Routledge
Taylor & Francis Group

Aging, Neuropsychology, and Cognition

A Journal on Normal and Dysfunctional Development

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/nanc20

Serial and strategic memory processes in younger and older adults

Dillon H. Murphy & Alan D. Castel

To cite this article: Dillon H. Murphy & Alan D. Castel (23 Jun 2024): Serial and strategic memory processes in younger and older adults, Aging, Neuropsychology, and Cognition, DOI: 10.1080/13825585.2024.2371177

To link to this article: https://doi.org/10.1080/13825585.2024.2371177

Published online: 23 Jun 2024.

AGING, NEUROPSYCHOLOGY, AND COGNITION
https://doi.org/10.1080/13825585.2024.2371177

Routledge
Taylor & Francis Group

Serial and strategic memory processes in younger and older adults

Dillon H. Murphy and Alan D. Castel

Department of Psychology, University of California Los Angeles, Los Angeles, CA, USA

ABSTRACT

We investigated age-related differences in serial and strategic processing during the encoding and retrieval of high-value words. Younger and older adults were presented with word triads positioned left, center, and right, with one word being more valuable than the others. In Experiment 1, younger adults more effectively recalled the middle, high-value word, demonstrating enhanced strategic memory. Younger adults were more likely to initiate recall with a high-value word whereas older adults were equally likely to initiate recall with a left and high-value word. Additionally, older adults were more likely to recall words in their presented order while younger adults strategically recalled successive high-value words. However, both age groups demonstrated strategic processing in Experiments 2 and 3, even without prior knowledge of the high-value word's location. Thus, serial and strategic processing may differ based on age and task demands, but strategic processing is preserved in older adults in certain contexts.

ARTICLE HISTORY
Received 15 January 2024
Accepted 18 June 2024

KEYWORDS
Memory; aging; serial processing; strategic processing; selectivity

People often rely on habitual, automatic cognitive processes when presented with information. For example, when reading a book, people usually process information from left to right and top to bottom (when reading in English or other left-to-right languages). However, there may be situations where this habitual processing needs to be overcome. For example, when remembering items on a shopping list, information at the top is likely processed first but there may be items lower on the list that are important to remember. Thus, rather than relying on automatic or habitual processing, prioritizing valuable information during encoding can lead to better memory utility (Ariel et al., 2011; Dunlosky & Ariel, 2011a), and this strategic processing may help individuals overcome the limitations of automatic or serial processing.

To measure strategic memory, which involves the engagement of higher-order cognitive processes such as attention, organization, rehearsal, elaboration, and retrieval strategies to optimize the encoding, storage, and retrieval of information, researchers often employ value-directed remembering tasks whereby learners are presented with words paired with point values that count toward their score if recalled (e.g., Castel et al., 2002; Elliott et al., 2020; see; Knowlton & Castel, 2022; Madan et al., 2017 for reviews). Prior work suggests that while older adults display

CONTACT Dillon H. Murphy dmurphy8@ucla.edu Department of Psychology, University of California, 502 Portola Plaza, Los Angeles, CA 90095, USA

an overall memory deficit (i.e., they recall fewer total words), older adults demonstrate similar recall for the highest-valued items relative to younger adults, illustrating preserved memory selectivity (Castel, 2024; Knowlton & Castel, 2022). Thus, despite many cognitive deficits accompanying healthy aging (Hess, 2005; Lustig & Flegal, 2008; Naveh-Benjamin, 2000; Park & Festini, 2017; Salthouse, 2010, 2019; Thomas & Gutchess, 2020), strategic memory processes can be preserved in older adults in certain contexts.

In some cases, older adults may rely more on automatic, habitual processes (e.g., Murphy et al., 2024) as their ability for more controlled processing tends to decline with age (Jennings & Jacoby, 1993; Lustig & Flegal, 2008; Rhodes & Kelley, 2005). On the other hand, older adults often engage in strategic processing, particularly when they perceive the information as valuable, such as with assigned values or emotionally positive content (Castel, 2024; Eich & Castel, 2016). This selective engagement could be an adaptive strategy to conserve cognitive resources, aligning with findings like the positivity effect in older adults (e.g., Mather & Carstensen, 2005) which is seen as a controlled, strategic process. In contrast, younger adults might incidentally encode both low- and high-value words without the need for deliberate strategic processing, potentially retrieving these words more easily than older adults.

In tasks involving visual-spatial information (e.g., a value-directed remembering task where all to-be-remembered words are presented simultaneously), there is extensive evidence indicating a left-gaze bias, with information on the left side of the screen being processed first compared to information on the right (Kwak & Huettel, 2018). This left-to-right scanning pattern in visual space has been consistently observed (Durgin et al., 2008; Guo et al., 2009; Kazandjian & Chokron, 2008; Speedie et al., 2002; see also Román et al., 2013, 2015), and constitutes a habitual reading bias (Chokron & De Agostini, 1995, 2000; Eviator, 1995; Shaki et al., 2009; Spalek & Hammad, 2005; Van der Henst & Schaeken, 2005; see; Ouellet et al., 2010 for a review). However, it is important to note that the left-to -right, horizontal bias is culture-specific. Specifically, this bias is prevalent in languages and cultures that adopt a left-to-right reading and/or writing system, such as English and many European languages. In contrast, in cultures that read from right to left or top to bottom, such as Arabic and Hebrew, the reading bias follows the direction of their respective writing systems (Ariel et al., 2011; see also Keenan, 1972).

In addition to influencing how we direct attention, the serial processing of information based on habitual reading patterns can also impact memory performance. For instance, the information presented on the left and top of the screen during the study phase is often better recalled compared to information on the right or bottom of the screen (Ariel & Dunlosky, 2013; Ariel et al., 2011; Murphy & Castel, 2021). This suggests that habitual scanning patterns during encoding may influence subsequent memory performance, with left- and top-most information receiving more attention and being better remembered. However, learners can overcome this habitual reading bias (Ariel & Dunlosky, 2013). Specifically, when habitual responding fails to maximize reward, it is important to optimize the recall of valuable information via a more deliberate and effortful encoding/retrieval process. Thus, learners should strategically employ top-down, goal-based processes to overcome bottom-up habitual or serial processing biases and enhance memory utility.

When learners study information of varying value simultaneously, they tend to be more selective toward high-value information than when information is presented sequentially (Middlebrooks & Castel, 2018; see also Ariel et al., 2009; Dunlosky & Thiede, 2004; Robison & Unsworth, 2017; Schwartz et al., 2020; A. L. M. Siegel & Castel, 2018a, 2018b; A. L. M. Siegel et al., 2021). When studying words sequentially, learners face the challenge of maintaining their agenda, remembering previously studied items, anticipating future items, and being aware of word value or importance (see Ariel et al., 2009; Dunlosky & Ariel, 2011b; Thiede & Dunlosky, 1999). As such, the sequential presentation of information appears to limit learners' ability to implement selective strategies at encoding. Specifically, the top-down, strategic allocation of focused attention toward incoming information is hindered by the uncertainty of when upcoming to-be-prioritized information will appear during the encoding phase. This is because the high-value items appear in random order and are often interleaved amongst low-value information, making it difficult to anticipate and prioritize them on a trial-by-trial basis throughout the task.

In contrast, simultaneous presentation may impose a lower cognitive load on learners as all items and their value or importance do not need to be actively maintained in working memory to execute a goal-based agenda (Middlebrooks & Castel, 2018). As such, high working memory participants are less affected by presentation format compared to low working memory participants (e.g., Ariel et al., 2009; Dunlosky & Thiede, 2004). Moreover, low working memory individuals are less likely to use effective, value-based study strategies compared to high working memory individuals (Robison & Unsworth, 2017). These findings suggest that engaging in bottom-up habitual or serial processing, rather than more top-down, strategic processing, may be favored because it is less cognitively demanding in terms of creating, maintaining, and executing a goal-based agenda.

In terms of potential age-related differences with simultaneous presentation, older adults may tend to rely more on serial processing, similar to younger adults with low working memory. This tendency could potentially be attributed to a combination of factors including impaired selective attention (Cansino et al., 2011; Vallesi et al., 2021), difficulty overcoming interference (Murphy & Castel, 2022a, 2023), challenges in engaging inhibitory processes (Rey-Mermet & Gade, 2018), and the reliance on habitual reading patterns (Hartman & Hasher, 1991; Warrington et al., 2019). Specifically, older adults may experience inhibitory deficits that hinder their ability to shift focus away from information located in areas they habitually attend to, such as the left or center of a screen (Campbell et al., 2020; Hasher et al., 1991). This difficulty in redirecting attention might make it challenging for older adults to adjust away from their usual reading habits and engage in strategic processing, thus predisposing them toward more serial processing of information, such as the sequential reading of words in sentences. However, it remains unclear whether there are age-related differences in serial and strategic processing when studying both low- and high-value information simultaneously.

In addition to strategic encoding operations contributing to the selective memory of valuable items (e.g., Hennessee et al., 2019), retrieval processes also play a role in memory selectivity (e.g., Halamish & Stern, 2022; Murphy et al., 2023; Stefanidi et al., 2018). Specifically, both younger and older adults tend to initiate recall with high-value items and prioritize the retrieval of valuable information before low-value items (Murphy & Castel, 2022b), potentially as a strategy to reduce output interference – the lower likelihood of retrieving a given item when other items are recalled (Bäuml, 1998; Roediger, 1974; Roediger & Schmidt, 1980). By analyzing retrieval patterns such as recall initiation and item transitions, we can observe distinct markers of serial and strategic processes. For instance, if participants predominantly initiate recall with high-value words or strategically transition between successive high-value words, this would suggest the engagement of strategic memory processes. Conversely, a higher frequency of recall in the presented order or limited strategic transitions would indicate a reliance on serial processes. The present work seeks to elucidate how value influences the retrieval process, particularly in older adults, when information is presented simultaneously during encoding.

Previous work investigated how strategic processing can override bottom-up, serial processes in memory. Specifically, Murphy and Castel (2022a) presented younger adult participants with a list of word triads and the participants' goal was to maximize their score by focusing on a single high-value word in each triad. Without a value structure, participants tended to engage in serial remembering whereby recall was guided by the location of words within the study phase. However, when one of the words in each triad was more valuable than the others, participants demonstrated selectivity for high-value words and attempted to override serial remembering by engaging in strategic remembering, guided by value. This suggests that to maximize memory utility, it may be beneficial to override habitual processes, initiate retrieval with high-value words, and recall valuable items together. However, some habitual processes persisted even when engaging in strategic memory, indicating that a combination of strategic and habitual processes govern recall, but it remains unclear how the interplay between serial and strategic processes in memory encoding and retrieval impacts older adults.

The current study

In the current study, we used a similar procedure as Murphy and Castel (2022a) whereby participants study lists of word triads to remember for a later test. In each experiment, one of the words in each triad was more valuable than the other two words, and younger and older adults' goal was to maximize their task scores by recalling as many words (especially high-value words) as they could. We hypothesized that older adults would show a greater reliance on bottom-up, habitual/serial processes compared to younger adults during both the encoding and retrieval of high-value words. This may be due to decreased attentional control in older adults, which could make it more difficult to maintain and execute a top-down, controlled agenda for encoding and retrieval. As a result, older adults may be less able to prioritize and recall high-value words compared with younger adults when strategic memory processes require older adults to overcome interference, engage inhibitory control, and focus on selective attention, particularly in situations where the encoding and retrieval tasks involve complex cognitive demands. These effects may be manifested through patterns of memory performance as well as retrieval tendencies such as participants' recall initiation and item transition behaviors during output, allowing us to gain a deeper understanding of how younger and older adults employ serial and strategic memory processes and how these processes contribute to age-related differences in memory performance.

Experiment 1

In Experiment 1, we provided younger and older adults with sets of 15 words (presented in triads) to remember for a later test. Some participants were instructed to recall as many words as possible while other participants were told that the middle word of each triad was worth 5 points, but the words on the left and right were worth 1 point each. These participants' goal was to maximize their point score (the sum of the values of recalled words). In the absence of value instructions, we predicted that participants would exhibit a habitual reading bias (Ariel et al., 2011), recalling words on the left best, followed by those in the middle, and least for those on the right. Additionally, we hypothesized that this pattern would be particularly evident in older adults whose memory may be more governed by bottom-up, habitual processing. Specifically, given that older adults have spent more years reading from left to right than younger adults, this habitual reading pattern may result in a more automatic approach for older adults compared to younger adults who have relatively less experience with this reading orientation. We further anticipated that participants, particularly younger adults, would recall high-value words before low-value words rather than relying on the temporal proximity of items during the study phase for retrieval.

Method

Transparency and openness

We report an analysis of our sample size and describe all data exclusions, manipulations, and measures in the study. All data and research materials are available on OSF. Data were analyzed using JASP (Love et al., 2019) and all information needed to reproduce the analyses is available. This study's design and its analysis were not preregistered.

Participants

Data in each experiment were collected from November 2021 to April 2022. In each experiment, all reported participant info does not include excluded participants. Younger adults ($n = 119$; $M_{age} = 19.93$, $SD_{age} = 1.61$; 101 female, 17 male, 1 other; 66 Asian/Pacific Islander, 5 Black, 14 Hispanic, 29 White, 5 other/unknown; in terms of the highest level of education achieved, 24 High School Graduate, 81 some college but no degree, 6 Associates degree, 8 Bachelor's degree) were recruited from the UCLA Human Subjects Pool, tested online, and received course credit for their participation. Older adults ($n = 112$; $M_{age} = 71.55$, $SD_{age} = 4.83$; 87 female, 25 male; 1 American Indian/Alaskan Native, 3 Asian/Pacific Islander, 7 Black, 1 Hispanic, 99 White, 1 other/unknown; in terms of the highest level of education achieved, 1 some high school, 23 High School Graduate, 24 some college but no degree, 15 Associates degree, 23 Bachelor's degree, 26 Graduate degree (Masters, Doctorate, etc.)) were recruited from Amazon's Cloud Research (Chandler et al., 2019), a Web site that allows users to complete small tasks for pay (see https://go.cloudresearch.com/knowledge/how-are-participants-on-prime-panels-compensated for information regarding compensation). Participants were all located in the United States. We did not implement specific measures to assess whether the older adults recruited through Cloud Research were cognitively normal. No inclusion criteria related to diagnoses of Mild Cognitive Impairment or dementia were applied, nor were performance checks used to evaluate their cognitive status. While it is plausible that older adults' ability to engage with Cloud Research suggests a level of technological proficiency possibly indicative of intact cognition, explicit data confirming their cognitive health were not collected.

In each experiment, 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 from the younger adult group and 10 exclusions from the older adult group. In each experiment, we aimed to collect around 50 younger adults and 50 older adults per condition, consistent with prior work using a similar design (Murphy et al., 2022). A sensitivity analysis indicated that, with this sample size, an actual correlation of $r = .26$ between repeated measures (recall from each triad position), assuming alpha = .05 and power = 80%, the smallest effect (interaction between age/condition and triad position) that we could reliably detect was Cohen's $d = .20$. Informed consent was acquired, and the study was completed in accordance with the UCLA Institutional Review Board (Memory, Attention, Emotion and Aging: IRB#12–000617).

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 seconds. 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. Words were English nouns between 4 and 7 letters ($M = 4.99$, $SD = .98$). On the log-transformed Hyperspace Analogue to Language frequency scale (with lower values indicating lower frequency in the English language and higher values indicating higher frequency), words ranged from 5.48–12.65 and averaged a score of 8.81 ($SD = 1.57$). In terms of concreteness (with lower values indicating lower concreteness and higher values indicating higher concreteness), words ranged from 2.50–5.00 and averaged a score of 4.52 ($SD = .46$). Frequency and concreteness ratings were generated using the English Lexicon Project website (Balota et al., 2007).

One group of participants ($n_{young} = 61$, $n_{old} = 61$) was informed that each word was worth a point value counting toward their score if correctly recalled. Specifically, these participants were told that the middle word in the triad was worth 5 points while the left and right words were worth 1 point each; 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 minute to recall the words on that list. Participants recalled words by typing them into an on-screen text box. Immediately following the recall test, these 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 ($n_{young} = 58$, $n_{old} = 51$) was not given any instructions regarding the values of the words or any kind of task feedback; their goal was only to recall as many words as possible. Providing feedback in the value conditions helps participants by reinforcing their understanding of which items are more valuable, thereby guiding them to allocate their attention and memory resources more effectively toward these high-value items. In contrast, feedback is not necessary for the no-value condition because, without differentiated values assigned to items, there is no need to adjust memory strategies or prioritize certain information over others based on their importance.

Analytical plan

In each analysis, we used a mixed-subjects ANOVA and, to control for multiple comparisons, we used the Holm-adjusted *p*-value (also known as the Holm-Bonferroni correction) in all posthoc tests. We examined memory performance as a function of position within each triad in the study phase and the presence of values for younger and older adults. To analyze participants' retrieval patterns, we analyzed the probability of first recall (PFR) and lag conditional-response probabilities (lag-CRPs). The PFR measures how participants initiate recall and is calculated as 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). For example, if the first word recalled was the 2nd, 5th, 8th, 11th, or 14th item presented on three of the six lists, the PFR for middle items would be .5.

We also computed lag-CRPs to investigate retrieval patterns. These probabilities measure the *lag-recency effect* which suggests that items studied closely together in time are often recalled in close temporal proximity during recall (Kahana, 1996; Sederberg et al., 2010; Spillers & Unsworth, 2011). Specifically, contextual features or the temporal context associated with an item during encoding can facilitate the retrieval of neighboring items during recall (e.g., items may be retrieved in the order they were presented during encoding). While lag-CRPs can be evaluated in both the forward (e.g., recalling an item in serial position 4, followed by 5) and backward direction (e.g., recalling an item in serial position 4, followed by 3), previous research by Kahana (1996) demonstrated that CRPs are twice as likely to occur in the forward direction and three times as likely for adjacent items compared to remote items. This finding suggests that participants tend to recall items in close proximity and in the order that they were presented rather than recalling them randomly. In the present analysis of CRPs, we analyze transitions for lags −5 to + 5. Although transitions beyond 5 lags in each direction are possible (subjects could transition + 14 lags from the 1st item on the list to the 15th item), it is common to limit CRP analyses to 5 lags (e.g., Unsworth, 2019; see; Farrell & Lewandowsky, 2008 for the limitations of this approach).

In Experiment 1, if participants were primarily recalling items using a serial/habitual processing approach, the lag-CRP curves would reflect the typical forward asymmetry whereby participants show an elevated CRP for items of lag + 1 (representing the retrieval of items in their presented order). However, if participants were primarily recalling items using a strategic processing approach, this forward asymmetry would be specific to lag + 3 (high-value words are separated by three serial positions so a transition of lag + 3 indicates the retrieval of successive high-value words).

Results

The proportion of words recalled as a function of position within each triad in the study phase and the presence of values for younger and older adults is shown in Figure 1. To examine potential differences, we conducted a 2 (age: young, old) × 2 (presence of values: control, values) × 3 (triad position: left, middle, right) mixed-

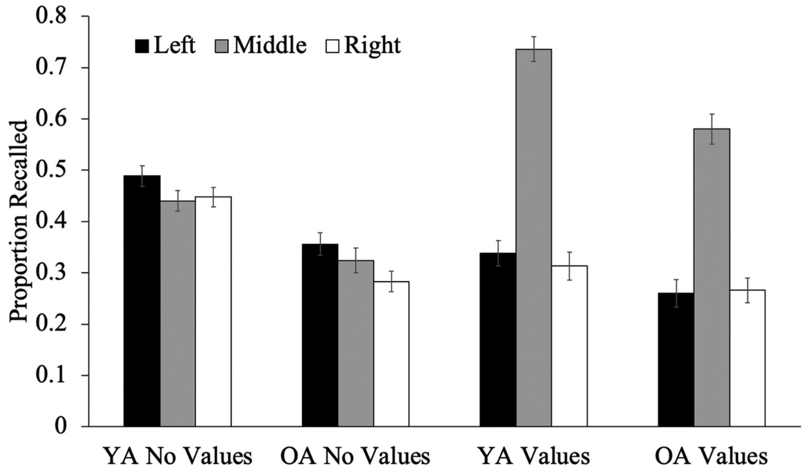

Figure 1. Recall as a function of position within each word triad in the study phase and the presence of values for younger adults (YA) and older adults (OA) in Experiment 1. Error bars reflect the standard error of the mean.

subjects ANOVA. However, Mauchly's test of sphericity indicated violations for triad position [Mauchly's $W = .57$, $p < .001$]. Huynh-Feldt corrected results revealed a main effect of triad position [$F(1.41, 318.97) = 109.14$, $p < .001$, $\eta_p^2 = .33$] such that the middle words ($M = .53$, $SD = .24$) were better remembered than the left ($M = .36$, $SD = .20$), [$p_{holm} < .001$, $d = .88$] and right words ($M = .33$, $SD = .24$), [$p_{holm} < .001$, $d = 1.06$]; additionally, the left words were better recalled than the right words [$p_{holm} = .018$, $d = .18$]. Results did not reveal a main effect of the presence of values [$F(1, 227) = 2.04$, $p = .155$, $\eta_p^2 = .01$] such that participants studying words without values ($M = .39$, $SD = .14$) recalled a similar proportion of words as participants studying words supplied with a point value structure ($M = .42$, $SD = .15$). Moreover, younger adults recalled a greater proportion of words ($M = .46$, $SD = .14$) than older adults ($M = .35$, $SD = .13$), [$F(1, 227) = 42.48$, $p < .001$, $\eta_p^2 = .16$]. The presence of values did not interact with age [$F(1, 227) = 1.52$, $p = .220$, $\eta_p^2 = .01$] and age did not interact with triad position [$F(1.41, 318.97) = .77$, $p = .422$, $\eta_p^2 < .01$], but triad position interacted with the presence of values [$F(1.41, 318.97) = 122.70$, $p < .001$, $\eta_p^2 = .35$] such that when each word was worth the same value, participants recalled words on the left better than the right [$p_{holm} = .026$, $d = .31$], but not better than words in the middle [$p_{holm} = .140$, $d = .22$], and words in the middle and on the right were similarly recalled [$p_{holm} = .828$, $d = .09$]; when the middle word was given a high point value, it was best recalled [both $ps < .001$]. There was a significant three-way interaction between triad position, age, and the presence of values [$F(1.41, 318.97) = 4.05$, $p = .031$, $\eta_p^2 = .02$] such that when the middle word was worth the most points, left and right words were similarly recalled by each age group [both $ps > .999$] but younger adults better recalled high-value words relative to older adults [$p_{holm} < .001$, $d = .86$].

Next, we examined the PFR as a function of position within each triad in the study phase and the presence of values for younger and older adults (see Figure 2). A 2 (age: young, old) × 2 (presence of values: control, values) × 3 (triad position: left, middle, right) mixed-subjects ANOVA revealed a main effect of triad position [Mauchly's $W = .43$, $p < .001$; Huynh-Feldt corrected results: $F(1.27, 289.21) = 190.47$, $p < .001$, $\eta_p^2 = .46$] such that the words on the left were more likely to be recalled first than middle words [$p_{holm} < .001$, $d = 1.11$] and right words [$p_{holm} < .001$, $d = 2.22$]; additionally, middle words were more likely to be recalled first than the right words [$p_{holm} < .001$, $d = 1.11$]. There was not an effect of the presence of values [$F(1, 227) = .22$, $p = .639$, $\eta_p^2 < .01$] but there was an effect of age [$F(1, 227) = 10.78$, $p = .001$, $\eta_p^2 = .05$], though these effects are conceptually meaningless (e.g., the only differences that could result in an effect are instances where a subject did not recall any words or the first recalled word was incorrect; otherwise, lists will always have a single word on each list that was the first recalled). The presence of values did not interact with age [$F(1, 227) = .44$, $p = .507$, $\eta_p^2 < .01$] and age did not interact with triad position [$F(1.27, 289.21) = 2.15$, $p = .138$, $\eta_p^2 = .01$], but triad position interacted with the presence of values [$F(1.27, 289.21) = 128.49$, $p < .001$, $\eta_p^2 = .36$] such that when each word was worth the same value, participants were more likely to initiate recall with words on the left than words in the middle or on the right [both *p*s < .001] and words in the middle and on the right were similarly likely to be recalled first [$p_{holm} = .593$, $d = .17$]; however, when the middle word was given a high point value, it was more likely to be recalled first than adjacent words [both *p*s < .001], but left words were still more likely to be recalled first than right words [$p_{holm} < .001$, $d = 1.33$]. There was a three-way interaction between triad position, age, and the presence of values [$F(1.27, 289.21) = 5.95$, $p = .010$, $\eta_p^2 = .03$]. An examination of this interaction revealed that when the middle word was worth the most points, younger adults were more likely to initiate recall with a high-value word than a left word [$p_{holm} < .001$, $d = .94$] or a right word [$p_{holm} < .001$, $d = 2.30$], but younger adults were still more likely to initiate recall with a left word than a right word [$p_{holm} < .001$, $d = 1.35$]; older adults were more likely to initiate recall with a high-value word compared with a right word [$p_{holm} < .001$, $d = 1.79$] and were more likely to initiate recall with a left word compared with a right word [$p_{holm} < .001$, $d = 1.31$],

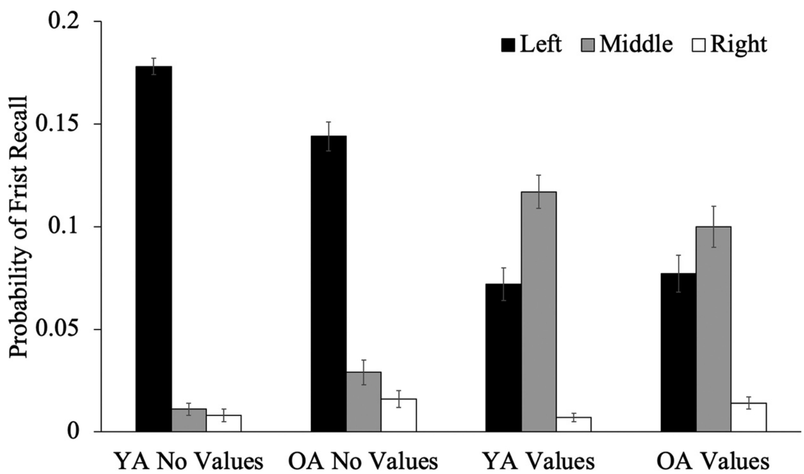

Figure 2. Probability of first recall (PFR) as a function of position within each word triad in the study phase and the presence of values for younger adults (YA) and older adults (OA) in Experiment 1. Error bars reflect the standard error of the mean.

but older adults were similarly likely to initiate recall with a high-value word compared with a left word [$p_{holm} = .492$, $d = .48$]; in the no-value condition, both younger and older adults were more likely to initiate recall with a left word relative to a middle or right word [all $ps < .001$] and the likelihood of initiating recall with a middle versus a right word was similar [both $ps > .999$].

The probability of recalling an item from serial position *x* followed by an item from serial position *y* for different lags as a function of the presence of values for younger and older adults is shown in Figure 3. To examine CRPs, we conducted a 5 (lag: 1–5; within-subjects factor) × 2 (direction: forward vs backward) × 2 (age: young, old) × 2 (presence of values: control, values) mixed-subjects ANOVA. For simplicity, the results are reported in Table 1. To focus on the critical four-way interaction between direction, lag, age, and the presence of values, results revealed that when the middle word was worth more points than its neighbors, younger adults were more likely to recall words strategically (i.e., making recall transitions of lag + 3 which represents the serial distance between successive high-value

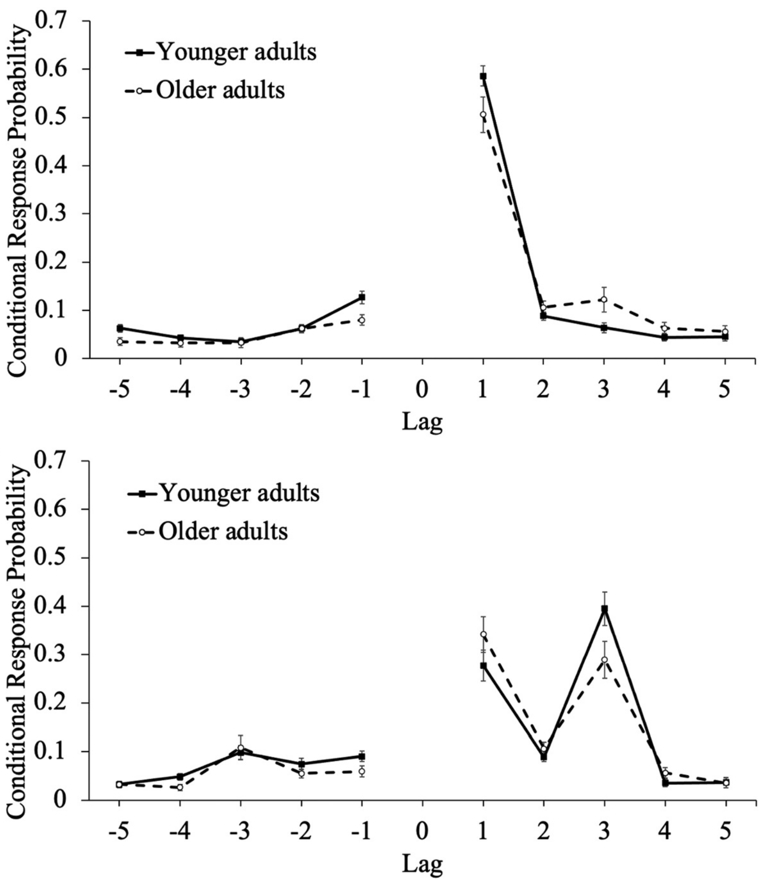

Figure 3. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag and age for participants not given any value instructions (a) and participants told the middle word was worth more points (b) in Experiment 1. Error bars reflect the standard error of the mean.

Table 1. Results of a 5 (lag: 1–5; within-subjects factor) × 2 (direction: forward vs backward) × 2 (age: young, old) × 2 (presence of values: control, values) Mixed-Subjects ANOVA on Lag-CRPs in Experiment 1.

	df	*F*	*p*	η^2_p
Within Subjects Effects				
Direction	1	642.451	<.001	0.739
Direction ∗ Condition	1	1.519	0.219	0.007
Direction ∗ Age Group	1	3.876	0.05	0.017
Direction ∗ Condition ∗ Age Group	1	0.399	0.528	0.002
Residuals	227			
Lag	4	172.75	<.001	0.432
Lag ∗ Condition	4	57.058	<.001	0.201
Lag ∗ Age Group	4	0.635	0.638	0.003
Lag ∗ Condition ∗ Age Group	4	4.047	0.003	0.018
Residuals	908			
Direction ∗ Lag	4	140.792	<.001	0.383
Direction ∗ Lag ∗ Condition	4	33.344	<.001	0.128
Direction ∗ Lag ∗ Age Group	4	1.18	0.318	0.005
Direction ∗ Lag ∗ Condition ∗ Age Group	4	5.41	<.001	0.023
Residuals	908			
Between Subjects Effects				
Condition	1	0.001	0.973	5.072×10^{-6}
Age Group	1	5.243	0.023	0.023
Condition ∗ Age Group	1	9.796×10^{-4}	0.975	4.315×10^{-6}
Residuals	227			

words), [$p_{\text{holm}} = .003$, $d = .82$]; additionally, although the comparison between younger and older adults for transitions of lag + 1 did not reach significance [$p_{\text{holm}} > .999$, $d = .50$], likely because of the large number of comparisons in this four-way interaction, this medium effect size suggests that older adults were more likely to recall words in their presented order (but we note that this should be interpreted cautiously).

Discussion

When all words were worth the same value, participants showed a serial recall bias such that words on the left were better recalled than words on the right. However, when the middle word was given a higher point value, it was better recalled than the adjacent words. Furthermore, when the middle word was worth the most points, younger adults were more likely to initiate recall with a high-value word while older adults were similarly likely to initiate recall with a left word and a high-value word. Additionally, when the middle word was worth more points than its neighbors, younger adults were more likely to recall words strategically compared with older adults. These findings suggest that younger adults have better strategic memory and are more likely to recall words based on their value rather than their serial position.

Experiment 2

In Experiment 2, we wanted to require both younger and older adults to process all words before engaging in strategic processing (as in Experiment 1, participants could employ a strategy where they fixate their gaze on the middle position to prioritize the processing of high-value words at the expense of the more peripheral locations). As such, in Experiment 2, participants had to process all three words before getting a signal indicating which word in each triad was the high-value word. Specifically, participants were presented with words in sets of three for a few seconds and then one of the words became underlined, indicating it was of high value (the high-value word could be in any of the three positions). Delaying the value cue in Experiment 2 influences the encoding process by introducing uncertainty and removing the opportunity for participants to selectively prioritize the processing of high-value items during initial encoding. Specifically, this manipulation is designed to probe post-presentation encoding mechanisms such as maintenance rehearsal or other processes involved in sustaining the information in working memory. Although participants might defer encoding until after the values are disclosed – mirroring the conditions of Experiment 1—the primary goal of maximizing their overall score should motivate them to encode all presented words. Specifically, even though low-value items contribute less to the overall score (1 point versus 5 points for high-value items), the incentive to enhance their total score should encourage participants to remember these items as well.

The task used in Experiment 2 May be particularly difficult for older adults who have difficulty with various forms of inhibition and selective attention (Cansino et al., 2011; Hasher et al., 1991; Hasher & Zacks, 1988; McDowd, 1997; see also Zanto & Gazzaley, 2017). As such, we expected that requiring participants to process all three words before knowing which position contains the high-value word would result in reduced memory selectivity in older adults. Specifically, older adults may encounter challenges in effectively encoding and prioritizing high-value information due to limitations in inhibitory control and attentional allocation during the initial encoding phase. Alternatively, older adults may benefit from this procedure by allowing older adults to engage in strategic processing more effectively once the high-value item is distinctly marked. Specifically, older adults may initially engage in serial processing but once the valuable word is underlined, it may be easier for older adults to disengage from serial processing and engage in strategic processing of the high-value word, potentially reducing age-related differences in memory for high-value words as seen in Experiment 1 when habitual processes impaired selectively attending to the central item.

Method

Participants

Younger adults ($n = 51$; $M_{age} = 19.61$, $SD_{age} = 1.10$; 36 female, 15 male; 21 Asian/Pacific Islander, 1 Black, 5 Hispanic, 18 White, 2 other/unknown; in terms of the highest level of education achieved, 9 High School Graduate, 34 some college but no degree, 2 Associates degree, 6 Bachelor's degree) were recruited from the UCLA Human Subjects Pool, tested online, and received course credit for their participation. Older adults ($n = 44$; $M_{age} = 71.91$, $SD_{age} = 4.83$; 26 female, 18 male; 1 American Indian/Alaskan Native, 1 Black, 40 White, 2 other/unknown; in terms of the highest level of education achieved, 6 High School Graduate, 13 some college but no degree, 4 Associates degree, 10 Bachelor's degree, 11 Graduate degree) were recruited from Amazon's Cloud Research. No younger adults were excluded but eight older adults were excluded for cheating. A sensitivity analysis indicated that, with this sample size, an actual correlation of $r = .87$ between repeated measures (recall from each triad position), assuming alpha = .05 and power = 80%, the smallest effect (interaction between age and triad/high-value position) that we could reliably detect was Cohen's $d = .13$.

Materials and procedure

The stimuli in Experiment 2 were the same as in Experiment 1 and the task in Experiment 2 was similar to Experiment 1. Participants were presented with six lists of words with each list containing 18 words, with words presented in triads. However, triads were initially presented for 4 seconds and then for another 4 seconds with one word in the triad underlined. Which position in the triad was underlined (left, middle, or right) was randomized on each trial but the frequency was evenly distributed among the three positions throughout the task (e.g., there were two triads per list where the high-value word was the right word). Participants were informed that each word was worth a point value counting toward their score if correctly recalled (with their goal being to maximize their score) and that the underlined word would be worth 5 points while words that do not become underlined are worth 1 point each.

Results

The proportion of words recalled as a function of position within each triad in the study phase and the location of the high-value word for younger and older adults is shown in Figure 4. A 3 (triad position: left, middle, right) × 3 (high-value position: left, middle, right) × 2 (age: young, old) mixed-subjects ANOVA did not reveal a main effect of the high-value location [$F(2, 186) = 2.08$, $p = .128$, $\eta_p^2 = .02$] but there was a main effect of triad position [$F(2, 186) = 7.01$, $p = .001$, $\eta_p^2 = .07$] such that the left words ($M = .44$, $SD = .18$) were better remembered than the middle ($M = .41$, $SD = .16$), [$p_{holm} = .009$, $d = .11$] and right words ($M = .40$, $SD = .17$), [$p_{holm} = .002$, $d = .14$]; the middle and right words were similarly recalled [$p_{holm} = .543$, $d = .02$]. Younger adults recalled a greater proportion of words ($M = .47$, $SD = .15$) than older adults ($M = .36$, $SD = .16$), [$F(1, 93) = 12.63$, $p < .001$, $\eta_p^2 = .12$]. Age did not interact with the location of the high-value word [$F(2, 186) = .91$, $p = .404$, $\eta_p^2 = .01$] or triad position [$F(2, 186) = .22$, $p = .804$, $\eta_p^2 < .01$]. However, triad position interacted with the location of the high-value word [Mauchly's $W = .02$, $p < .001$; Huynh-Feldt corrected results: $F(1.30, 121.11) = 100.69$, $p < .001$, $\eta_p^2 = .52$] such that the high-value words were best recalled regardless of which triad position they appeared in [all ps < .001]. There was not a three-way interaction between triad position, the location of the high-value word, and age [$F(1.30, 121.11) = 1.57$, $p = .216$, $\eta_p^2 = .02$], indicating that younger and older adults similarly engaged in the strategic processing of high-value words.

Next, we examined the PFR as a function of position within each triad in the study phase and the location of the high-value word for younger and older adults (see Figure 5). A 3 (triad position: left, middle, right) × 3 (high-value position: left, middle, right) × 2 (age: young, old) mixed-subjects ANOVA revealed a main effect of the high-value location [$F(2, 186) = 6.61$, $p = .002$, $\eta_p^2 = .07$] and a main effect of triad position [Mauchly's $W = .57$, $p < .001$; Huynh-Feldt corrected results: $F(1.41, 131.09) = 87.89$, $p < .001$, $\eta_p^2 = .49$] and triad position interacted with high-value location [Mauchly's $W = .30$, $p < .001$; Huynh-Feldt corrected results: $F(1.41, 131.09) = 74.43$, $p < .001$, $\eta_p^2 = .46$] such that the left words

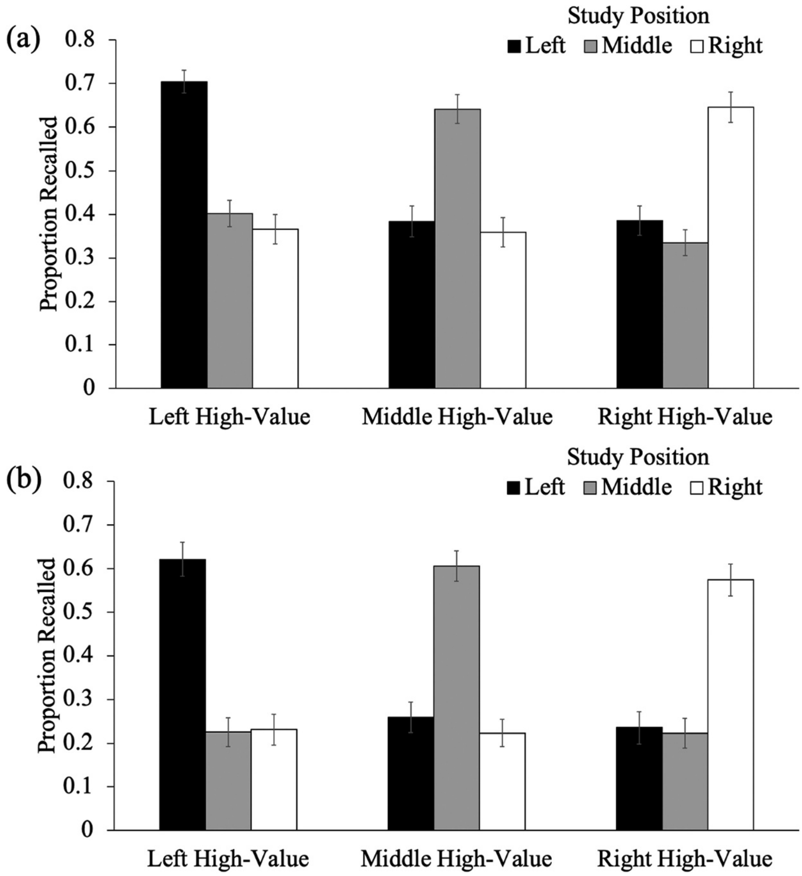

Figure 4. Probability of recall as a function of position within each word triad in the study phase as well as the position of the high-value word for younger adults (a) and older adults (b) in Experiment 2. Error bars reflect the standard error of the mean.

were most likely to be recalled first when the left words were the most valuable [all *ps* $< .001$]; when the high-value word was in the middle or on the right, participants were similarly likely to initiate recall serially (left word) or strategically (high-value word), [both *ps* $> .134$], but serial and strategic initiation of recall was more likely than recalling a middle or right low-value word [all *ps* $< .001$]. There was not an effect of age [$F(1, 93) = 1.45$, $p = .232$, $\eta_p^2 = .02$], and age did not interact with the location of the high-value word [$F(2, 186) = .08$, $p = .925$, $\eta_p^2 < .01$] or triad position [$F(1.41, 131.09) = .42$, $p = .585$, $\eta_p^2 = .01$]. There was not a three-way interaction between triad position, the location of the high-value word, and age [$F(2.68, 249.33) = 1.03$, $p = .376$, $\eta_p^2 = .01$].

Given that the high-value word changed locations throughout each list in Experiment 2, the lag-CRP curves primarily provide a measure of serial processing or the likelihood of participants recalling items in the order they were read (in Experiment 1, the middle word always being highly valuable allowed us to evaluate both serial processing (adjacency effects) and strategic processing (transitioning between successive high-value words)). Nevertheless, to examine lag-recency effects (see Figure 6), we conducted a 5 (lag: 1–5) × 2 (direction: forward vs

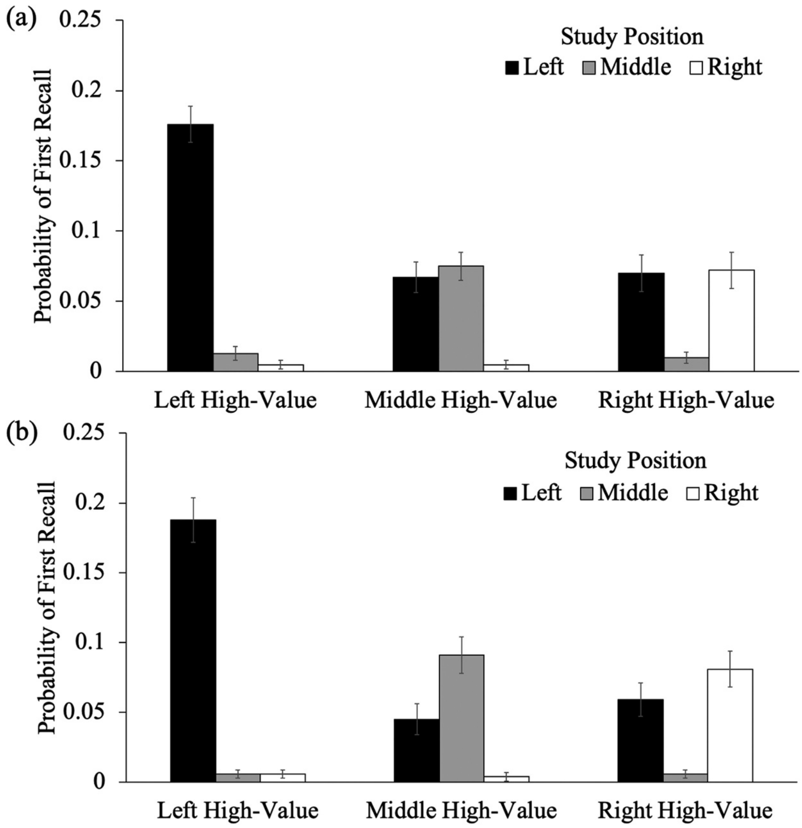

Figure 5. Probability of first recall as a function of position within each word triad in the study phase as well as the position of the high-value word for younger adults (a) and older adults (b) in Experiment 2. Error bars reflect the standard error of the mean.

backward) × 2 (age: young, old) mixed subjects ANOVA. Results revealed that participants showed a forward preference for the direction of transitions [$F(1, 93) = 284.78$, $p < .001$, $\eta_p^2 = .75$]. Additionally, participants showed strong adjacency effects [Mauchly's $W = .11$, $p < .001$; Huynh-Feldt corrected results: $F(1.78, 165.11) = 61.88$, $p < .001$, $\eta_p^2 = .40$] such that participants tended to recall items that were studied in close proximity together. Furthermore, there was an interaction between direction and lag [Mauchly's $W = .17$, $p < .001$; Huynh-Feldt corrected results: $F(2.02, 187.58) = 37.59$, $p < .001$, $\eta_p^2 = .29$] such that recall of adjacent items was most likely in the forward direction of lag 1 [all *p*s < .001]. There was an effect of age [$F(1, 93) = 6.97$, $p = .010$, $\eta_p^2 = .07$] such that younger adults showed stronger lag-recency effects than older adults. Age did not interact with lag [$F(1.78, 165.11) = 2.48$, $p = .093$, $\eta_p^2 = .03$] but age interacted with direction [$F(1, 93) = 7.54$, $p = .007$, $\eta_p^2 = .08$] such that younger adults were more likely to transition backward than older adults [$p_{holm} < .001$, $d = .24$]. There was not a three-way interaction between direction, lag, and age [$F(2.02, 187.58) = .63$, $p = .535$, $\eta_p^2 = .01$].

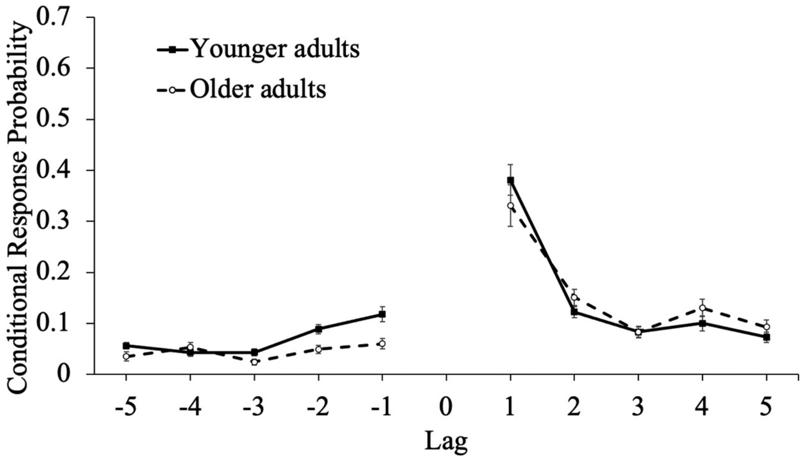

Figure 6. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag and age for younger and older adults in Experiment 2. Error bars reflect the standard error of the mean.

Discussion

In Experiment 2, there was evidence of both habitual and strategic recall such that, regardless of the position of the high-value word, left words were best recalled and the high-value words were best recalled regardless of which triad position they appeared in. Moreover, the left words were most likely to be recalled first when the left words were the most valuable, demonstrating an additive effect of serial and strategic processing, though this pattern was similar in younger and older adults. Together, the lack of age-related differences in Experiment 2 suggests that younger and older adults engaged in serial and strategic processing to a similar extent, consistent with other work using different paradigms (Knowlton & Castel, 2022). These findings suggest that both younger and older adults' memory performance is influenced by a combination of bottom-up (serial) and top-down (strategic) processing.

Experiment 3

In Experiment 2, after studying each triad for 4 seconds, the high-value word became underlined, allowing participants to begin engaging in strategic memory processes to remember it for an additional 4 seconds. However, this procedure allowed participants to view the high-value word after it had been revealed, potentially letting participants wait to encode the items until they knew which word was valuable (akin to Experiment 1). In Experiment 3, we employed a procedure requiring learners to encode all items before a cue indicated which one was the most valuable, and once the valuable item was revealed, it no longer appeared on the screen. Specifically, participants studied the triads for 4 seconds before they disappeared, and a cue (lasting 4 seconds) then indicated the position of the high-value word for that triad. We expected older adults to struggle to recall high-value words relative to younger adults due to older adults' challenges with focused selective attention (Cansino et al., 2011; Vallesi et al., 2021), overcoming interference (Murphy & Castel, 2022a, 2023), and engaging inhibitory processes (Rey-Mermet & Gade, 2018), which can make it difficult to maintain information in working memory until the value cue is revealed (Hayes et al., 2013). Thus, older adults might display more serial processing than younger adults while younger adults are more able to engage in strategic processing.

Method

Participants

Younger adults ($n = 48$; $M_{age} = 19.69$, $SD_{age} = 2.04$; 42 female, 6 male; 25 Asian/Pacific Islander, 2 Black, 2 Hispanic, 17 White, 2 other/unknown; in terms of the highest level of education achieved, 8 High School Graduate, 30 some college but no degree, 6 Associates degree, 4 Bachelor's degree) were recruited from the UCLA Human Subjects Pool, tested online, and received course credit for their participation. Older adults ($n = 49$; $M_{age} = 72.94$, $SD_{age} = 6.35$; 31 female, 17 male, 1 other; 1 Black, 1 Hispanic, 45 White, 2 other/unknown; in terms of the highest level of education achieved, 2 some high school, 11 High School Graduate, 10 some college but no degree, 5 Associates degree, 12 Bachelor's degree, 9 Graduate degree) were recruited from Amazon's Cloud Research. One younger adult and three older adults were excluded for cheating. A sensitivity analysis indicated that, with this sample size, an actual correlation of $r = .87$ between repeated measures (recall from each triad position), assuming alpha = .05 and power = 80%, the smallest effect (interaction between age and triad/high-value position) that we could reliably detect was Cohen's $d = .13$.

Materials and procedure

The stimuli in Experiment 3 were the same as in Experiments 1 and 2, and the task in Experiment 3 was similar to Experiment 2. However, after the initial 4-second presentation of a triad, rather than remaining on-screen for another 4 seconds with the high-value word underlined, the words disappeared and for another 4 seconds, a cue signaled which position the high-value word had been presented in (without the words present on the screen). For example, the triad "twig crumb noodle" could be presented for 4 seconds, followed by "___ *** ___" for 4 seconds, indicating that the high-value word was "crumb." Similar to Experiment 2, the position of the high-value word was randomized but appeared in each position with equal frequency throughout each list.

Results

The proportion of words recalled as a function of position within each triad in the study phase and the location of the high-value word for younger and older adults is shown in Figure 7. A 3 (triad position: left, middle, right) × 3 (high-value position: left, middle, right) × 2 (age: young, old) mixed-subjects ANOVA did not reveal a main effect of the high-value location [$F(2, 190) = .23$, $p = .794$, $\eta_p^2 < .01$] but there was a main effect of triad position [Mauchly's $W = .93$, $p = .035$; Huynh-Feldt corrected results: $F(1.91, 181.21) = 12.56$, $p < .001$, $\eta_p^2 = .12$] such that the left words ($M = .39$, $SD = .21$) were better remembered than the middle ($M = .35$, $SD = .19$), [$p_{holm} < .001$, $d = .18$] and right words ($M = .35$, $SD = .19$), [$p_{holm} < .001$, $d = .19$]; the middle and right words were similarly recalled [$p_{holm} = .708$, $d = .02$].

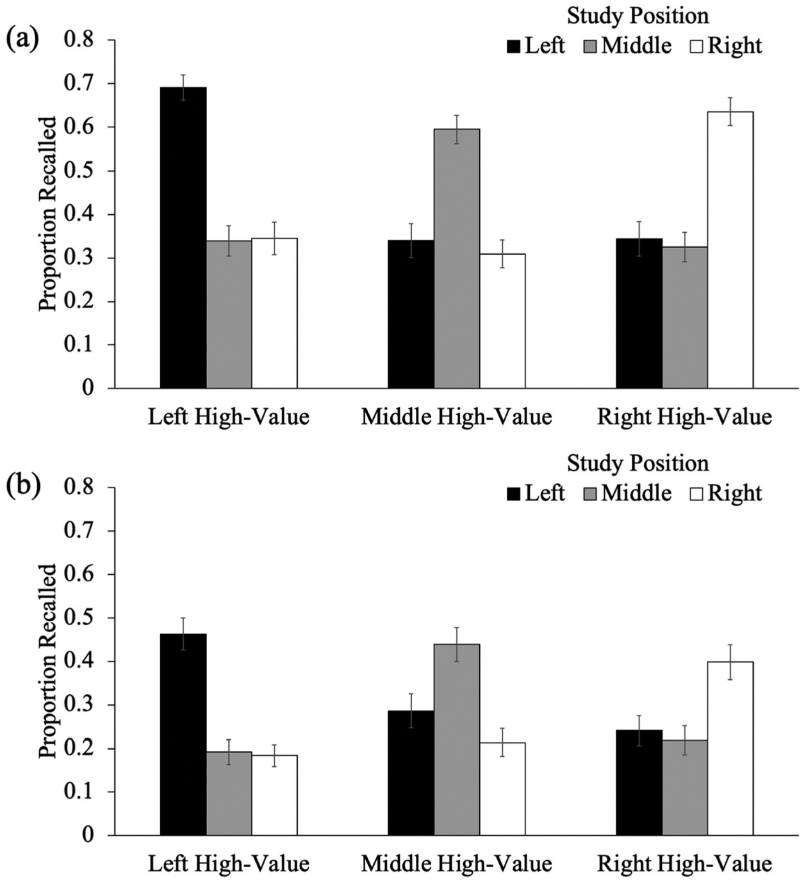

Figure 7. Probability of recall as a function of position within each word triad in the study phase as well as the position of the high-value word for younger adults (a) and older adults (b) in Experiment 3. Error bars reflect the standard error of the mean.

Younger adults recalled a greater proportion of words ($M = .44$, $SD = .17$) than older adults ($M = .29$, $SD = .18$), [$F(1, 95) = 16.17$, $p < .001$, $\eta_p^2 = .15$]. Age did not interact with triad position [$F(1.91, 181.21) = 1.72$, $p = .183$, $\eta_p^2 = .02$] but age interacted with the location of the high-value word [$F(2, 190) = 4.78$, $p = .009$, $\eta_p^2 = .05$] such that the magnitude of the difference in recall between younger and older adults was greatest when the high-value word was in the left position [$p_{holm} < .001$, $d = .74$] and right positions [$p_{holm} = .002$, $d = .62$] compared with the middle [$p_{holm} = .062$, $d = .42$]. Triad position interacted with the location of the high-value word [Mauchly's $W = .06$, $p < .001$; Huynh-Feldt corrected results: $F(1.54, 146.50) = 77.24$, $p < .001$, $\eta_p^2 = .45$] such that the high-value words were best recalled regardless of which triad position they appeared in [all ps $< .001$]. There was not a three-way interaction between triad position, the location of the high-value word, and age [$F(1.54, 146.50) = 2.71$, $p = .084$, $\eta_p^2 = .03$].

Next, we examined the PFR as a function of position within each triad in the study phase and the location of the high-value word for younger and older adults (see Figure 8). A 3 (triad position: left, middle, right) × 3 (high-value position: left, middle,

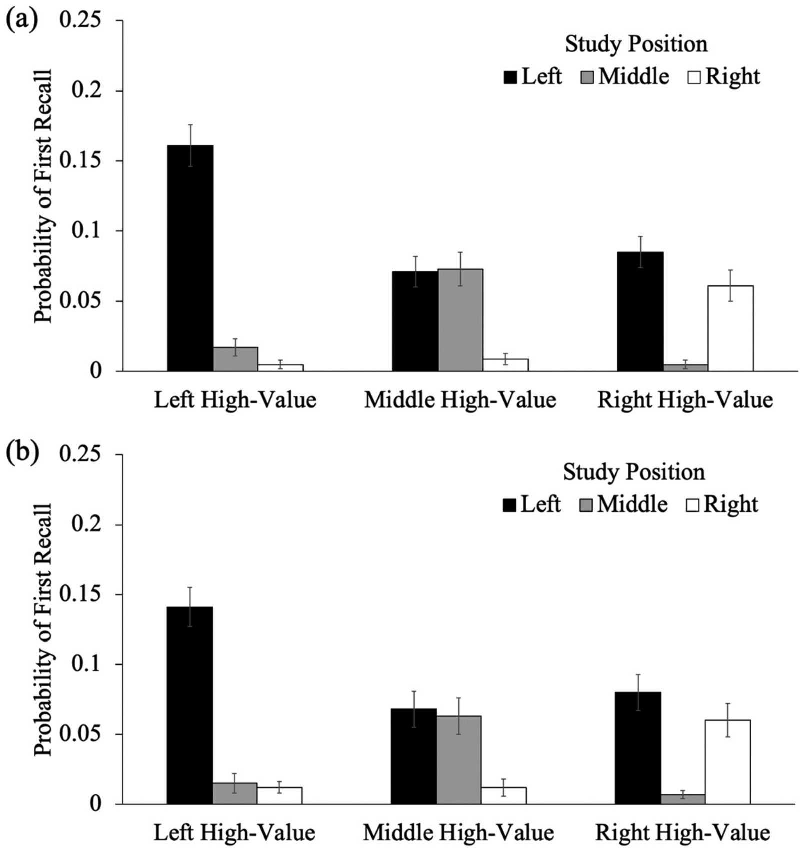

Figure 8. Probability of first recall as a function of position within each word triad in the study phase as well as the position of the high-value word for younger adults (a) and older adults (b) in Experiment 3. Error bars reflect the standard error of the mean.

right) × 2 (age: young, old) mixed-subjects ANOVA did not reveal a main effect of the high-value location [$F(2, 190) = 1.69$, $p = .187$, $\eta_p^2 = .02$] but there was a main effect of triad position [Mauchly's $W = .76$, $p < .001$; Huynh-Feldt corrected results: $F(1.64, 155.84) = 91.79$, $p < .001$, $\eta_p^2 = .49$] and triad position interacted with the high-value location [Mauchly's $W = .53$, $p < .001$; Huynh-Feldt corrected results: $F(3.16, 300.50) = 35.21$, $p < .001$, $\eta_p^2 = .27$] such that the left words were most likely to be recalled first when the left words were the most valuable [all *ps* $< .001$]; when the high-value word was in the middle or on the right, participants were similarly likely to initiate recall serially (left word) or strategically (high-value word), [both *ps* $> .406$], but serial and strategic initiation of recall was more likely than recalling a middle or right low-value word [all *ps* $< .001$]. There was an effect of age [$F(1, 95) = 5.44$, $p = .022$, $\eta_p^2 = .05$], but again, this effect is conceptually meaningless. Age did not interact with the location of the high-value word [$F(2, 190) = .05$, $p = .953$, $\eta_p^2 < .01$] or triad position [$F(1.64, 155.84) = .50$, $p = .572$, $\eta_p^2 = .01$], and there was not a three-way interaction between triad position, the location of the high-value word, and age [$F(3.16, 300.50) = .30$, $p = .836$, $\eta_p^2 < .01$].

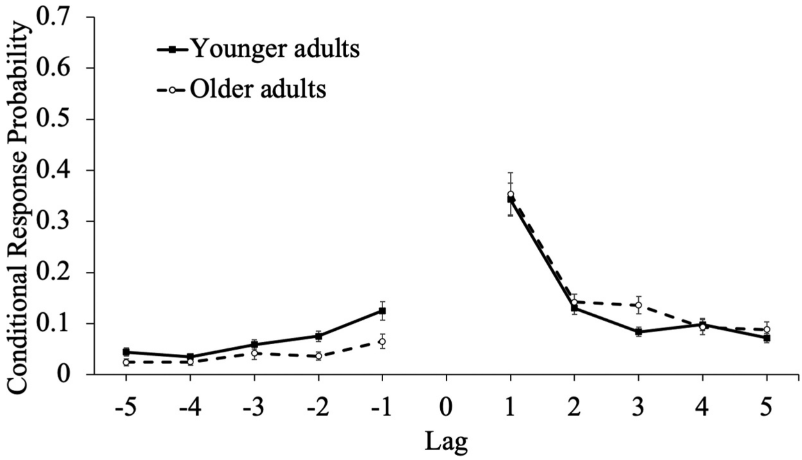

Figure 9. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag and age for younger and older adults in Experiment 3. Error bars reflect the standard error of the mean.

Although only indicative of serial processing in Experiment 3, we again examined lag-recency effects (see Figure 9). We conducted a 5 (lag: 1–5) × 2 (direction: forward vs backward) × 2 (age: young, old) mixed subjects ANOVA. Results revealed that participants showed a forward preference for the direction of transitions [$F(1, 95) = 267.50$, $p < .001$, $\eta_p^2 = .74$]. Additionally, participants showed strong adjacency effects [Mauchly's $W = .11$, $p < .001$; Huynh-Feldt corrected results: $F(1.78, 169.52) = 56.11$, $p < .001$, $\eta_p^2 = .37$] such that participants tended to recall items that were studied in close proximity together. Furthermore, there was an interaction between direction and lag [Mauchly's $W = .17$, $p < .001$; Huynh-Feldt corrected results: $F(1.96, 185.70) = 28.76$, $p < .001$, $\eta_p^2 = .23$] such that recall of adjacent items was most likely in the forward direction of lag 1 [all *p*s < .001]. There was not an effect of age [$F(1, 95) = 2.14$, $p = .147$, $\eta_p^2 = .02$] and age did not interact with lag [$F(1.78, 169.52) = .73$, $p = .468$, $\eta_p^2 = .01$], but age interacted with direction [$F(1, 95) = 14.25$, $p < .001$, $\eta_p^2 = .13$] such that older adults were more likely to transition forward [$p_{holm} = .021$, $d = .15$] while younger adults were more likely to transition backward [$p_{holm} < .001$, $d = .26$]. There was not a three-way interaction between direction, lag, and age [$F(1.96, 185.70) = .71$, $p = .490$, $\eta_p^2 = .01$].

Discussion

In Experiment 3, there was some evidence of habitual processing such that the left words were better recalled than the middle and right words, and there was also evidence of strategic processing such that the high-value words were best recalled regardless of their position within the triad. Moreover, the left words were most likely to be recalled first when they were the most valuable, but participants were similarly likely to initiate recall serially and strategically when the high-value word was in the middle or on the right. Thus, although we expected older adults to experience difficulty maintaining information in working memory before engaging in the selective encoding of high-value words, Experiment 3 demonstrates that older adults' ability to engage in the strategic processing of high-value words was intact. This indicates that both younger and older adults can override serial processes to remember valuable information, even when the high-value word is revealed after items are studied.

General discussion

In the present study, younger and older adults were presented with sets of word triads to remember for a later test, similar to a procedure developed by Murphy and Castel (2022a) to examine serial and strategic memory processes in younger adults. For each experiment in the present investigation, younger and older participants were presented with three words simultaneously in a left, center, and right location, with one word being more valuable than the other two (the middle word in Experiment 1; the high-value word could appear in any of the three positions in Experiments 2 and 3). Participants' goal was to maximize their task scores (the sum of the values of recalled words). We compared serial versus strategic processing by examining memory performance for each of the three triad positions as a function of the location of the high-value word as well as younger and older adults' retrieval patterns.

In this paradigm, if participants relied on serial processing, they should be more likely to remember the high-value word when it appeared in the left position as this is typically the most attended position (Ariel et al., 2011). Additionally, their output during recall should reflect the order in which information was presented. However, if participants engaged in strategic processing, they should have been able to recall the high-value word regardless of its position within the triad if they used strategies to prioritize the encoding and retrieval of high-value information. Moreover, strategic processers should be more likely to initiate recall with high-value items and value should influence their recall transitions. By comparing the recall of high-value words in different positions within the triad, the present study provides evidence for the use of serial and/or strategic processing strategies in the context of value-based memory in younger and older adults.

In Experiment 1, younger adults exhibited better strategic memory, recalling the middle word (which was worth more points) more frequently than older adults. Younger adults were also more likely to initiate recall with a high-value word relative to words on the left side of the screen, while older adults were similarly likely to begin recall with left words and high-value words. Additionally, lag-CRPs indicated that younger adults were more likely to successively recall high-value words relative to older adults who were slightly more likely to recall words in their serial order. In Experiment 2, there was evidence of both habitual and strategic recall such that words positioned on the left were recalled more effectively than those in the middle and right positions, and high-value words achieved the highest recall rates, irrespective of their placement within the triad. Additionally, there was an additive effect of serial and strategic processing such that the left words were most likely to be recalled first when the left words were the most valuable, though this was prevalent in both younger and older adults, possibly due to a strong habitual bias biased on a culturally-guided reading experience (Shaki et al., 2009). Experiment 3 revealed a similar pattern of habitual processing favoring left words as well as strategic processing such that valuable words were best recalled regardless of their position within a triad. Together, these findings indicate that both younger and older adults' memory is influenced by serial processing as well as strategic processing, and older adults' ability to engage in strategic processing can be impaired in certain contexts.

In terms of retrieval dynamics, across all experiments, both younger and older adults tended to begin recall with valuable information (as measured by PFR), consistent with prior work (Murphy & Castel, 2022b; Murphy et al., 2023), but the initiation of recall can involve both effortful retrieval selection processes and spontaneous fluency effects. Effortful retrieval selection processes refer to the deliberate and conscious decision-making involved in selecting the first item to recall, and participants may strategically choose to initiate recall with a particular position based on factors such as item salience, value, or positional cues. On the other hand, spontaneous fluency effects suggest that the initiation of recall is influenced by the ease with which the information is retrieved from memory, and this can be influenced by factors such as item familiarity, primacy effects, or the recency of exposure during the study phase. The present study suggests that both these factors – effortful retrieval selection (i.e., strategic choice) and spontaneous fluency effects (i.e., automatic ease) – play a role in how participants decide which items to recall first such that the most accessible items in memory may also be those of high value. The relative contributions of these mechanisms may vary depending on the specific task demands, individual differences, and experimental conditions, and further research is needed to elucidate their relative influences in different contexts.

When considering younger and older adults' transitions during retrieval, we demonstrated that younger adults were more strategic by recalling successive high-value words. Specifically, relative to older adults, younger adults demonstrated an increased likelihood of transitioning forward in lags of 3 (see Figure 3(b)), the serial distance between consecutive high value words. In contrast, there was some evidence that older adults were more likely than younger adults to make forward transitions of one lag, indicating that older adults were more likely to recall words in the serial order they were presented. Although we considered transitions of lag + 3 as evidence of strategic processing and transitions of lag + 1 as evidence of serial processing (in combination with evidence from PFR curves), recalling the first item in the triad could be considered somewhat strategic. Specifically, given that people use the temporal contextual information of a just-recalled item to recall additional items, if older adults recall a left item which assists them in successfully transitioning to the next item (which they do, according to Figure 3), this could increase the likelihood of recalling the high-value items in the middle. While this method may be less direct compared to recalling the middle (high-value) item and transitioning three serial positions to reach the next high-value item – a strategy participants employed at a comparable rate to just transitioning one item – it may still represent a form of strategic processing.

Serial processing, which can involve recalling items in the order they were presented, is considered more habitual and intuitive because it relies on the automatic activation of memory traces based on their temporal sequence. This type of processing is often associated with perceptual-level representations where the focus is on the physical properties, positions, and temporal characteristics of the stimuli, indicating its more habitual nature (e.g., Kahana, 1996). On the other hand, strategic processing involves prioritizing and attending to high-value information which requires the strategic allocation of attention and goal-directed behavior (e.g., Castel, 2008). This type of processing is conceptual and involves the activation of cognitive control mechanisms to guide encoding and retrieval based on the value or significance of the information. Thus, value-directed processing involves higher-level cognitive processes beyond mere perception and is driven by strategic considerations, but habitual reading and serial encoding can influence retrieval processes, and the present study suggests that both younger and older adults use value-driven processes to guide retrieval.

In terms of the distinction between perception-level (location-based) and conception-level (value-directed) processing, it is plausible that the present task could influence younger and older adults in different ways. By manipulating the location of the high-value word within each triad, we are manipulating the perception-level aspect of processing. However, since participants' goal was to maximize their scores by recalling as many high-value words as possible, the conceptual or value-directed processing becomes relevant as well. Specifically, participants need to strategically prioritize and attend to the high-value information, transcending a mere location-based or perception-level processing, and older adults appear to be able to do this under some conditions, consistent with some work that has examined this issue using value and feature-based integration of objects in working memory (cf. Allen et al., 2021).

While the current study does not explicitly manipulate perception-level versus conception-level processing, the findings suggest that serial processing is more habitual and intuitive for participants whereas value-directed processing is more strategic and goal-oriented. The observed results fit with research on value-based feature binding in working memory and the use of strategic attention which suggests that these mechanisms may be intact in older adults under some conditions (Allen et al., 2021). In the context of the present study, value-based feature binding involves participants associating specific features of words (such as their meaning, position on the screen, or any distinctive visual or contextual trait) with assigned point values. By effectively binding the value to the features of the words, participants can enhance the recall process, focusing on retrieving words that offer the highest value. The present study suggests that when older adults are presented with tasks that involve distinguishing between items of varying value, they can employ strategic attention to prioritize and bind features of high-value items in their working memory. This indicates that the cognitive mechanisms for strategic processing, though potentially compromised with age, remain functional when the tasks align well with their capabilities.

The present work provides important theoretical insight regarding how younger and older adults can use habits and agendas to regulate attention and memory (see also Ariel et al., 2015). While both age groups may resort to serial processing, younger adults often excel in strategic memory, especially when motivated by specific goals that demand attention to high-value items amidst habitual distractions. Specifically, younger adults tended to recall centrally positioned high-value words more frequently than older adults, possibly using working memory to focus attention on high-value items in the presence of competition via a focused spotlight model of attention whereas older adults are less able to do so as a result of stimulus competition (Loaiza & Souza, 2019). Moreover, given that the age-related recall differences were greatest when the high-value word was in the left position, this may suggest that younger adults can engage in dual-processing of reward position relative to older adults (cf., Castel, 2024; Knowlton & Castel, 2022).

The present findings highlight the importance of considering the presentation format of information to accommodate age-related differences in processing. Specifically, in situations where individuals encounter substantial amounts of information presented in a serial order, such as lists of medication side effects or labels on medications, older adults may rely on the inherent structure of the presentation format to aid their memory. To optimize the retention of crucial medication information, it may be beneficial to consider interventions that strategically engage older adults' memory processes. For instance, utilizing larger print or presenting essential information in a position likely to be read first (e.g., the top left for English speakers) could enhance the engagement of strategic memory processes, facilitating better encoding and subsequent retrieval of important information (Hargis & Castel, 2018b, 2018b, 2019).

One limitation of the current research lies in our ability to separate the processes of encoding and retrieval. Specifically, the observed retrieval patterns might be reflective of the strength of encoding and the subsequent availability of information in memory rather than denoting any specific strategic retrieval process. Thus, it is difficult to distinguish whether the observed differences in recall are a result of strategies employed during retrieval or if they are echoes of how information was encoded in memory. Future work could aim to isolate and examine encoding and retrieval independently. Future work could also use eye tracking to examine where learners direct their gaze during encoding to further elucidate how younger and older adults prioritize certain items at encoding. Disentangling these processes is crucial for developing targeted interventions that could enhance memory performance in older populations, adapting to older adults' cognitive processing capabilities at different stages of memory formation and recall.

Another potential limitation of the present work is that participants in the control condition were not given any feedback whereas the value-directed remembering condition was told their score after each list. The presence of feedback could influence participants' metacognitive assessments and strategy adjustments, particularly for older adults given their varying metacognitive abilities and motivational levels, potentially affecting how effectively they could engage in the encoding and retrieval processes (see McGillivray & Castel, 2011; A. L. Siegel & Castel, 2019). Future research should consider the inclusion of feedback in all learning conditions to better understand its impact on metacognitive accuracy and memory efficacy across different age groups. Additionally, it may be that people who have greater experience reading would show more of a propensity to recall items serially. Future research could examine this by measuring reading skill and speed as well as eye movements. Older adults likely have greater reading experience, and prior work has shown that older adults, by virtue of greater vocabulary and intact verbal knowledge, show benefits on a variety of cognitive tasks (e.g., Ichien et al., 2024; Murphy & Castel, 2024), and it would be informative to see how reading skill may lead to more serial processing but could be overridden by some individuals.

In sum, the present study demonstrated that both younger and older adults can use strategic processing to remember high-value information, even when it is cued after encoding (Experiments 2 and 3), although older adults' ability to engage in strategic processing may be impaired in some contexts (Experiment 1). This indicates that although older adults often exhibit deficits in selective attention (Cansino et al., 2011; Vallesi et al., 2021), face difficulties in overcoming interference (Murphy & Castel, 2022a, 2023), encounter challenges with inhibitory processes (Rey-Mermet &

Gade, 2018), and rely on habitual reading patterns (Hartman & Hasher, 1991; Warrington et al., 2019), there are conditions where older adults can effectively engage in strategic processing to recall valuable information. Furthermore, we found an additive effect of both serial and strategic processing, indicating that presenting valuable information in contexts known to benefit memory may optimize learning outcomes. Together, the present results suggest that the use of serial and strategic processing during memory encoding and retrieval may differ based on age, task demands, and cognitive ability, but older adults' ability to engage in strategic processing is preserved in certain contexts.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was supported by the National Institutes of Health (National Institute on Aging; Award Number R01 AG044335 to Alan Castel). 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. The experiments reported in this article were not preregistered. The stimuli and data have been made available on the Open Science Framework: https://osf.io/37vpe/?view_only=e17f122db6dd4f8bb1acc143b3356789. This work was presented at the 2022 Cognitive Aging Conference.

ORCID

Dillon H. Murphy http://orcid.org/0000-0002-5604-3494
Alan D. Castel http://orcid.org/0000-0003-1965-8227

References

Allen, R. J., Atkinson, A. L., & Nicholls, L. A. B. (2021). Strategic prioritisation enhances young and older adults' visual feature binding in working memory. *Quarterly Journal of Experimental Psychology*, *74*(2), 363–376. https://doi.org/10.1177/1747021820960712

Ariel, R., Al-Harthy, I. S., Was, C. A., & Dunlosky, J. (2011). Habitual reading biases in the allocation of study time. *Psychonomic Bulletin and Review*, *18*(5), 1015–1021. https://doi.org/10.3758/s13423-011-0128-3

Ariel, R., & Dunlosky, J. (2013). When do learners shift from habitual to agenda-based processes when selecting items for study? *Memory & Cognition*, *41*(3), 416–428. https://doi.org/10.3758/s13421-012-0267-4

Ariel, R., Dunlosky, J., & Bailey, H. (2009). Agenda-based regulation of study-time allocation: When agendas override item-based monitoring. *Journal of Experimental Psychology: General*, *138*(3), 432–447. https://doi.org/10.1037/a0015928

Ariel, R., Price, J., & Hertzog, C. (2015). Age-related associative memory deficits in value-based remembering: The contribution of agenda-based regulation and strategy use. *Psychology and Aging*, *30*(4), 795–808. https://doi.org/10.1037/a0039818

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., Neely, J. H., Nelson, D. L., Simpson, G. B., & Treiman, R. (2007). The English lexicon project. *Behavior Research Methods*, *39*(3), 445–459. https://doi.org/10.3758/BF03193014

Bäuml, K. (1998). Strong items get suppressed, weak items do not: The role of item strength in output interference. *Psychonomic Bulletin & Review*, *5*(3), 459–463. https://doi.org/10.3758/BF03208822
Campbell, K. L., Lustig, C., & Hasher, L. (2020). Aging and inhibition: Introduction to the special issue. *Psychology and Aging*, *35*(5), 605–613. https://doi.org/10.1037/pag0000564
Cansino, S., Guzzon, D., Martinelli, M., Barollo, M., & Casco, C. (2011). Effects of aging on interference control in selective attention and working memory. *Memory & Cognition*, *39*(8), 1409–1422. https://doi.org/10.3758/s13421-011-0109-9
Castel, A. D. (2008). The adaptive and strategic use of memory by older adults: Evaluative processing and value-directed remembering. In A. S. Benjamin & B. H. Ross (Eds.), *The psychology of learning and motivation* (Vol. 48, pp. 225–270). Academic Press. https://doi.org/10.1016/S0079-7421(07)48006-9
Castel, A. D. (2024). Memory selectivity in older age. *Current Opinion in Psychology*, *55*, 101744. https://doi.org/10.1016/j.copsyc.2023.101744
Castel, A. D., Benjamin, A. S., Craik, F. I. M., & Watkins, M. J. (2002). The effects of aging on selectivity and control in short-term recall. *Memory & Cognition*, *30*(7), 1078–1085. https://doi.org/10.3758/BF03194325
Chandler, J., Rosenzweig, C., Moss, A. J., Robinson, J., & Litman, L. (2019). Online panels in social science research: Expanding sampling methods beyond mechanical turk. *Behavior Research Methods*, *51*(5), 2022–2038. https://doi.org/10.3758/s13428-019-01273-7
Chokron, S., & De Agostini, M. (1995). Reading habits and line bisection: A developmental approach. *Cognitive Brain Research*, *3*(1), 51–58. https://doi.org/10.1016/0926-6410(95)00018-6
Chokron, S., & De Agostini, M. (2000). Reading habits influence aesthetic preference. *Cognitive Brain Research*, *10*(1–2), 45–49. https://doi.org/10.1016/S0926-6410(00)00021-5
Dunlosky, J., & Ariel, R. (2011a). The influence of agenda-based and habitual processes on item selection during study. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(4), 899–912. https://doi.org/10.1037/a0023064
Dunlosky, J., & Ariel, R. (2011b). Self-regulated learning and the allocation of study time. *Psychology of Learning and Motivation*, *54*, 103–140. https://doi.org/10.1016/B978-0-12-385527-5.00004-8
Dunlosky, J., & Thiede, K. W. (2004). Causes and constraints of the shift-to-easier-materials effect in the control of study. *Memory & Cognition*, *32*(5), 779–788. https://doi.org/10.3758/BF03195868
Durgin, F. H., Doyle, E., & Egan, L. (2008). Upper-left gaze bias reveals competing search strategies in a reverse stroop task. *Acta Psychologica*, *127*(2), 428–448. https://doi.org/10.1016/j.actpsy.2007.08.007
Eich, T. S., & Castel, A. D. (2016). The cognitive control of emotional versus value-based information in younger and older adults. *Psychology and Aging*, *31*(5), 503–512. https://doi.org/10.1037/pag0000106
Elliott, B. L., McClure, S. M., & Brewer, G. A. (2020). Individual differences in value-directed remembering. *Cognition*, *201*, 104275. https://doi.org/10.1016/j.cognition.2020.104275
Eviator, Z. (1995). Reading direction and attention: Effects on lateralized ignoring. *Brain and Cognition*, *29*(2), 137–150. https://doi.org/10.1006/brcg.1995.1273
Farrell, S., & Lewandowsky, S. (2008). Empirical and theoretical limits on lag recency in free recall. *Psychonomic Bulletin & Review*, *15*(6), 1236–1250. https://doi.org/10.3758/PBR.15.6.1236
Guo, K., Meints, K., Hall, C., Hall, S., & Mills, D. (2009). Left gaze bias in humans, rhesus monkeys and domestic dogs. *Animal Cognition*, *12*(3), 409–418. https://doi.org/10.1007/s10071-008-0199-3
Halamish, V., & Stern, P. (2022). Motivation-based selective encoding and retrieval. *Memory & Cognition*, *50*(4), 736–750. https://doi.org/10.3758/s13421-021-01238-2
Hargis, M. B., & Castel, A. D. (2018a). Improving medication understanding and adherence using principles of memory and metacognition. *Policy Insights from the Behavioral and Brain Sciences*, *5*(2), 147–154. https://doi.org/10.1177/2372732218781643
Hargis, M. B., & Castel, A. D. (2018b). Younger and older adults' associative memory for medication interactions of varying severity. *Memory*, *26*(8), 1151–1158. https://doi.org/10.1080/09658211.2018.1441423

Hargis, M. B., & Castel, A. D. (2019). Knowing what others know: Younger and older adults' perspective-taking and memory for medication information. *Journal of Applied Research in Memory and Cognition*, *8*(4), 481–493. https://doi.org/10.1016/j.jarmac.2019.09.004

Hartman, M., & Hasher, L. (1991). Aging and suppression: Memory for previously relevant information. *Psychology and Aging*, *6*(4), 587–594. https://doi.org/10.1037/0882-7974.6.4.587

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(1), 163–169. https://doi.org/10.1037/0278-7393.17.1.163

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. *Psychology of Learning and Motivation*, *22*, 193–225. https://doi.org/10.1016/S0079-7421(08)60041-9

Hayes, M. G., Kelly, A. J., & Smith, A. D. (2013). Working memory and the strategic control of attention in older and younger adults. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *68*(2), 176–183. https://doi.org/10.1093/geronb/gbs057

Hennessee, J. P., Patterson, T. K., Castel, A. D., & Knowlton, B. J. (2019). Forget me not: Encoding processes in value-directed remembering. *Journal of Memory and Language*, *106*, 29–39. https://doi.org/10.1016/j.jml.2019.02.001

Hess, T. M. (2005). Memory and aging in context. *Psychological Bulletin*, *131*(3), 383–406. https://doi.org/10.1037/0033-2909.131.3.383

Howard, M. W., & Kahana, M. J. (1999). Contextual variability and serial position effects in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*(4), 923–941. https://doi.org/10.1037/0278-7393.25.4.923

Ichien, N., Stamenković, D., Whatley, M. C., Castel, A. D., & Holyoak, K. J. (2024). Advancing with age: Older adults excel in comprehension of novel metaphors. *Psychology and Aging*.

Jennings, J. M., & Jacoby, L. L. (1993). Automatic versus intentional uses of memory: Aging, attention, and control. *Psychology and Aging*, *8*(2), 283–293. https://doi.org/10.1037/0882-7974.8.2.283

Kahana, M. J. (1996). Associative retrieval processes in free recall. *Memory & Cognition*, *24*(1), 103–109. https://doi.org/10.3758/BF03197276

Kazandjian, S., & Chokron, S. (2008). Paying attention to reading direction. *Nature Reviews Neuroscience*, *9*(12), 965–965. https://doi.org/10.1038/nrn2456-c1

Keenan, V. (1972). Effects of Hebrew and English letters on children's perceptual set. *Journal of Experimental Child Psychology*, *13*(1), 71–84. https://doi.org/10.1016/0022-0965(72)90008-2

Knowlton, B. J., & Castel, A. D. (2022). Memory and reward-based learning: A value-directed remembering perspective. *Annual Review of Psychology*, *73*(1), 25–52. https://doi.org/10.1146/annurev-psych-032921-050951

Kwak, Y., & Huettel, S. (2018). The order of information processing alters economic gain-loss framing effects. *Acta Psychologica*, *182*, 46–54. https://doi.org/10.1016/j.actpsy.2017.11.013

Loaiza, V. M., & Souza, A. S. (2019). An age-related deficit in preserving the benefits of attention in working memory. *Psychology and Aging*, *34*(2), 282–293. https://doi.org/10.1037/pag0000326

Love, J., Selker, R., Marsman, M., Jamil, T., Dropmann, D., Verhagen, J., Ly, A., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Wild, A., Knight, P., Rouder, J. N., Morey, R. D., & Wagenmakers, E. J. (2019). JASP: Graphical statistical software for common statistical designs. *Journal of Statistical Software*, *88*(2), 1–17. https://doi.org/10.18637/jss.v088.i02

Lustig, C., & Flegal, K. (2008). Age differences in memory: Demands on cognitive control and association processes. *Advances in Psychology*, *139*, 137–149. https://doi.org/10.1016/S0166-4115(08)10012-7

Madan, C. R., Zwaan, R., & Madan, C. (2017). Motivated cognition: Effects of reward, emotion, and other motivational factors across a variety of cognitive domains. *Collabra: Psychology*, *3*(1), 24. https://doi.org/10.1525/collabra.111

Mather, M., & Carstensen, L. L. (2005). Aging and motivated cognition: The positivity effect in attention and memory. *Trends in Cognitive Sciences*, *9*(10), 496–502. https://doi.org/10.1016/j.tics.2005.08.005

McDowd, J. M. (1997). Inhibition in attention and aging. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *52*(6), 265–P273. https://doi.org/10.1093/geronb/52B.6.P265
McGillivray, S., & Castel, A. D. (2011). Betting on memory leads to metacognitive improvement in younger and older adults. *Psychology and Aging*, *26*, 137–142.
Middlebrooks, C. D., & Castel, A. D. (2018). Self-regulated learning of important information under sequential and simultaneous encoding conditions. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *44*(5), 779–792. https://doi.org/10.1037/xlm0000480
Murphy, D. H., & Castel, A. D. (2021). Metamemory that matters: Judgments of importance can engage responsible remembering. *Memory*, *29*(3), 271–283. https://doi.org/10.1080/09658211.2021.1887895
Murphy, D. H., & Castel, A. D. (2022a). Differential effects of proactive and retroactive interference in value-directed remembering for younger and older adults. *Psychology and Aging*, *37*(7), 787–799. https://doi.org/10.1037/pag0000707
Murphy, D. H., & Castel, A. D. (2022b). The role of attention and aging in the retrieval dynamics of value-directed remembering. *Quarterly Journal of Experimental Psychology*, *75*(5), 954–968. https://doi.org/10.1177/17470218211046612
Murphy, D. H., & Castel, A. D. (2023). Age-related differences in overcoming interference when selectively remembering important information. *Experimental Aging Research*, *50*(2), 190–205. https://doi.org/10.1080/0361073X.2023.2176629
Murphy, D. H., & Castel, A. D. (2024). Knowing more than we know: Metacognition, semantic fluency, and originality in younger and older adults. *Aging, Neuropsychology & Cognition*, *31*(2), 279–300. https://doi.org/10.1080/13825585.2022.2149691
Murphy, D. H., Hoover, K. M., Castel, A. D., & Knowlton, B. J. (2024). Memory and automatic processing of valuable information in younger and older adults. *Aging, Neuropsychology & Cognition*, 1–27. https://doi.org/10.1080/13825585.2024.2360226
Murphy, D. H., Schwartz, S. T., & Castel, A. D. (2022). Serial and strategic memory processes in goal-directed selective remembering. *Cognition*, *225*, 105178. https://doi.org/10.1016/j.cognition.2022.105178
Murphy, D. H., Schwartz, S. T., & Castel, A. D. (2023). 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*, *50*, 17–38. https://doi.org/10.1037/xlm0001264
Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(5), 1170–1187. https://doi.org/10.1037/0278-7393.26.5.1170
Ouellet, M., Santiago, J., Israeli, Z., & Gabay, S. (2010). Is the future the right time? *Experimental Psychology*, *57*(4), 308–314. https://doi.org/10.1027/1618-3169/a000036
Park, D. C., & Festini, S. B. (2017). Theories of memory and aging: A look at the past and a glimpse of the future. *Journals of Gerontology: Psychological Sciences*, *72*(1), 82–90. https://doi.org/10.1093/geronb/gbw066
Rey-Mermet, A., & Gade, M. (2018). Inhibition in aging: What is preserved? What declines? A meta-analysis. *Psychonomic Bulletin & Review*, *25*(5), 1695–1716. https://doi.org/10.3758/s13423-017-1384-7
Rhodes, M. G., & Kelley, C. M. (2005). Executive processes, memory accuracy, and memory monitoring: An aging and individual difference analysis. *Journal of Memory and Language*, *52*(4), 578–594. https://doi.org/10.1016/j.jml.2005.01.014
Robison, M. K., & Unsworth, N. (2017). Working memory capacity, strategic allocation of study time, and value-directed remembering. *Journal of Memory and Language*, *93*, 231–244. https://doi.org/10.1016/j.jml.2016.10.007
Roediger, H. L., III. (1974). Inhibiting effects of recall. *Memory & Cognition*, *2*(2), 261–269. https://doi.org/10.3758/BF03208993

Roediger, H. L., III, & Schmidt, S. R. (1980). Output interference in the recall of categorized and paired-associate lists. *Journal of Experimental Psychology: Human Learning & Memory*, *6*(1), 91–105. https://doi.org/10.1037/0278-7393.6.1.91
Román, A., El Fathi, A., & Santiago, J. (2013). Spatial biases in understanding descriptions of static scenes: The role of reading and writing direction. *Memory & Cognition*, *41*(4), 588–599. https://doi.org/10.3758/s13421-012-0285-2
Román, A., Flumini, A., Lizano, P., Escobar, M., & Santiago, J. (2015). Reading direction causes spatial biases in mental model construction in language understanding. *Scientific Reports*, *5*(1), 1–8. https://doi.org/10.1038/srep18248
Salthouse, T. A. (2010). Selective review of cognitive aging. *Journal of the International Neuropsychological Society*, *16*(5), 754–760. https://doi.org/10.1017/S1355617710000706
Salthouse, T. A. (2019). Trajectories of normal cognitive aging. *Psychology and Aging*, *34*(1), 17–24. https://doi.org/10.1037/pag0000288
Schwartz, S. T., Siegel, A. L. M., & Castel, A. D. (2020). Strategic encoding and enhanced memory for positive value-location associations. *Memory & Cognition*, *48*(6), 1015–1031. https://doi.org/10.3758/s13421-020-01034-4
Sederberg, P. B., Miller, J. F., Howard, M. W., & Kahana, M. J. (2010). The temporal contiguity effect predicts episodic memory performance. *Memory & Cognition*, *38*(6), 689–699. https://doi.org/10.3758/MC.38.6.689
Shaki, S., Fischer, M. H., & Petrusic, W. M. (2009). Reading habits for both words and numbers contribute to the SNARC effect. *Psychonomic Bulletin & Review*, *16*(2), 328–331. https://doi.org/10.3758/PBR.16.2.328
Siegel, A. L., & Castel, A. D. (2019). Age-related differences in metacognition for memory capacity and selectivity. *Memory*, *27*(9), 1236–1249. https://doi.org/10.1080/09658211.2019.1645859
Siegel, A. L. M., & Castel, A. D. (2018a). Memory for important item-location associations in younger and older adults. *Psychology and Aging*, *33*(1), 30–45. https://doi.org/10.1037/pag0000209
Siegel, A. L. M., & Castel, A. D. (2018b). The role of attention in remembering important item-location associations. *Memory & Cognition*, *46*(8), 1248–1262. https://doi.org/10.3758/s13421-018-0834-4
Siegel, A. L. M., Schwartz, S. T., & Castel, A. D. (2021). Selective memory disrupted in intra-modal dual-task encoding conditions. *Memory & Cognition*, *49*(7), 1453–1472. https://doi.org/10.3758/s13421-021-01166-1
Spalek, T. M., & Hammad, S. (2005). The left-to-right bias in inhibition of return is due to the direction of reading. *Psychological Science*, *16*(1), 15–18. https://doi.org/10.1111/j.0956-7976.2005.00774.x
Speedie, L. J., Wertman, E., Verfaellie, M., Butter, C., Silberman, N., Liechtenstein, M., & Heilman, K. M. (2002). Reading direction and spatial neglect. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *38*(1), 59–67. https://doi.org/10.1016/S0010-9452(08)70638-5
Spillers, G. J., & Unsworth, N. (2011). Variation in working memory capacity and temporal–contextual retrieval from episodic memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(6), 1532–1539. https://doi.org/10.1037/a0024852
Stefanidi, A., Ellis, D. M., & Brewer, G. A. (2018). Free recall dynamics in value-directed remembering. *Journal of Memory and Language*, *100*, 18–31. https://doi.org/10.1016/j.jml.2017.11.004
Thiede, K. W., & Dunlosky, J. (1999). Toward a general model of self-regulated study: An analysis of selection of items for study and self-paced study time. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*(4), 1024–1037. https://doi.org/10.1037/0278-7393.25.4.1024
Thomas, A. K., & Gutchess, A. (Eds.). (2020). *The Cambridge Handbook of Cognitive Aging: A Life Course Perspective*. Cambridge University Press.
Unsworth, N. (2019). Individual differences in long-term memory. *Psychological Bulletin*, *145*(1), 79–139. https://doi.org/10.1037/bul0000176
Vallesi, A., Tronelli, V., Lomi, F., & Pezzetta, R. (2021). Age differences in sustained attention tasks: A meta-analysis. *Psychonomic Bulletin & Review*, *28*(6), 1755–1775. https://doi.org/10.3758/s13423-021-01908-x
Van der Henst, J. B., & Schaeken, W. (2005). The wording of conclusions in relational reasoning. *Cognition*, *97*(1), 1–22. https://doi.org/10.1016/j.cognition.2004.06.008

Warrington, K. L., McGowan, V. A., Paterson, K. B., & White, S. J. (2019). Effects of adult aging on letter position coding in reading: Evidence from eye movements. *Psychology and Aging*, *34*(4), 598–612. https://doi.org/10.1037/pag0000342

Zanto, T. P., & Gazzaley, A. (2017). Selective attention and inhibitory control in the aging brain. In R. Cabeza, L. Nyberg, & D. C. Park (Eds.), *Cognitive neuroscience of aging: Linking cognitive and cerebral aging* (pp. 207–234). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199372935.003.0009