiment 1b

In Experiment 1a, results revealed that in the absence of values, learners engaged in serial remembering but when using value to guide the encoding and subsequent retrieval processes, participants engaged in strategic processing. In Experiment 1b, we were interested in how these effects are impacted following a delay between encoding and retrieval to determine if strategic processing can lead to longer-term memory effects. Specifically, we attempted to replicate the effects observed in Experiment 1a when a brief distracted delay precedes the recall phase, which may prevent a recency effect in recall.

3.1. Method

3.1.1. Participants

Participants were 100 undergraduate students ($M_{age} = 21.20$, $SD_{age} = 3.15$) recruited from the 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 post-task questionnaire (they were told they would still receive credit if they cheated). This exclusion process resulted in two exclusions. A sensitivity analysis based on the observed sample indicated that for a 2 (condition: control, values) × 3 (triad position: left, middle, right) mixed-subjects ANOVA, assuming alpha = 0.05, power = 0.80, and a correlation of $r = 0.32$ between repeated measures (recall of left, middle, and right words), the smallest effect the design could reliably detect is $\eta_p^2 = 0.04$.

3.1.2. Materials and procedure

The materials and procedure used in Experiment 1b were similar to those of Experiment 1a except that instead of completing each free recall test immediately after the study phase, participants first completed a 30-s distractor task requiring them to rearrange the digits of several three-digit numbers in descending order (e.g., "456" would be rearranged to "654"; adapted from Rohrer & Wixted, 1994; Unsworth, 2007). Participants were given 3 s to view each of the 10 three-digit numbers and subsequently rearrange the digits. Similar to Experiment 1a, participants were either instructed to maximize their point scores ($n = 50$) or were not given any instructions regarding value; their only goal was to maximize the total number of words recalled ($n = 50$).

3.2. Results

Recall as a function of position within each triad in the study phase and the presence of values is shown in Fig. 4. A 2 (condition: control, values) × 3 (triad position: left, middle, right) mixed-subjects ANOVA revealed a main effect of triad position [Mauchly's $W = 0.70$, $p < .001$; Huynh-Feldt corrected results: $F(1.56, 153.10) = 49.21$, $p < .001$, $\eta_p^2 = 0.33$] such that the middle words ($M = 0.50$, $SD = 0.24$) were better remembered than the left ($M = 0.35$, $SD = 0.16$), [$t = 8.17$, $p_{holm} <$

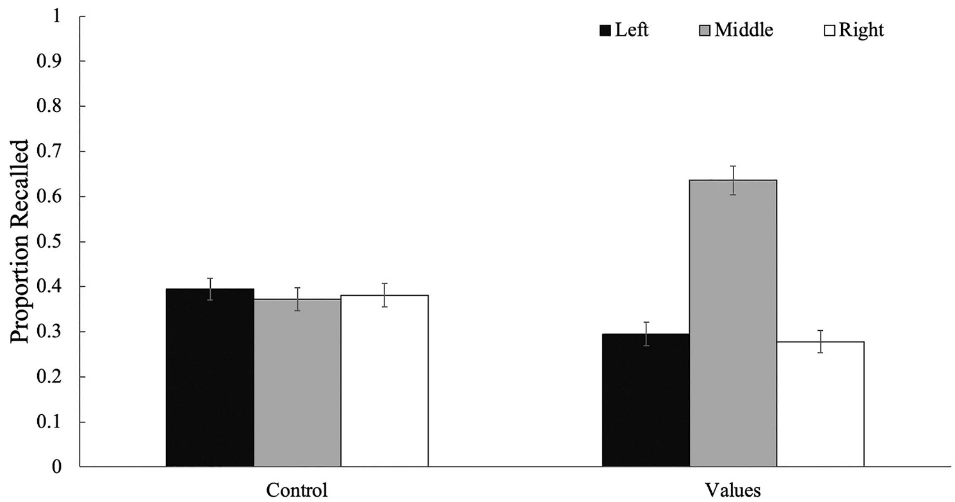

Fig. 4. Probability of recall as a function of position within each triad in the study phase and the presence of values in Experiment 1b. Error bars reflect the standard error of the mean.

0.001, $d = 0.86$] and right words ($M = 0.33$, $SD = 0.19$), [$t = 8.96$, $p_{\text{holm}} < 0.001$, $d = 0.94$] but the left and right words were recalled with similar accuracy [$t = 0.79$, $p_{\text{holm}} = 0.433$, $d = 0.08$]. Results did not reveal a main effect of the presence of values [$F(1, 98) = 0.48$, $p = .492$, $\eta_p^2 = 0.01$] such that participants studying words without values ($M = 0.38$, $SD = 0.16$) recalled a similar proportion of words as participants studying words given point values ($M = 0.40$, $SD = 0.14$). Moreover, triad position significantly interacted with the presence of values [$F(1.56, 153.10) = 58.51$, $p < .001$, $\eta_p^2 = 0.37$] when the middle word was given a high point value, it was recalled better than the left [$t = 12.38$, $p_{\text{holm}} < 0.001$, $d = 1.84$] and right words [$t = 12.98$, $p_{\text{holm}} < 0.001$, $d = 1.92$] but in the absence of point values, the middle word was recalled at a similar rate as left [$t = 0.82$, $p_{\text{holm}} > 0.999$, $d = 0.12$] and right words [$t = 0.31$, $p_{\text{holm}} > 0.999$, $d = 0.05$]; additionally, the enhanced recall of the middle word in the value condition nearly came at the expense of recall for the left [$t = 2.69$, $p_{\text{holm}} = 0.062$, $d = 0.54$] and right words [$t = 2.76$, $p_{\text{holm}} = 0.057$, $d = 0.55$].

Next, we examined the PFR as a function of position within each triad in the study phase (see Fig. 5). A 2 (condition: control, values) × 3 (triad position: left, middle, right) mixed-subjects ANOVA revealed a main effect of triad position [Mauchly's $W = 0.71$, $p < .001$; Huynh-Feldt corrected results: $F(1.57, 153.91) = 42.91$, $p < .001$, $\eta_p^2 = 0.31$] such that the left words were more likely to be recalled first than the right words [$t = 8.65$, $p_{\text{holm}} < 0.001$, $d = 1.48$] but not middle words [$t = 1.45$, $p_{\text{holm}} = 0.149$, $d = 0.25$]; additionally, the middle words were more likely to be recalled first than the right words [$t = 7.20$, $p_{\text{holm}} < 0.001$, $d = 1.23$]. Triad position interacted with the presence of values [$F(1.57, 153.91) = 68.64$, $p < .001$, $\eta_p^2 = 0.41$] such that in the absence of point values, participants tended to initiate recall with the left word more than the middle [$t = 9.25$, $p_{\text{holm}} < 0.001$, $d = 2.24$] or right words [$t = 9.38$, $p_{\text{holm}} < 0.001$, $d = 2.27$]; however, when the middle word was worth more points than its neighbors, participants were still less likely to initiate recall with the right compared with the left [$t = 2.86$, $p_{\text{holm}} = 0.033$, $d = 0.69$] and middle words [$t = 10.06$, $p_{\text{holm}} < 0.001$, $d = 2.43$] but participants did not show a left bias—rather they showed a middle bias such that middle words were more likely to be recalled first than left words [$t = 7.20$, $p_{\text{holm}} < 0.001$, $d = 1.74$].

The probability of recalling an item from serial position *x* followed by an item from serial position *y* for different lags is shown in Fig. 6. A 5 (lag: 1–5; within-subjects factor) × 2 (direction: forward vs backward) × 2 (presence of values: control, values) mixed-subjects ANOVA did not reveal a main effect of the presence of values [$F(1, 98) = 1.06$, $p = .305$, $\eta_p^2 = 0.01$]. However, participants showed a forward preference for the direction of transitions [$F(1, 98) = 97.76$, $p < .001$, $\eta_p^2 = 0.50$] but this

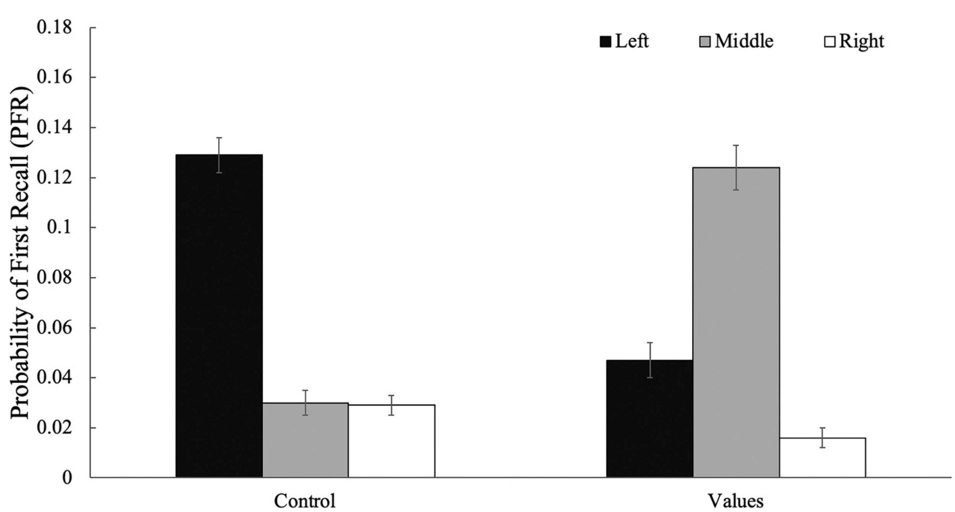

Fig. 5. Probability of first recall (PFR) as a function of position within each triad in the study phase and the presence of values in Experiment 1b. Error bars reflect the standard error of the mean.

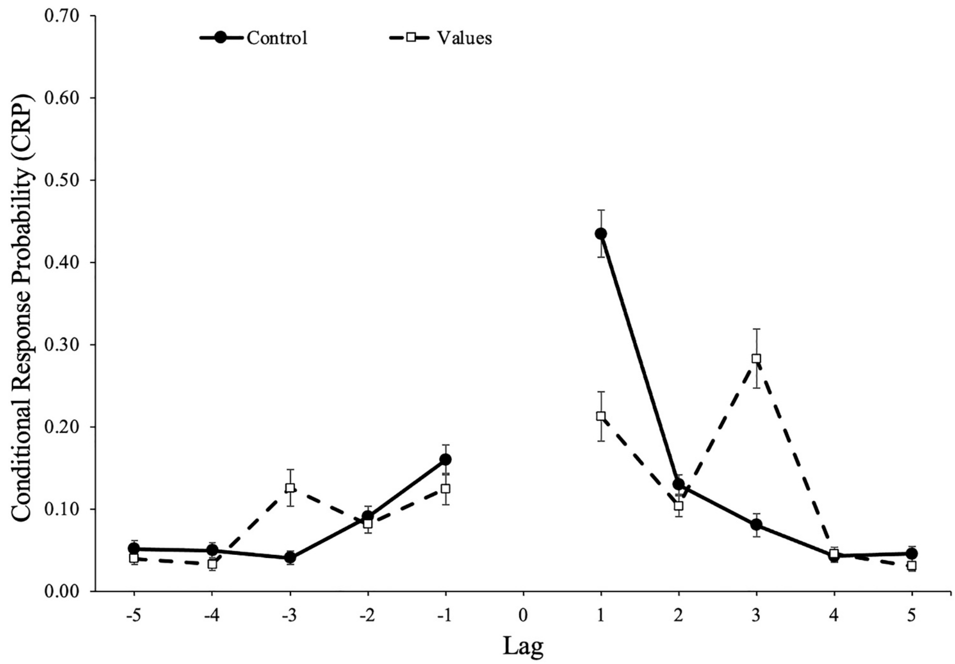

Fig. 6. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag and the presence of values in Experiment 1b. Error bars reflect the standard error of the mean.

did not differ as a function of the presence of values [$F(1, 98) = 1.30$, $p = .258$, $\eta_p^2 = 0.01$]. Additionally, participants showed strong adjacency effects [Mauchly's $W = 0.07$, $p < .001$; Huynh-Feldt corrected results: $F(1.77, 173.27) = 63.91$, $p < .001$, $\eta_p^2 = 0.39$], and lag significantly interacted with the presence of values [$F(1.77, 173.27) = 23.99$, $p < .001$, $\eta_p^2 = 0.20$] such that participants studying words without point values were more likely to make transitions of lag 1 than participants studying words given values [$t = 7.03$, $p_{holm} < 0.001$, $d = 1.09$] while participants studying words given values were more likely to make transitions of lag 3 (the distance between successive high-value words) than participants studying words without point values [$t = 7.86$, $p_{holm} < 0.001$, $d = 1.22$]. Furthermore, there was an interaction between direction and lag [Mauchly's $W = 0.28$, $p < .001$; Huynh-Feldt corrected results: $F(1.64, 258.20) = 27.81$, $p < .001$, $\eta_p^2 = 0.22$] such that recall transitions of lags 1 and 3 in the forward direction were most likely [all $ps < 0.001$]. Finally, there a three-way interaction between direction, lag, and the presence of values [$F(1.64, 258.20) = 13.29$, $p < .001$, $\eta_p^2 = 0.12$] such that participants studying words without point values demonstrated a classic lag-recency effect whereby they were most likely to transition in the forward direction of 1 lag [all $ps < 0.001$] while participants studying words given values also demonstrated a similar lag-recency effect [all $ps < 0.001$], they were similarly likely to make transitions of lag +1 as lag +3 [$t = 2.79$, $p_{holm} = 0.532$, $d = 0.59$]; participants studying words given values were also more likely to make transitions of lag −3 than participants studying words without point values [$t = 3.64$, $p_{holm} = 0.036$, $d = 0.73$].

3.3. Discussion

In Experiment 1b, we largely replicated the effects observed in Experiment 1a such that recall of the middle word in each triad was only enhanced when associated with a high point value. Additionally, similar to Experiment 1a when recall immediately followed the presentation of the final triad, participants not given any value instructions engaged in serial processing whereas participants told to maximize their point scores engaged in strategic processing. Thus, learners can overcome some habitual processes and engage in strategic remembering to maximize memory utility.

4. Experiment 2

In Experiment 1, the high-value words were always presented in the center of each word triad. In Experiment 2, we were interested in how the location of the high-value word within each triad influenced selective memory to determine if participants could flexibly attend to different locations when engaging in strategic remembering and if serial processing may influence this ability. Specifically, we again presented participants with six lists, but (i) on two lists the left word was worth 5 points while the middle and right words were worth 1 point each, (ii) on two lists the middle word was worth 5 points while the left and right words were worth 1 point each (similar to Experiment 1), and (iii) on two lists the right word was worth 5 points while the left and middle words were worth 1 point each. We expected participants to selectively recall valuable words, regardless of their location within the triad, illustrating strategic processing and that there may be an additive effect of serial and strategic processing that may favor high-value information in the left-most location.

4.1. Method

4.1.1. Participants

Participants were 101 undergraduate students ($M_{age} = 20.52$, $SD_{age} = 20.82$) recruited from the 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 post-task questionnaire (they were told they would still receive credit if they cheated). This exclusion process resulted in zero exclusions. A sensitivity analysis based on the observed sample indicated that for a 2 (recall time: immediate, delayed) × 3 (triad position: left, middle, right) mixed-subjects ANOVA, assuming alpha = 0.05, power = 0.80, and a correlation of $r = 0.59$ between repeated measures (recall of left, middle, and right words), the smallest effect the design could reliably detect is $\eta_p^2 = 0.05$.

4.1.2. Materials and procedure

The materials and procedure used in Experiment 2 were similar to those of Experiment 1 except that all participants were instructed to maximize their point scores. Additionally, although participants were again presented with six lists of triads, (i) on two lists the left word was worth 5 points while the middle and right words were worth 1 point each, (ii) on two lists the middle word was worth 5 points while the left and right words were worth 1 point each, and (iii) on two lists the right word was worth 5 points while the left and middle words were worth 1 point each. List order was counterbalanced but value placement occurred in blocks (i.e., the two lists where the left word was worth 5 points while the middle and right words were worth 1 point each occurred consecutively). After the presentation of each list, one group of participants (n = 51) completed immediate free recall tests while another group of participants (n = 50) completed delayed free recall tests (these participants completed the same 30-second distractor task as in Experiment 1b).

4.2. Results

Recall as a function of position within each triad in the study phase, the location of the high-value word, and the timing of recall is shown in Fig. 7. A 2 (recall: delayed, immediate) × 3 (triad position: left, middle, right) × 3 (high-value position: left, middle, right) mixed-subjects ANOVA did not reveal a main effect of the time of recall [$F(1, 99) < 0.01$, $p = .990$, $\eta_p^2 < 0.01$] such that participants recalling the words immediately after the study phase ($M = 0.42$, $SD = 0.10$) recalled a similar proportion of words as participants recalling the words following a delay ($M = 0.42$, $SD = 0.15$). There was not a main effect of triad position [$F(2, 198) = 0.55$, $p = .580$, $\eta_p^2 = 0.01$] such that the left ($M = 0.41$, $SD = 0.15$), middle ($M = 0.42$, $SD = 0.15$), and right words ($M = 0.42$, $SD = 0.15$) were similarly recalled; triad position did not interact with the time of recall [$F(2, 198) = 0.47$, $p = .624$, $\eta_p^2 = 0.01$]. Moreover, there was not a main effect of high-value position [$F(2, 198) = 2.20$, $p = .114$, $\eta_p^2 = 0.02$] such that recall of words from each triad was similar regardless of where the high-value word was placed; high-value position did not interact with the time of recall [$F(2, 198) = 0.38$, $p = .683$, $\eta_p^2 < 0.01$]. However, triad position interacted with high-value position [Mauchly's $W = 0.22$, $p < .001$; Huynh-Feldt corrected results: $F(2.12, 210.08) = 109.66$, $p < .001$, $\eta_p^2 = 0.53$] such that whichever word was the most valuable within each triad was best recalled [all $ps < 0.001$]. The three-way interaction between triad position, high-value position, and timing of recall reached significance [$F(2.12, 210.08) = 3.15$, $p = .042$, $\eta_p^2 = 0.03$] but there were no significant comparisons of interest.

Next, we examined the PFR as a function of position within each triad in the study phase, the location of the high-value word, and the timing of recall (see Fig. 8). A 2 (recall: delayed, immediate) × 3 (triad position: left, middle, right) × 3 (high-value position: left, middle, right) mixed-subjects ANOVA revealed a main effect of triad position [Mauchly's $W = 0.69$, $p < .001$; Huynh-Feldt corrected results: $F(1.55, 153.04) = 33.04$, $p < .001$, $\eta_p^2 = 0.25$] such that the left words were more likely to be recalled first than the middle [$t = 7.14$, $p_{holm} < 0.001$, $d = 0.74$] and right words [$t = 6.94$, $p_{holm} < 0.001$, $d = 0.72$]; however, the middle words were similarly likely to be recalled first as the right words [$t = 0.20$, $p_{holm} = 0.843$, $d = 0.02$]; triad position did not interact with

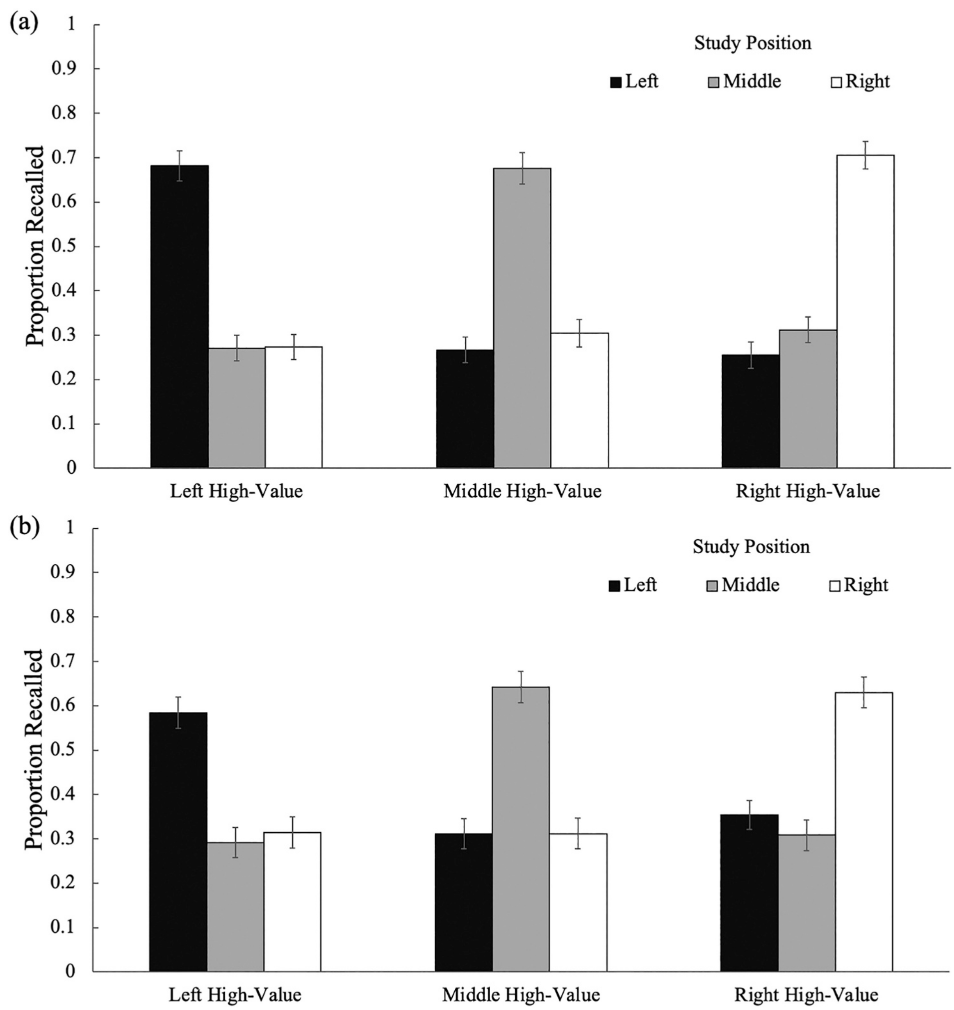

Fig. 7. Probability of recall as a function of position within each triad in the study phase as well as the position of the high-value word (a) when recall was immediate and (b) when recall followed a delay in Experiment 2. Error bars reflect the standard error of the mean.

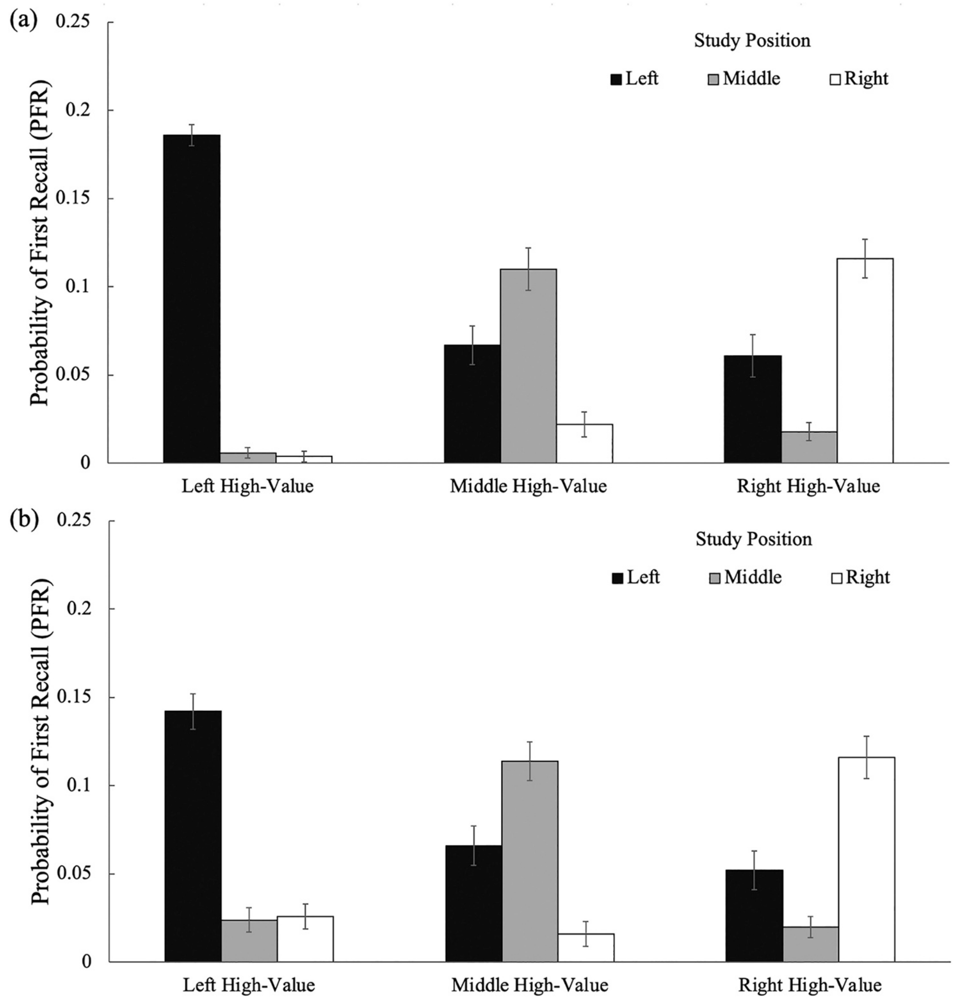

Fig. 8. Probability of first recall (PFR) as a function of position within each triad in the study phase as well as the position of the high-value word (a) when recall was immediate and (b) when recall followed a delay in Experiment 2. Error bars reflect the standard error of the mean.

the timing of recall [$F(1.55, 153.04) = 2.38$, $p = .109$, $\eta_p^2 = 0.02$]. Moreover, there was not a main effect of high-value position [Mauchly's $W = 0.91$, $p = .010$; Huynh-Feldt corrected results: $F(1.87, 185.04) = 1.81$, $p = .169$, $\eta_p^2 = 0.02$] and high-value position did not interact with the time of recall [$F(1.87, 185.04) = 0.21$, $p = .794$, $\eta_p^2 < 0.01$]. However, triad position interacted with high-value position [Mauchly's $W = 0.26$, $p < .001$; Huynh-Feldt corrected results: $F(2.58, 255.08) = 86.28$, $p < .001$, $\eta_p^2 = 0.47$] such that whichever word was the most valuable within each triad was most likely to be recalled first [all $ps < 0.001$]; there was also a left bias such that when the high-value word was in the middle, the left word was more likely to be recalled first than the right word [$t = 4.35$, $p_{holm} < 0.001$, $d = 0.74$] and when the right word was the high-value word, the left word was more likely to be recalled first than the middle word [$t = 3.44$, $p_{holm} = 0.006$, $d = 0.59$]. There was not a significant three-way interaction between triad position, high-value position, and timing of recall [$F(2.58, 255.08) = 1.81$, $p = .155$, $\eta_p^2 = 0.02$].

The probability of recalling an item from serial position x followed by an item from serial position y for different lags is shown in Fig. 9. A 5 (lag: 1–5; within-subjects factor) × 2 (direction: forward vs backward) × 2 (recall: delayed, immediate) mixed-subjects ANOVA did not reveal a main effect of the timing of recall [$F(1, 98) = 0.22$, $p = .643$, $\eta_p^2 < 0.01$]. However, participants showed a forward preference for the direction of transitions [$F(1, 98) = 113.77$, $p < .001$, $\eta_p^2 = 0.54$] but this differed as a function of the timing of recall [$F(1, 98) = 18.14$, $p < .001$, $\eta_p^2 = 0.16$] such that, compared with participants completing the delayed free recall test, participants completing the immediate free recall test showed stronger lag-recency effects in the forward direction [$t = 3.41$, $p_{holm} < 0.001$, $d = 20$] and weaker lag-recency effects in the backward direction than [$t = 3.89$, $p_{holm} < 0.001$, $d = 0.23$]. Additionally, participants showed strong adjacency effects [Mauchly's $W = 0.02$, $p < .001$; Huynh-Feldt corrected results: $F(1.43, 140.56) = 65.64$, $p < .001$, $\eta_p^2 = 0.40$] but lag did not interact with the timing of recall [$F(1.43, 140.56) = 1.53$, $p = .222$, $\eta_p^2 = 0.02$]. Furthermore, there was an interaction between direction and lag [Mauchly's $W = 0.12$, $p < .001$; Huynh-Feldt corrected results: $F(2.08, 203.89) = 32.35$, $p < .001$, $\eta_p^2 = 0.25$] such that recall transitions of lags 1 and 3 in the forward direction were most likely [all $ps < 0.001$]; transitions of lag −3 were more likely than transitions of lag −2 [$t = 3.87$, $p_{holm} = 0.003$, $d = 0.58$] but not lag −1 [$t = 1.16$, $p_{holm} > 0.999$, $d = 0.18$]. Finally, there was a three-way interaction between direction, lag, and the timing of recall [$F(2.08, 203.89) = 6.86$, $p = .001$, $\eta_p^2 = 0.07$] such that participants completing immediate free recall tests demonstrated an enhanced likelihood of transitioning in the forward direction of lag 3 [$t = 5.21$, $p_{holm} < 0.001$, $d = 1.04$].

4.3. Discussion

In Experiment 2, recall performance did not differ as a function of position within the study phase; rather, recall was driven by value. Specifically, high-value words were better recalled than low-value words, regardless of triad position in the study phase. This selectivity likely arose due to strategic processing during retrieval such that

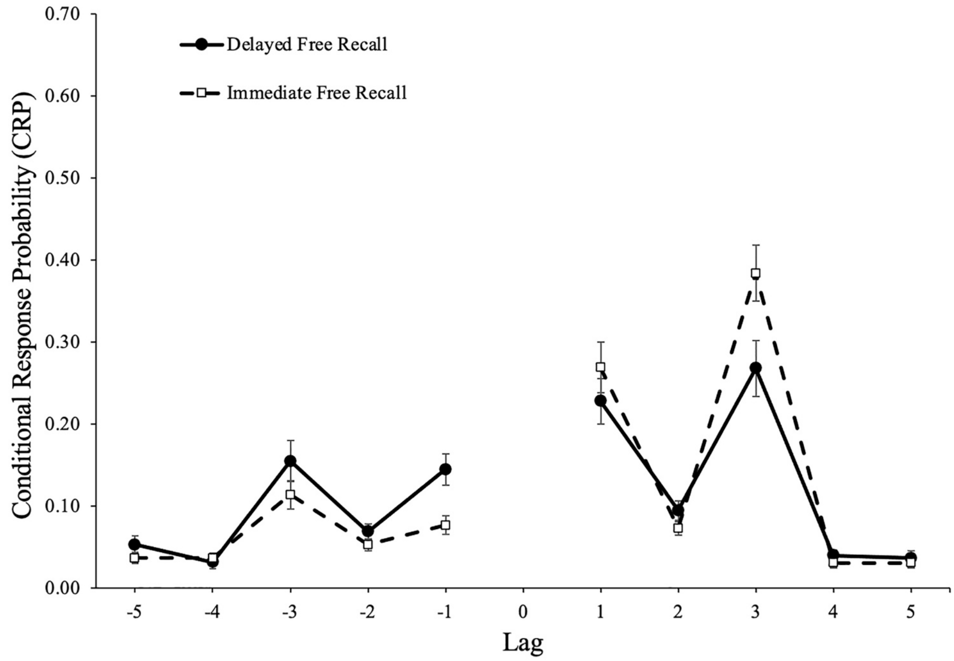

Fig. 9. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag and the timing of recall in Experiment 2. Error bars reflect the standard error of the mean.

participants tended to initiate recall with high-value words more than low-value words, although participants did not completely override the tendency to engage in serial processing (i.e., participants still demonstrated an increased PFR for words presented in the left-most position within a triad). Similarly, CRP curves illustrated that participants demonstrated both a preference for making transitions of 1 lag (illustrating serial processing) as well as lags of 3 (the distance between consecutive high-value words; illustrating strategic processing). Thus, Experiment 2 demonstrates that regardless of a valuable item's position in a semi-simultaneous study phase, learners can partially override serial processing and engage in strategic processing to maximize memory utility.

5. Experiment 3a

Although learners prioritized the high-value words in Experiments 1 and 2, participants could have read the words in a different order based on value and this could change the nature of their rehearsal processes leading to the observed pattern of performance at retrieval. To prevent this potential strategy and further examine learners' ability to strategically process to-be-remembered information, in Experiment 3a we presented participants with word triads but had the location of the high-value word vary within each list and did not immediately reveal the location of the high-value word on each trial (i.e., learners could not anticipate the location of the valuable word). Specifically, participants studied each triad for 4 s before one of the words became underlined, a cue indicating which of the words was worth 5 points (and the other, not-underlined words were worth 1 point each). Thus, learners could not simply read the word triads in a different order based on point values known before each trial (changing the nature of their rehearsal processes). Similar to Experiments 1 and 2, we expected participants to best remember valuable words, despite not knowing which word was the most important to remember until all words had been initially perceived.

5.1. Method

5.1.1. Participants

Participants were 54 undergraduate students (M_{age} = 19.98, SD_{age} = 1.51) recruited from the 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 post-task questionnaire (they were told they would still receive credit if they cheated). This exclusion process resulted in one exclusion. A sensitivity analysis based on the observed sample indicated that for a 3 (triad position: left, middle, right) × 3 (high-value position: left, middle, right) repeated-measures ANOVA, assuming alpha = 0.05, power = 0.80, and a correlation of r = 0.34 between repeated measures (recall as a function of triad and high-value position), the smallest effect the design could reliably detect is $\eta_p^2 = 0.04$.

5.1.2. Materials and procedure

The materials and procedure used in Experiment 3a were similar to those of Experiments 1 and 2. However, participants studied a total of 18 words on each list (6 triads). Additionally, participants studied each triad for 4 s. Then, one of the three words became underlined, and this cue indicated that the word was worth 5 points while not-underlined words were worth 1 point each. Once one of the words became underlined, the words remained on-screen for another 4 s and there was a 2 s lag between the presentation of each triad. On each list, the high-value word appeared in the left position twice, the center position twice, and the right position twice (and occurred in random order).

5.2. Results

Recall as a function of position within each triad in the study phase and location of the high-value word is shown in Fig. 10. A 3 (triad position: left, middle, right) × 3 (high-value position: left, middle, right) repeated-measures ANOVA did not reveal a main effect of triad position [$F(2, 106) = 0.77$, $p = .467$, $\eta_p^2 = 0.01$] such that the left (M = 0.44, SD = 0.16), middle (M = 0.43, SD = 0.18), and right words (M = 0.42, SD = 0.15) were similarly recalled. There was not a main effect of high-value position [$F(2, 106) = 2.69$, $p = .073$, $\eta_p^2 = 0.05$] but triad position

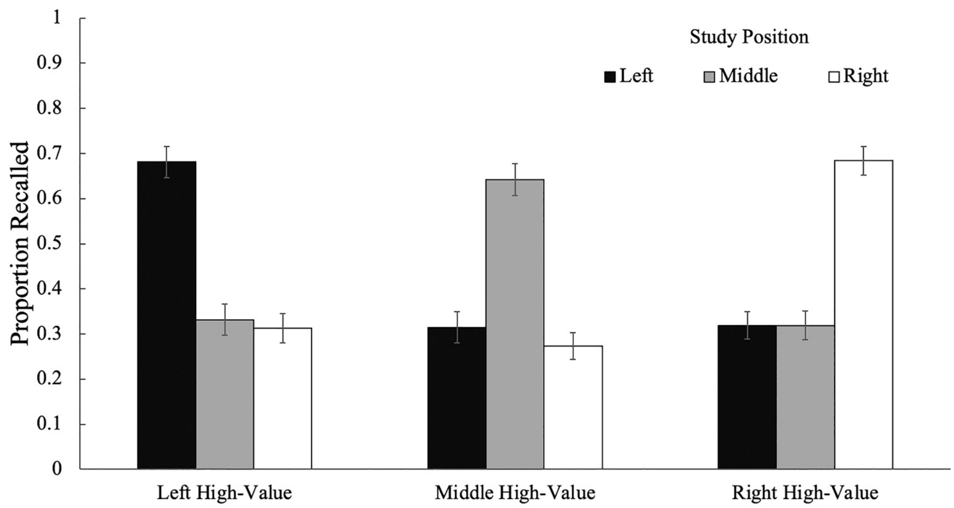

Fig. 10. Probability of recall as a function of position within each triad in the study phase and location of the high-value word in Experiment 3a. Error bars reflect the standard error of the mean.

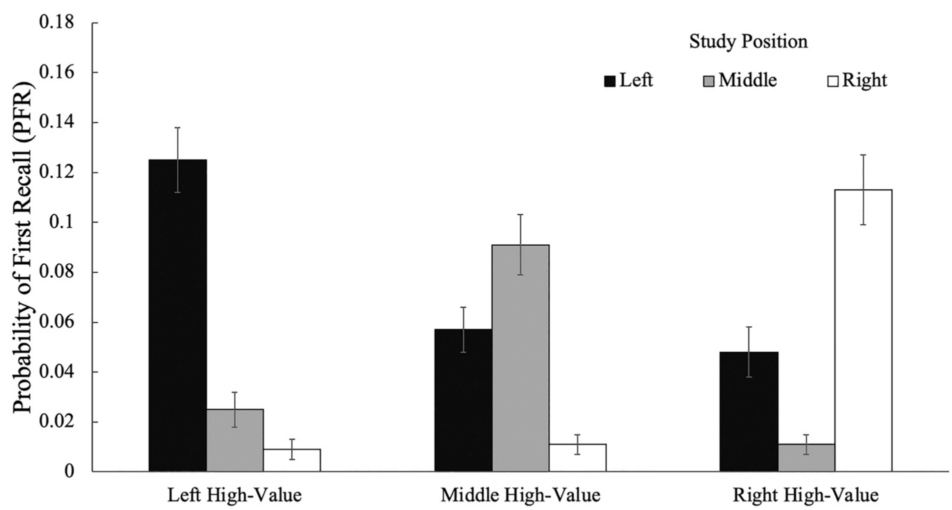

Fig. 11. Probability of first recall as a function of position within each triad in the study phase and location of the high-value word in Experiment 3a. Error bars reflect the standard error of the mean.

interacted with high-value position [Mauchly's W = 0.02, p < .001; Huynh-Feldt corrected results: F(1.33, 70.22) = 55.75, p < .001, η_p^2 = 0.51] such that value drove recall regardless of its position in the study phase [all ps < 0.001].

Next, we examined the PFR as a function of position within each triad in the study phase and location of the high-value word (see Fig. 11). A 3 (triad position: left, middle, right) × 3 (high-value position: left, middle, right) repeated-measures ANOVA revealed a main effect of triad position [F(2, 106) = 11.10, p < .001, η_p^2 = 0.17] such that the left words were recalled first more often than middle [t = 4.20, p_{holm} < 0.001, d = 0.50] and right words [t = 3.95, p_{holm} < 0.001, d = 0.47]; middle and right words were first recalled at a similar rate [t = 0.25, p_{holm} = 0.802, d = 0.03]. There was not a main effect of high-value position [F(2, 106) = 0.22, p = .807, η_p^2 < 0.01] but triad position interacted with high-value position [Mauchly's W = 0.34, p < .001; Huynh-Feldt corrected results: F(2.83, 150.02) = 33.40, p < .001, η_p^2 = 0.39] such that whichever word was the most valuable within each triad was most likely to be recalled first [all ps < 0.001]; there was also a left bias such that when the high-value word was in the middle, the left word was more likely to be recalled first than the right word [t = 3.20, p_{holm} = 0.027, d = 0.67] but when the right word was the high-value word, the left word was not significantly more likely to be recalled first than the middle word [t = 2.56, p_{holm} = 0.153, d = 0.54].

To examine lag-recency effects (see Fig. 12), we conducted a 5 (lag: 1–5) × 2 (direction: forward vs backward) repeated-measures ANOVA. Results revealed that participants showed a forward preference for the direction of transitions [F(1, 53) = 116.01, p < .001, η_p^2 = 0.54]. Additionally, participants showed strong adjacency effects [Mauchly's W = 0.14, p < .001; Huynh-Feldt corrected results: F(1.92, 101.87) = 37.56, p < .001, η_p^2 = 0.42] such that participants recalled items studied in close proximity together. Furthermore, there was an interaction between direction and lag [Mauchly's W = 0.27, p < .001; Huynh-Feldt corrected results: F(2.37, 125.75) = 8.18, p < .001, η_p^2 = 0.13] such that recall of adjacent items was most likely in the forward direction of lag 1 [all ps < 0.001]. We note that we did not observe an increased rate of transitions of lag 3 (as seen in Experiments 1 and 2), likely because the position of the high-value word (left, middle, or right) was now randomized within the lists.

5.3. Discussion

In Experiment 3a, learners could not direct their attention to the

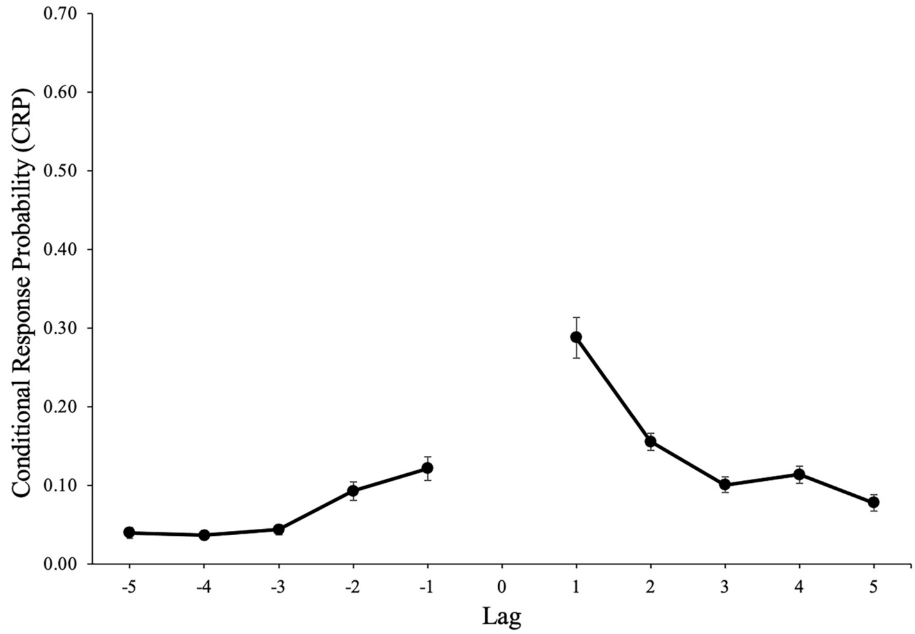

Fig. 12. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag in Experiment 3a. Error bars reflect the standard error of the mean.

high-value words as soon as they appeared during the study phase and simultaneously impede the processing of low-value words. Rather, since the location of the high-value word was not immediately revealed or predictable, learners likely first processed the word triads serially (from left to right). However, once the high-value word was revealed, they engaged in strategic processing of these words to maximize memory utility. As such, value was the main driver of recall (not triad position) and although there were still some serial biases in their retrieval (i.e., initiating recall with left words more than middle or right words), participants were most likely to initiate recall with valuable words.

6. Experiment 3b

In Experiment 3a, although learners could not immediately focus on the high-value word or predict its location during encoding (prior to the value cue onset), they were still able to view the words once the valuable word was revealed. In Experiment 3b, participants again studied the word triads before a cue indicated which position contained the high-value word, but the words disappeared after the high-value cue. Specifically, after studying a given triad for 4 s, the words disappeared from the screen followed by a cue indicating which position contained the high-value word, and this cue remained on-screen for 4 s. Thus, learners again needed to process all the to-be-remembered words before engaging in strategic processing; they had to hold the items in working memory while integrating the associated values prior to engaging value-directed strategic processing of the high-value word.

6.1. Method

6.1.1. Participants

Participants were 54 undergraduate students ($M_{age} = 20.22$, $SD_{age} = 1.56$) recruited from the 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 post-task questionnaire (they were told they would still receive credit if they cheated). This exclusion process resulted in two exclusions. A sensitivity analysis based on the observed sample indicated that for a 3 (triad position: left, middle, right) × 3 (high-value position: left, middle, right) repeated-measures ANOVA, assuming alpha = 0.05, power = 0.80, and a correlation of $r = 0.42$ between repeated measures (recall as a function of triad and high-value position), the smallest effect the design could reliably detect is $\eta_p^2 = 0.03$.

6.1.2. Materials and procedure

The materials and procedure used in Experiment 3b were similar to those of Experiment 3a except that after the triads were studied for 4 s, they disappeared. Rather than one of the words being underlined, a cue (***) appeared in either the left, middle, or right position to indicate which word had been the high-value word, and the cue remained on-screen for 4 s before a 2 s lag between triads.

6.2. Results

Recall as a function of position within each triad in the study phase and location of the high-value word is shown in Fig. 13. A 3 (triad position: left, middle, right) × 3 (high-value position: left, middle, right) repeated-measures ANOVA did not reveal a main effect of triad position [$F(2, 106) = 1.68, p = .191, \eta_p^2 = 0.03$] such that the left ($M = 0.40, SD = 0.17$), middle ($M = 0.38$, $SD = 0.15$), and right words ($M = 0.38$, $SD = 0.16$) were similarly recalled. There was not a main effect of high-value position [$F(2, 106) = 1.29$, $p = .280$, $\eta_p^2 = 0.02$] but triad position interacted with high-value position [Mauchly's $W = 0.09$, $p < .001$; Huynh-Feldt corrected results: $F(1.70, 90.18) = 70.61$, $p < .001$, $\eta_p^2 = 0.57$] such that value drove recall regardless of its position in the study phase [all $ps < 0.001$].

Next, we examined the PFR as a function of position within each triad in the study phase and location of the high-value word (see Fig. 14). A 3 (triad position: left, middle, right) × 3 (high-value position: left, middle, right) repeated-measures ANOVA revealed a main effect of triad position [Mauchly's $W = 0.84$, $p = .010$; Huynh-Feldt corrected results: $F(1.77, 93.98) = 54.12$, $p < .001$, $\eta_p^2 = 0.51$] such that the left words were recalled first more often than middle [$t = 8.98$, $p_{\text{holm}} < 0.001$, $d = 1.10$] and right words [$t = 9.04$, $p_{\text{holm}} < 0.001$, $d = 1.10$]; middle and right words were first recalled at a similar rate [$t = 0.06$, $p_{\text{holm}} = 0.951$, $d = 0.01$]. There was not a main effect of high-value position [$F(2, 106) = 0.14$, $p = .872$, $\eta_p^2 < 0.01$] but triad position interacted with high-value position [Mauchly's $W = 0.36$, $p < .001$; Huynh-Feldt corrected results: $F(3.01, 159.70) = 21.33$, $p < .001$, $\eta_p^2 =$

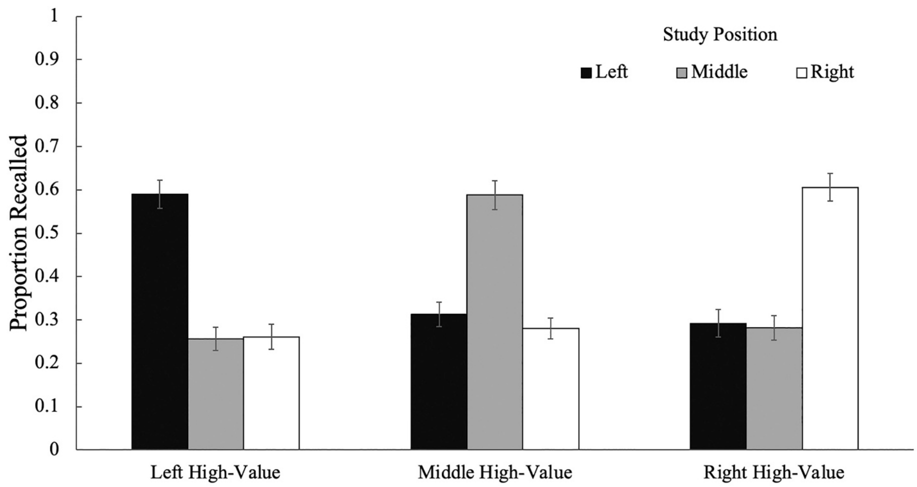

Fig. 13. Probability of recall as a function of position within each triad in the study phase and location of the high-value word in Experiment 3b. Error bars reflect the standard error of the mean.

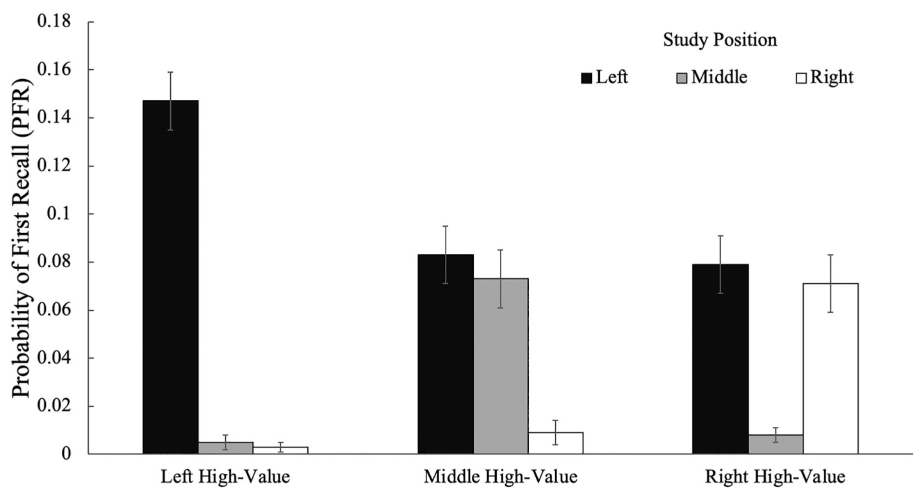

Fig. 14. Probability of first recall as a function of position within each triad in the study phase and location of the high-value word in Experiment 3b. Error bars reflect the standard error of the mean.

0.29] such that when the left word was the highest valued word, it was more likely to be recalled first than middle [$t = 9.95$, $p_{holm} < 0.001$, $d = 2.09$] and right words [$t = 10.06$, $p_{holm} < 0.001$, $d = 2.11$], and was the most likely word to be first recalled [all $ps < 0.001$]; when the high-value word was in the middle, participants were more likely to initiate with left [$t = 5.19$, $p_{holm} < 0.001$, $d = 1.09$] and middle words compared with right words [$t = 4.43$, $p_{holm} < 0.001$, $d = 0.93$] but the PFR was similar for left and middle words [$t = 0.76$, $p_{holm} > 0.999$, $d = 0.16$]; when the right word was the high-value word, the left [$t = 4.97$, $p_{holm} < 0.001$, $d = 1.04$] and right words were more likely to be recalled first than the middle word [$t = 4.43$, $p_{holm} < 0.001$, $d = 0.93$] but the PFR was similar for the left and right words [$t = 0.54$, $p_{holm} > 0.999$, $d = 0.11$].

To examine lag-recency effects (see Fig. 15), we conducted a 5 (lag: 1–5) × 2 (direction: forward vs backward) repeated-measures ANOVA. Results revealed that participants showed a forward preference for the direction of transitions [$F(1, 53) = 201.20$, $p < .001$, $\eta_p^2 = 0.79$]. Additionally, participants showed strong adjacency effects [Mauchly's $W = 0.23$, $p < .001$; Huynh-Feldt corrected results: $F(2.26, 119.64) = 35.94$, $p < .001$, $\eta_p^2 = 0.40$] such that participants recalled items studied in close proximity together. Furthermore, there was an interaction between direction and lag [Mauchly's $W = 0.16$, $p < .001$; Huynh-Feldt corrected results: $F(1.96, 103.66) = 19.63$, $p < .001$, $\eta_p^2 = 0.27$] such that recall of adjacent items was most likely in the forward direction of lag 1 [all $ps < 0.001$]. Again, we likely did not see frequent transitions of lag 3 due to the randomized location of the high-value word within each list.

6.3. Discussion

In contrast to Experiment 3a where words remained on-screen during the high-value cue, in Experiment 3b, learners had to hold the presented words in working memory before engaging in the strategic encoding of the high-value word. Results largely replicated Experiment 3a such that value drove memory. However, participants again illustrated some serial processing such that 1) when the left word was the high-value word, there was an additive effect on PFR such that these words were most likely to be recalled first, 2) when the middle word was the high-value word, the left word was similarly likely to be recalled first as middle words (with both more likely than right words), and 3) when the right word was the high-value word, the left word was similarly likely to be recalled first as right words (with both more likely than middle words). Thus, Experiment 3 further illustrates that learners can overcome serial processing and engage in strategic processing to maximize memory utility.

Finally, we note that, relative to the earlier experiments, the probability of first recall appears to be influenced more by reading order in

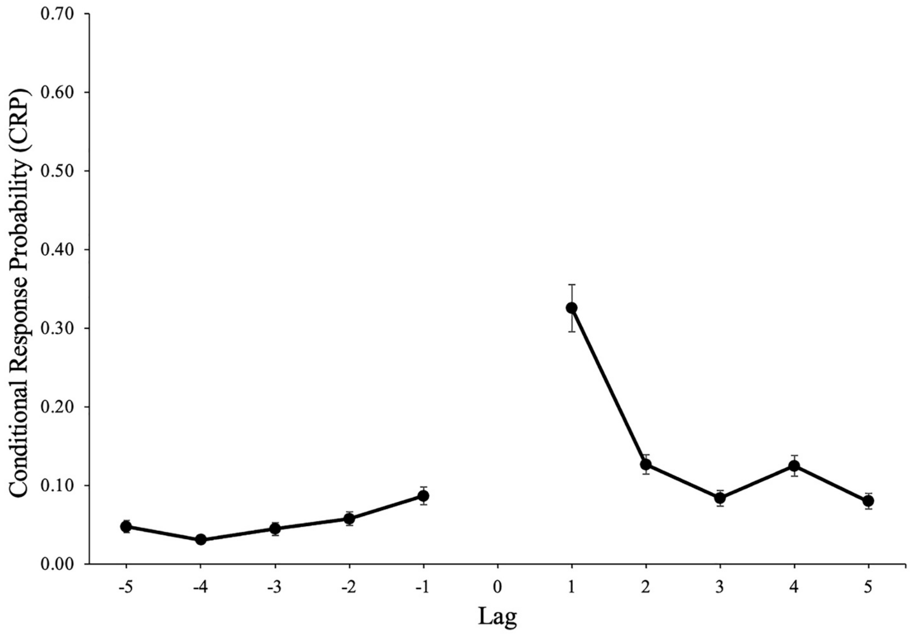

Fig. 15. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag in Experiment 3b. Error bars reflect the standard error of the mean.

Experiment 3b. This may have resulted from participants holding the three words in some short-term or working memory system leading to the recruitment of serial rehearsal mechanisms that involved using the presented reading order. As a result, this could have led to the stronger effect of reading order in Experiment 3b than in the experiments where participants did not have to hold/rehearse words in working memory prior to the value cue. This may suggest that strategic rehearsal can be influenced by serial reading order under these conditions, although future research should examine this in more detail, perhaps by systematically varying the amount of time that is needed to hold this information in working memory prior to the onset of the value cue or revealing the words in a random/unpredictable order prior to the onset of the value cue.

7. General discussion

When presented with information to process and remember, people often engage in habitual or more serial processing—leading to better memory for information that is presented first in a list. In the current study, we tested how strategic processing can override more bottom-up, serial processes by having participants study triads of words where some words within the triad were more important to remember than the others. Specifically, during encoding, words were presented in sets of three with some participants being told that one of the words in each triad was more valuable than the others. We expected that in the absence of point values associated with each word, participants would largely engage in serial processing and serial remembering such that an item's position on the screen would influence subsequent memory and retrieval processes. Particularly, we expected these participants to demonstrate a habitual reading bias (e.g., Ariel et al., 2011; Ariel & Dunlosky, 2013; see also Dunlosky & Ariel, 2011b) and thus best remember the words present on the left side of the screen. However, when given instructions that certain words are more valuable than their neighbors within each triad, we expected participants to engage in strategic processing by prioritizing the recall of these words.

In Experiment 1, results largely supported our hypotheses such that when learners were not given any instructions regarding the values of the words, participants engaged in serial remembering, regardless of whether the recall test occurred immediately following the study phase or after a delay. Specifically, although there were no significant differences in recall as a function of position within the study phase, participants frequently initiated retrieval with words presented in the left position of a triad and demonstrated strong lag-recency effects whereby learners recruited accompanying temporal-contextual cues of a just-recalled word to recall additional words. This illustrates serial remembering and a habitual reading bias such that participants not given any value instructions were highly likely to recall adjacent words and transition in the forward direction, similar to how information is read.

In contrast, when learners were given instructions about the values of the words in each triad, these participants engaged in strategic processing. Specifically, these participants best recalled the most valuable words at the expense of low-value words, and to achieve this selective memory, participants had to overcome the habitual reading bias and serial processing. To illustrate, despite the middle word in each triad being worth more than its neighbors, participants showed a tendency to initiate recall with words presented on the left and high-value words similarly. Thus, even when learners used value to guide retrieval, they were also influenced by the habitual reading bias. This pattern also manifested in an analysis of their retrieval transitions such that there was a strong pattern of forward transitions for adjacent items (similar to reading), but transitions in the forward direction of lag 3 (the distance between consecutive high-value words) were also highly frequent.

In Experiments 2 and 3, certain words within each triad were given high point values compared to other words in the triad, and we manipulated the location of the high-value word within each triad. Results revealed similar recall rates as a function of a word's location within the study phase, but similar to Experiment 1, participants were highly sensitive to the value of the to-be-remembered words. Yet, an analysis of the probability of first recall indicated that participants were most likely to begin recall with a word presented on the left side of the screen even though we counterbalanced the location of the high-value word within each triad (i.e., sometimes it was the left word, sometimes it was the middle word, and sometimes it was the right word). In addition to this serial remembering, participants also demonstrated a tendency to initiate recall with high-value words compared with low-value words (strategic remembering). This pattern was also reflected in their recall transitions such that participants were highly likely to transition in the forward direction of both 1 lag and 3 lags, but the likelihood of transitioning between consecutive high-value words (lag 3) was greater than the likelihood of transitioning between adjacent words (lag 1), particularly when the recall test immediately followed the study phase.

Collectively, the present study revealed that when learners were only told to maximize their total recall, they frequently engaged in serial remembering whereby retrieval was guided by an item's location within the study phase (see Murdock, 1962; Murphy, Friedman, & Castel, 2022 for serial position effects of sequentially presented items). However, when words were paired with point values that counted towards participants' scores if correctly recalled, in addition to being selective for high-value words, participants attempted to override the tendency to engage in serial remembering and instead appeared to engage in strategic remembering whereby encoding and subsequent retrieval was guided by value.

In the current study, we observed typical lag-recency effects when items were not assigned point values because study order was presumably driven by habitual reading order. The lag-recency effect likely reflects encoding strategies (e.g., rehearsal; Hintzman, 2016) but is often reduced under incidental encoding conditions (e.g., Mundorf, Lazarus, Uitvlugt, & Healey, 2021). Thus, the temporal context at encoding is directly related to the left-to-right ordering of items in each array. However, when items in each array varied in value in Experiments 1 and 2, learners may have ignored low-value words and allocated most of their attention towards the high-value words' location. If this was the case, the temporal context of subsequent high-value words may be similar to the temporal context of words in the no-value condition (i.e., the learner focuses only on each subsequent high-value word while ignoring low-value words). In this instance, the memory search strategies could be the same for each group such that temporal context is driving memory search, but temporal context is determined by the ordering of one's study choices which are driven by habitual and/or agenda-based processes at encoding. However, in Experiment 3, the location of the high-value word was not known when initially studying the words so the temporal context of encoding should be driven by position on the screen. Thus, strategic encoding and subsequent retrieval (potentially the product of strategic encoding processes) processes need to override serial processing.

The current work fits with related theories of attention and memory that emphasize a distinction between automatic and more controlled attentional and memory processes (e.g., Jacoby, 1991; Shiffrin & Schneider, 1984; see also Fisk & Schneider, 1984; Logan, Taylor, & Etherton, 1999). In the present context, while serial processing could be more automatic, strategic processes can be selectively engaged to maximize memory performance. Specifically, strategic remembering may be guided by mechanisms that involve inhibiting the encoding of lower value information, and this may be guided by executive control and working memory abilities (cf., Lustig, May, & Hasher, 2001). Future work should examine these issues in children who have attentional challenges (Castel, Lee, Humphreys, & Moore, 2011) and in older adults, who may have difficulty inhibiting serial processing under some circumstances (Hasher & Zacks, 1988).

The present results may challenge previous models of memory explaining the lag-recency effect. Specifically, models like the Temporal Context Model (Howard & Kahana, 2002) assume that context is bound and utilized at retrieval in an automatic/obligatory fashion (e.g., Healey, 2018) but the present results whereby value can alter temporal-contiguity effects challenge this model. Specifically, the dual peaks observed in the lag-CRP functions when words differed in value suggest a strong influence of strategic processes on how learners use temporal-contextual cues during retrieval. Thus, while the present data do offer some support for models of memory that explain lag-recency effects as being due to automatic/obligatory processes, we demonstrate that strategic processes that guide remembering can influence the temporal organization of memory and may inform parameters in future context-based memory models.

Although there may be some instances where serial processing is automatic, serial remembering may not have been an automatic process in the current study. For example, learners often engage in rehearsal when given little encoding time (e.g., Stoff & Eagle, 1971) and serial recall is partially a result of rehearsal of the words (e.g., Bhatarah, Ward, Smith, & Hayes, 2009; Tan & Ward, 2008; see also Laming, 2008, 2010). In the present study (which used fairly short presentation times), participants likely engaged in rehearsal rather than more effective strategies such as imagery, sentence generation, or grouping (Hertzog, McGuire, & Lineweaver, 1998; Richardson, 1998; Unsworth, 2016). Thus, rather than arising from automatic processes, serial processing likely occurred, at least in part, as a result of rehearsal.

While prior work has emphasized encoding processes, in the present work, we show how engaging in strategic processing is also a result of retrieval processes that allow for the successful prioritization of retrieving high-value information amongst competing low-value information. Specifically, participants generally initiated recall with high-value words and also recalled high-value words together, a strategy potentially employed to reduce output interference (see Bäuml, 1998; Roediger, 1974; Roediger & Schmidt, 1980). Thus, consistent with a growing body of work (Halamish & Stern, 2022; Murphy & Castel, 2022; Stefanidi et al., 2018), strategic retrieval operations may be crucial for engaging in selective memory, and participants can somewhat override habitual or serial retrieval tendencies to strategically recall valuable information. However, future work could add a control condition that specifically instructs participants the order to read the materials in addition to using think-aloud or eye-tracking procedures to examine how learners process simultaneously presented information.

The control group in the current study did not receive performance-based feedback after retrieval trials. Here, we did not anticipate that utilizing feedback within our control group would have substantially influenced levels of free recall (see Castel et al., 2002), especially since participants could still monitor their output to evaluate their task performance. Critically, we were primarily interested in the relative recall of words in each position of the study phase rather than total output. However, future work may benefit from further investigating the role of post-retrieval feedback in control groups to consider potential group differences in motivational factors that could drive changes in the levels of recall.

In conclusion, previous work indicates that learners can overcome the habitual reading bias via metacognitive control mechanisms to enhance the recall of valuable information (e.g., Ariel et al., 2011; Ariel & Dunlosky, 2013). However, it was previously unclear how the habitual reading bias manifested in learners' retrieval. The studies presented here suggest that while learners may be able to use cognitive control mechanisms to overcome habitual biases (as indicated by prior work; Ariel, 2013; Ariel & Dunlosky, 2013; Ariel et al., 2009; Dunlosky & Ariel, 2011a, 2011b), the retrieval phase may also contribute to strategic memory. Specifically, to maximize memory utility, it may be beneficial to override habitual processes and initiate retrieval with high-value words, and when making recall transitions, to recall high-value words together. Crucially, even when certain to-be-remembered words were more valuable than their neighbors, participants in the present study still demonstrated some serial processing of the to-be-remembered words, indicating that, even when engaging in strategic memory, some habitual processes can persist.

Author contributions

All the authors developed the study concept and contributed to the study design. Dillon Murphy managed data collection, analyzed and interpreted the data, and drafted the manuscript under the supervision of Dr. Castel. Shawn Schwartz wrote code for the task implementation. All the authors approved the final version of the manuscript for submission.

Declaration of Competing Interest

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

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