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The role of attention and ageing in the retrieval dynamics of value-directed remembering

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Abstract

For memory to be efficient, people need to remember important information. This involves selective encoding and retrieval operations to maximise the recall of valuable information at the expense of less important information. While past research has examined this in terms of strategic encoding operations, we investigated differences in the dynamics of retrieval in value-directed remembering tasks with younger adults under full and divided attention during encoding as well as in older adults. Participants typically initiated recall with the first presented, last presented, or highest valued words and also strategically organised retrieval according to information value such that high-value words tended to be recalled before low-value words. However, the average value of older adults' first recalled word was greater than that of younger adults, likely contributing to their enhanced selectivity. In addition, there were no differences in lag-conditional-response probabilities in younger adults under full or divided attention, but older adults showed impairments in the retrieval of items sharing contextual features with nearby items, while younger adults relied more on temporal-contextual cues to recall words. Together, this study suggests that both strategic encoding and strategic retrieval operations contribute to selectivity for valuable information and older adults may be able to maximise retrieval operations despite displaying impairments in temporal binding during encoding and an overall recall deficit.

Keywords

Value-directed remembering; selectivity; retrieval; attention; ageing

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In everyday life, we are frequently presented with a series of events or lists of information to remember. Whether it be topics covered on an upcoming exam, foods to buy at the grocery store, or things to pack for a camping trip, we are usually unable to remember everything. Our ability to remember these items often depends on the time between presentation and recall, the presence or absence of a distracting task, presentation rate, and list length (Glanzer & Cunitz, 1966; Murdock, 1962). In addition to these factors, which items we remember and which we forget, how we initiate recall, how we transition between items, and the effects of value or information importance on remembering have long been of interest to memory researchers and often reveal systematic trends in participants' recall.

In the lab, free recall tasks typically involve presenting participants with lists of words to later remember. In these tasks, variation in the breakdown of recall performance based on presentation position is largely due to the primacy effect, the tendency to recall items presented first most accurately, and the recency effect, the tendency to recall items presented last most accurately, both relative to poorer recall of items in the middle of the list (Murdock, 1962; see also Murphy, Friedman, & Castel, 2022). Both younger and older adults demonstrate these serial position effects, but younger adults generally recall more words than older adults (e.g., Kahana et al., 2002). Although serial position curves reveal important recall tendencies, simply analysing recall probability based on the ordinal position in which a word is presented leaves many aspects of the dynamic retrieval process unexamined.

While the successful recall of an item often depends on the order in which it was presented, many other systematic tendencies have been documented (e.g., Howard &

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Kahana, 1999; Rohrer & Wixted, 1994). For example, when initiating recall, both younger and older adults typically begin recall with either the first or last word presented in the list (i.e., probability of first recall [PFR]; Howard & Kahana, 1999; Kahana et al., 2002), contributing to primacy and recency effects. This serial position curve for participants' first response also reveals that participants are more likely to initiate recall with the last presented item in the absence of a test delay (immediate free recall). However, in delayed free recall where participants' rehearsal is disrupted after the last word is presented during the study phase, participants demonstrate a reduced PFR for this last presented item and a greater PFR for the first presented item (Howard & Kahana, 1999), indicating the initiation of retrieval from long-term memory rather than short-term memory.

After initiating recall, often with the first or last presented word, more systematic tendencies are frequently observed in participants' retrieval in addition to elevated recall for primacy and recency items. Specifically, items presented in close temporal proximity tend to be recalled together, known as the *lag-recency effect*, a property measured by conditional-response probabilities (CRPs) as a function of lag (lag-CRPs; Kahana, 1996; see Hintzman, 2015, for a critique but see Healey et al., 2019, for response). Since items presented near each other share more contextual features than those that are farther apart, recalled items contain information that can then be used as a cue to continue the search for additional items, increasing the response probability of nearby items (Sederberg et al., 2010; Spillers & Unsworth, 2011). CRPs capture this property by providing a quantitative assessment of how individuals transition between responses during recall, and although lag-CRPs can be evaluated in both the forward (e.g., recalling an item in serial Position 4, followed by 5) and backward directions (e.g., recalling an item in serial Position 4, followed by 3), Kahana (1996) found CRPs to be twice as likely in the forward direction and three times as likely for adjacent items as opposed to remote items. Thus, participants tend to recall items in close proximity and in the order they were presented as opposed to randomly.

The CRP for a recall transition is calculated by taking the sum of the number of times the transition of a certain lag was made divided by the number of times that transition could have been made. Lag is the ordinal space between serial positions (e.g., the lag between serial Positions 8 and 9 would be 1), and the CRP illustrates the probability that an item from serial Position $i + \text{lag}$ is recalled immediately following an item from serial Position i. For example, if an individual recalls an item presented in serial Position 8, the CRP for a lag of 1 would be the probability that the item in serial Position 8 is recalled immediately after the item in serial Position 7 or 9 (as opposed to 6 or 10, which would illustrate a lag of 2).

Not only do CRPs provide additional insight into participants' recall, but increased CRPs also relate to elevated task performance (Sederberg et al., 2010; Spillers & Unsworth, 2011). Thus, using temporal-contextual cues of just recalled words to facilitate the retrieval of more words can be an effective recall tendency. In addition, the temporal proximity of items has a larger effect on recall transitions in younger adults compared with older adults (Kahana et al., 2002), consistent with the associative deficit hypothesis that older adults are worse at remembering associative information involving the binding of two or more pieces of information (see Old & Naveh-Benjamin, 2008).

In addition to the location of words in a studied list, the objective (associated point values or reward that is paired with words by the experimenter) value of an item can also influence recall probability (Castel et al., 2002; Elliott et al., 2020; Murphy, Agadzhanyan, et al., 2021). Value-directed remembering tasks pair to-be-remembered items with point values to evaluate how participants use value to guide the encoding and retrieval processes by measuring memory capacity (number of words recalled) and selectivity (the recall of high-value items relative to low-value items). On a subsequent test, if participants recall a to-be-remembered word, the "points" associated with that word are added to their score on the task (with participants' goal being to maximise their score). Previous work using these paradigms indicates that participants tend to be selective by prioritising recall for valuable information to optimise task performance (see Knowlton & Castel, in press; Madan, 2017 for review).

In value-directed remembering tasks, while older adults tend to recall fewer words than younger adults, older adults often demonstrate elevated recall for high-value items compared with low-value items (greater selectivity), resulting in comparable point scores (see Castel et al., 2002, 2007; McGillivray & Castel, 2017). Thus, older adults are more strategic in their recall by focusing on recalling valuable information at the expense of low-value information. While researchers often attribute these differences to strategic attention and encoding (e.g., Ariel et al., 2009, 2015; Castel, 2008; McGillivray & Castel, 2011), retrieval dynamics may play an important and understudied role.

Although evaluating the PFR and CRPs has revealed much about the dynamics of free recall, analyses of value-directed remembering tasks have been primarily limited to the probability of recall based on the point values assigned to each word (e.g., Ariel et al., 2015; Castel et al., 2002; Griffin et al., 2019; Nguyen et al., 2019; Robison & Unsworth, 2017; Wong et al., 2018). Some work using value-directed remembering procedures suggests that younger adults tend to initiate recall with high-value compared with low-value words and that CRPs are similar in participants completing a value-directed remembering task compared with controls where words are not paired with point values (see Stefanidi et al., 2018). However, it is unclear how the value of to-be-remembered information influences PFR curves, the lag-recency effect, and other retrieval tendencies in older adults. In addition, there may be an important attentional component during the encoding process contributing to the dynamics of free recall.

Similar to older adults, prior work suggests that participants under divided attention at encoding tend to recall fewer words but demonstrate preserved selectivity for valuable information compared with participants under full attention (Middlebrooks et al., 2017). There is a plethora of evidence indicating the memory costs that are conferred when attention is divided (Castel & Craik, 2003; Craik et al., 1996, 2010; Naveh-Benjamin et al., 2000), and theoretical accounts of cognitive ageing suggest that older adults suffer from reduced attentional resources (Anderson et al., 1998; Craik, 2006; Craik & Byrd, 1982). As a result, this reduction in older adults' attentional resources can lead to deficits in total recall and memory for associative information (Castel & Craik, 2003; Naveh-Benjamin, 2000).

Again, compared with younger adults, older adults display a specific deficit for associative information within the retrieval process (Kahana et al., 2002), but their selectivity for valuable information is enhanced (e.g., Castel et al., 2002, 2007; McGillivray & Castel, 2017). Thus, examining the retrieval dynamics of participants under full and divided attention as well as in younger and older adults could reveal the associated strategic retrieval processes involved in maximising memory utility in value-directed remembering tasks. Specifically, examining the PFR, lag-recency effect, organisation of recall, and how these factors relate to value-based recall could illuminate important strategic retrieval operations contributing to selective memory.

The current study

In this study, we investigated how attentional and age-related differences in the dynamics of free recall in value-directed remembering tasks contribute to selectivity for valuable information. Specifically, we examined data sets from two published studies that used similar value-directed remembering tasks (Middlebrooks et al., 2017; Siegel & Castel, 2019). These studies focused on the encoding processes associated with strategic remembering, and we examined retrieval dynamics in these data sets to provide novel theoretical insight regarding strategic value-guided retrieval processes by examining PFR curves, an analysis of output order, lag-CRPs (Kahana, 1996), and how these tendencies relate to memory selectivity.

While the PFR in free recall tasks is usually the greatest for the first or last presented item (Howard & Kahana, 1999), in value-directed remembering tasks, we expected that the PFR would be the highest for the most valuable items (consistent with prior work, see Stefanidi et al., 2018). However, we expected this effect to be more pronounced in older adults and participants under divided attention during encoding, contributing to their increased and preserved selectivity, respectively. In terms of output position, participants in immediate free recall tasks generally prioritise recall for items that they are actively rehearsing, resulting in strong recency effects (Howard & Kahana, 1999; Kahana et al., 2002). Similarly, when value-directed remembering tasks also employ immediate recall, we expected participants' increased rehearsal for valuable information (Hennessee et al., 2019) to result in the retrieval of high-value items before low-value items and for this trend to be associated with better selectivity.

Finally, we expected lag-recency effects to be preserved in participants under divided attention but to be decreased in older adults (see Kahana et al., 2002). Specifically, we expected increased CRPs to relate to better total recall (Healey et al., 2019; Sederberg et al., 2010; Spillers & Unsworth, 2011) but poorer selectivity such that less selective people (younger adults) would have higher CRPs as a consequence of using temporal-contextual information to recall items rather than using value to drive recall. Thus, we expected that relying on temporal-contextual cues during recall may reduce selectivity for high-value information, potentially indicating that older adults can engage retrieval strategies to override lag-recency effects and ensure selectivity.

Study 1

To examine retrieval dynamics in value-directed remembering, we first analysed data from Middlebrooks et al. (2017) who used a value-directed remembering task with participants under either full or divided attention during encoding. Specifically, participants were presented with six lists of 20 items (paired with values 1–10), and participants under divided attention completed a tone detection task, a tone discrimination task, or a one-back tone discrimination task. We expected participants to initiate retrieval with high-value items (Stefanidi et al., 2018), recall valuable items before low-value items, and demonstrate similar lag-CRPs whether under full or divided attention, contributing to preserved selectivity under divided attention.

Method

Participants. Participants were 96 younger adults ($M = 20.61$, $SD = 1.44$) recruited from the University of California, Los Angeles (UCLA) Human Subjects Pool, who received course credit for their participation. A sensitivity analysis indicated that for a fixed-effects analysis of variance (ANOVA) with two groups (numerator degrees of freedom = 4), assuming alpha = .05 and power = .80, the smallest effect size the design could reliably detect is $\eta^2 = .12$.

Materials and procedure. Participants were presented with six lists of 20 to-be-remembered words. Words were randomly paired with point values ranging from 1 to 10, with two words given each point value (two 10-point items per list, two 9-point items, etc.), and each word-point value pair was presented for 3 s. The serial position of point values was randomised within each list. Participants' goal was to remember as many of the words on each list as possible while also maximising their point score (sum of the points associated with correctly remembered words). In the testing phase, which occurred immediately following the presentation of the final word in each list and was user paced, participants typed their responses into an on-screen text box. At the end of each list, participants were given feedback on their memory performance (their point score out of 110 possible points).

In the original data, there were multiple divided attention conditions, but we combined these data.[1] Participants in the divided attention conditions ($n = 72$; see Middlebrooks et al., 2017 Experiment 2) were told that they would hear a series of low-pitched (400 Hz) and high-pitched (900 Hz) tones during the study phase. Each tone was played for 1 s with two tones played during each to-be-remembered item's presentation. Tone sequences were randomly generated for each participant. Some participants were instructed to indicate (on the keyboard) whether each pitch they heard was low or high. Other participants indicated whether the two tones played during a word's presentation were of the same pitch (i.e., both low-pitched or both high-pitched) or different pitches. Another group of participants was asked to indicate whether the current tone was the same pitch as the previous tone or a different pitch.[2]

In addition to their overall score, participants were scored for efficiency via a selectivity index. For this metric, we calculated each participant's point score relative to their chance and ideal score. The ideal score comprised the sum of only the highest values for the particular number of words recalled. For example, if a participant remembered four words, then ideally those words would be paired with the four highest values (e.g., $10 + 10 + 9 + 9 = 38$). Chance scores reflected no attention to value and were calculated as the product of the average point value and the number of recalled words. At chance, the score in this example would result in 5.5 (the average value of the points in the list) multiplied by the number of recalled words. If a participant only recalled words paired with the highest values, the resulting selectivity score would be 1, while a participant who only recalled words paired with the lowest values would receive a selectivity score of −1. Scores close to 0 indicate no sensitivity to value (see Castel et al., 2002, for more details).

Results

The results are divided into five primary sections. The first section reviews the findings of Middlebrooks et al. (2017), relating to the effects of task experience and divided attention on total recall and selectivity. In the second section, we examine the PFR, and in the third section, we investigate the organisation of participants' output. In the fourth section, we present CRPs, and in the final section, we discuss the relationships between recall, selectivity, the average value of participants' first recalled word, organisation of retrieval, and the lag-recency effect.

Recall, selectivity, and serial position effects. To review the findings of Middlebrooks et al. (2017), participants studying the words under full attention recalled a greater proportion of words than participants studying under divided attention (see Figure 1a), and recall increased with task experience in participants under divided attention. In addition, participants with full attention were similarly selective as participants under divided attention (see Figure 1b) and selectivity increased with task experience in both groups, but more so in participants under divided attention. To further examine total recall, we conducted a repeated-measures ANOVA with serial position (20 levels) as a within-subjects factor and attention (full or divided) as a between-subjects factor, but Mauchly's test of sphericity indicated violations for serial position (Mauchly's $W = .02$, $p < .001$). However, Huynh-Feldt corrected results revealed a main effect of serial position, suggesting clear primacy and recency effects—$F(14.09, 1{,}324.44) = 19.69$, $p < .001$, $\eta^2 = .17$. Specifically, post hoc comparisons indicated that words in the first and last serial positions were better recalled than words in other serial positions (all $p_{\text{bonf}} < .001$). In addition, serial position interacted with attention—$F(14.09, 1{,}324.44) = 3.25$, $p < .001$, $\eta^2 = .03$—such that participants under full attention showed stronger primacy effects.

PFR. Next, we examined the PFR as a function of serial position (see Figure 2a). As previously mentioned, the PFR measures how participants initiate recall and refers to the number of times the first recalled word comes from a given serial position divided by the number of times the first word recalled could have come from that serial position. A repeated-measures ANOVA with serial position (20 levels) as a within-subjects factor and attention (full or divided) as a between-subjects factor revealed a main effect of serial position such that participants tended to begin recall with the first or last presented word—Mauchly's $W < .01$, $p < .001$; Huynh-Feldt corrected results: $F(4.97, 567.21) = 32.47$, $p < .001$, $\eta^2 = .26$. Specifically, post hoc comparisons indicated that words in the first and last serial positions were recalled first more frequently than words in other serial positions (all $p_{\text{bonf}} < .001$). However, serial position did not interact with attention—$F(4.97, 567.21) = 0.86$, $p = .510$, $\eta^2 = .01$.

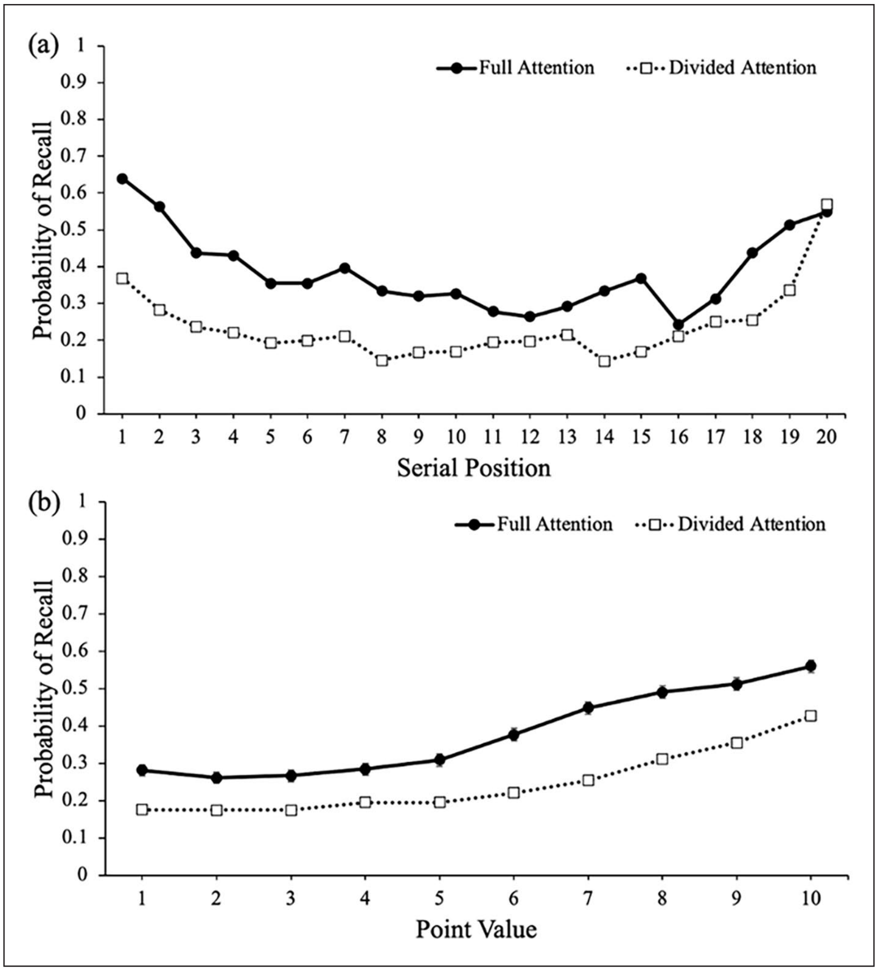

Figure 1. Probability of recall as a function of (a) serial position and attention at encoding as well as (b) value and attention at encoding in Study 1. Error bars reflect the standard error of the mean.

To determine whether the PFR differed as a function of value (see Figure 2b), a repeated-measures ANOVA with value (10 levels) as a within-subjects factor and attention (full, divided) as a between-subjects factor revealed a main effect of value, suggesting that participants tended to begin recall with higher valued words—Mauchly's $W = .45$, $p = .004$; Huynh-Feldt corrected results: $F(8.35, 785.03) = 8.90$, $p < .001$, $\eta^2 = .09$. Specifically, post hoc comparisons indicated that the 9- and 10-point words were recalled first more frequently than the words paired with values 1–6 (all $p_{\text{bonf}} < .044$). However, value did not interact with attention—$F(8.35, 785.03) = 1.42$, $p = .179$, $\eta^2 = .01$.

To determine whether the average value of participants' first recalled word differed between participants under full and divided attention, we computed an independent samples t-test. However, results revealed that the average value of the first recalled word for participants with full attention ($M = 6.82$, $SD = 1.42$) was similar to the average value of the first recalled word for participants under divided attention ($M = 6.40$, $SD = 1.40$), $t(94) = 1.27$, $p = .206$, $d = .30$. Together, these patterns suggest that whether under full or divided attention, participants tend to initiate recall with the first presented, last presented, or highest valued word. In addition, the value of the first recalled word did not differ as a function of attention at encoding, potentially contributing to their similar selectivity for high-value words.

Retrieval organisation. To determine how participants organised retrieval for items of various values, a Pearson's correlation between each item's output position (with larger numbers indicating later output) and the corresponding item's value was computed for each participant. A strong positive correlation would indicate that participants retrieved low-value items before high-value items, while a negative correlation would indicate that participants retrieved high-value items before low-value items. A correlation near 0 would indicate no organisation of retrieval based on value. Across participants and conditions, this relationship was significant ($r = -.10$, $p < .001$), indicating that retrieval was generally organised according to value.

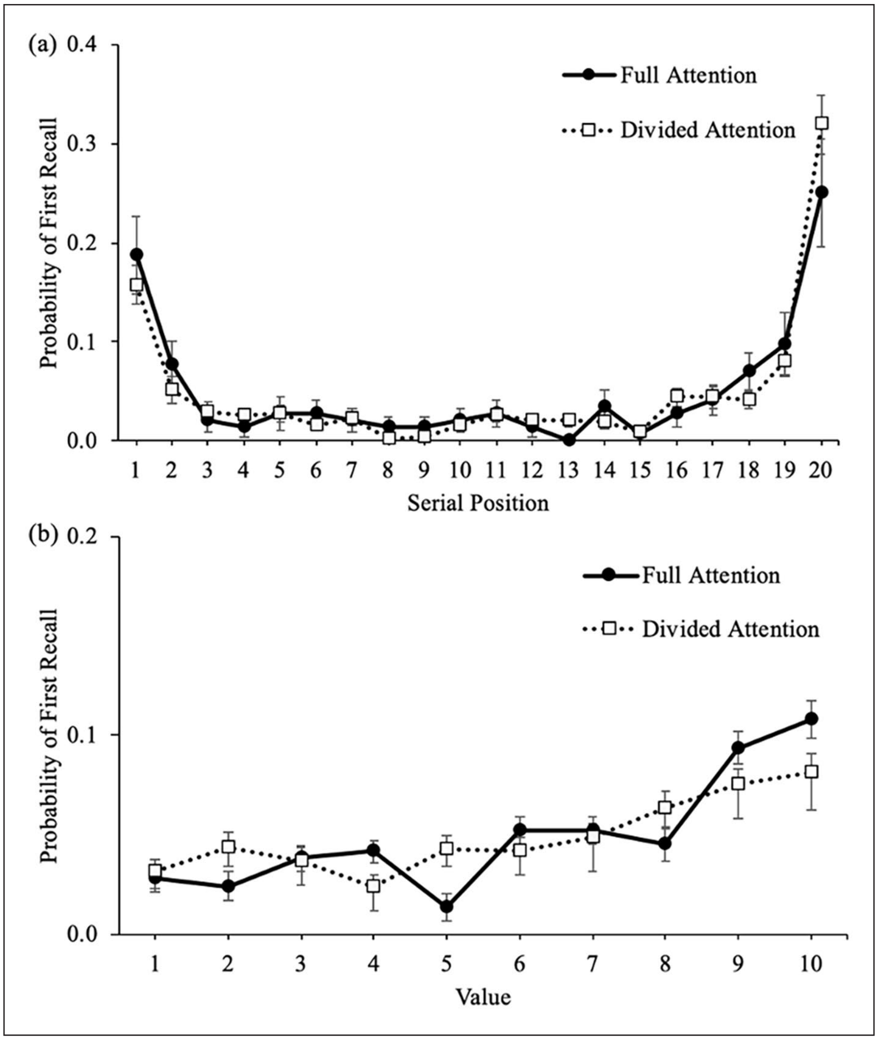

Figure 2. Probability of first recall (PFR) as a function of (a) serial position and attention at encoding as well as (b) value and attention at encoding in Study 1. Error bars reflect the standard error of the mean.

Before examining these correlations as a function of attention at encoding, to handle the non-normality of the sampling distribution of Pearson's r, we converted each participant's correlation using Fisher's z-transformation (see Alexander, 1990; Silver & Dunlap, 1987). The resulting values (full attention: $M = -.09$, $SD = .23$; divided attention: $M = -0.03$, $SD = 0.30$) served as the dependent variable in a 2 (attention: divided, full) × 6 (list) repeated-measures ANOVA. Results did not reveal a main effect of list—$F(5, 280) = 0.44$, $p = .823$, $\eta^2 = .01$, there was not a main effect of attention—$F(1, 56) = 0.12$, $p = .729$, $\eta^2 < .01$, and list did not interact with attention—$F(5, 280) = 1.49$, $p = .194$, $\eta^2 = .03$.

Lag-CRP. Lag-CRPs are another dynamic of retrieval that can affect performance via accompanying temporal and contextual information. Lag is a measure of the distance between successively recalled items and the direction of recall is indicated by the sign of the lag, with positive values indicating the forward direction and negative values indicating the backward direction. Lag-CRPs provide a useful means for analysing how individuals differ in their ability to use temporal-contextual cues during recall.[3,4] Plotting the probability of recalling an item from serial Position x followed by an item from serial Position y for different lags is shown in Figure 3.

A 5 (lag: 1–5;[5] within-subjects factor) × 2 (direction: forward vs. backward) × 2 attention (full, divided) repeated-measures ANOVA did not reveal a main effect of attention—$F(1, 94) = 1.00$, $p = .321$, $\eta^2 = .01$. However, participants showed a forward preference for the direction of transitions—$F(1, 94) = 99.15$, $p < .001$, $\eta^2 = .51$, but this did not differ as a function of attention—$F(1, 94) = 1.85$, $p = .177$, $\eta^2 = .01$. In addition, participants showed strong adjacency effects—Mauchly's $W = .46$, $p < .001$; Huynh-Feldt corrected results: $F(2.85, 267.79) = 64.24$, $p < .001$, $\eta^2 = .41$, but lag did not interact with attention—$F(2.85, 267.79) = 0.09$, $p = .963$, $\eta^2 < .01$. Furthermore, there was

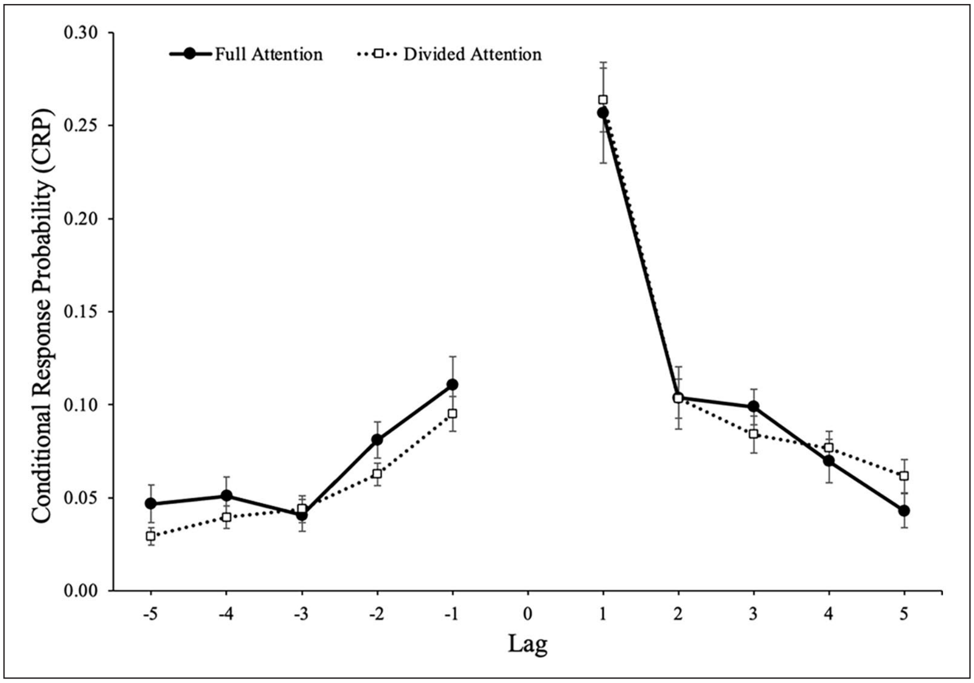

Figure 3. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag and attention at encoding in Study 1. Error bars reflect the standard error of the mean.

Table 1. Pearson's (*r*) correlations between the primary variables of interest (collapsed across conditions) in Study 1.

Measure	1	2	3	4	5
1. Recall	–				
2. Selectivity	−.015	–			
3. Average value of first recalled word	.133	.724***	–		
4. Output Position × Value of Pearson's *r*	−.153	−.264**	−.625***	–	
5. Exponential fit of lags +1 through +5	.247*	−.053	.034	.002	–

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

an interaction between direction and lag—Mauchly's $W = .69$, $p < .001$; Huynh-Feldt corrected results: $F(3.43, 322.26) = 19.82$, $p < .001$, $\eta^2 = .17$—such that participants were most likely to recall high-proximity items in the forward direction, but there was not a three-way interaction between direction, lag, and attention—$F(3.43, 322.26) = 0.61$, $p = .629$, $\eta^2 = .01$.

Correlations. The relationships between recall, selectivity, the average value of participants' first recalled word, organisation of retrieval, and the lag-recency effect[6] are shown in Table 1. As can be seen, the average value of participants' first recalled word was positively related to selectivity such that the greater the value of the first word participants recalled, the more selective they tended to be in their recall. In addition, the average value of participants' first recalled word was related to the organisation of recall such that participants who initiated retrieval with higher valued words were more likely to organise the rest of their retrieval according to value. Moreover, the organisation of recall according to value was related to selectivity such that the tendency to recall valuable items before less valuable items was associated with greater selectivity. Finally, the lag-recency effect for each participant was not related to PFR, the organisation of recall, or selectivity. Together, these relationships illuminate the strategic tendencies participants employ in value-directed remembering tasks that contribute to selective memory.

Discussion

In Study 1, we examined retrieval dynamics in a value-directed remembering paradigm with participants under either full or divided attention during encoding. Overall, participants with full attention recalled more words but there were no group differences in selectivity. In addition, results revealed that many of the systematic tendencies observed in participants' retrieval in standard immediate free recall tasks (where words are not paired with values) remained intact in the present value-directed remembering paradigm. For example, although participants were selective for high-value items, they still demonstrated a classic serial position curve by recalling items presented at the beginning and end of the presentation phase better than those in the middle.

In terms of retrieval dynamics, participants were more likely to initiate recall with high-value items compared with low-value items (as well as primacy and recency items), although this did not differ as a function of attention. Following the initiation of retrieval, participants generally organised recall according to value and this strategic tendency was related to better selectivity. We also investigated whether the use of temporal-contextual information to recall items differed under divided attention compared with full attention. Although there is debate about whether there are encoding contributions to the lag-recency effect (see Healey, 2018), participants showed adjacency effects for items sharing contextual features, but these effects did not differ based on attention. In sum, decreased attentional recourses available during encoding, while decreasing the quantity of words remembered, did not affect participants' retrieval dynamics or their ability to selectively remember valuable words.

Study 2

In Study 1, the retrieval tendencies contributing to selectivity for valuable information were preserved under divided attention. In Study 2, we analysed another published data set (Siegel & Castel, 2019) that used a similar value-directed remembering task as in Middlebrooks et al. (2017), but examined age-related differences in the retrieval dynamics of value-directed remembering. We combined data from their two experiments where younger and older adults were presented with four lists of 20 items (paired with values 1–10) and either predicted how many words they would remember or how many points they would earn. Again, we expected the PFR to be the greatest for high-value items (Stefanidi et al., 2018) but for this effect to be more pronounced in older adults, contributing to their increased selectivity. In addition, we expected older adults to demonstrate reduced lag-CRPs, consistent with Kahana et al. (2002), also potentially contributing to their elevated selectivity.

Method

Participants. Participants were 48 younger adults ($M=20.33$, $SD=2.17$) and 48 older adults ($M=76.56$, $SD=7.65$). Younger adults were recruited from the UCLA Human Subjects Pool, who received course credit for their participation. Older adults were recruited from the Los Angeles community and compensated US$10/hr, plus parking expenses. A sensitivity analysis indicated that for a fixed-effects ANOVA with two groups (numerator degrees of freedom=4), assuming alpha=.05 and power=.80, the smallest effect size the design could reliably detect is $\eta^2=.12$.

Materials and procedure. The task was similar to Study 1 (Middlebrooks et al., 2017); however, stimuli consisted of four lists (rather than six), each containing 20 words. Again, each word was randomly assigned a value from 1 to 10, with two words assigned to each point value on each list. Before each list, participants were asked to predict how many words they would recall on the upcoming list (Experiment 1) or were asked to make predictions about their point total on the upcoming list (Experiment 2). After making their prediction, participants were presented with the list of word-value pairs. At the end of each list, participants were given feedback on their memory performance. That is, participants were either told the number of words (out of 20) that they correctly recalled but not their total point score (Experiment 1), or they were told their point score (the number of points they earned on the current list) but not the number of words they recalled (Experiment 2).

Results

Recall, selectivity, and serial position effects. To review the findings of Siegel and Castel (2019), younger adults recalled a greater proportion of words than older adults (see Figure 4a), and this trend did not differ as a function of task experience. However, younger adults were less selective than older adults (see Figure 4b), but this also did not differ with increased task experience. To further examine total recall, a repeated-measures ANOVA with serial position (20 levels) as a within-subjects factor and age as a between-subjects factor revealed a main effect of serial position, suggesting clear primacy and recency effects—Mauchly's $W=.04$, $p<.001$; Huynh-Feldt corrected results: $F(16.26, 1{,}528.05)=19.15$, $p<.001$, $\eta^2=.17$. Specifically, post hoc comparisons indicated that words in the first and last serial positions were better recalled than words in other serial positions (all $p_{\text{bonf}}<.001$). In addition, serial position did not interact with age—$F(16.26, 1{,}528.05)=1.41$, $p=.129$, $\eta^2=.01$.

PFR. Next, we examined the PFR as a function of serial position (see Figure 5a). A repeated-measures ANOVA with serial position (20 levels) as a within-subjects factor and age as a between-subjects factor revealed a main effect of serial position—Mauchly's $W<.01$, $p<.001$; Huynh-Feldt corrected results: $F(5.02, 472.03)=33.36$, $p<.001$, $\eta^2=.26$, suggesting that participants tended to begin recall with the first or last presented word. Specifically, post hoc comparisons indicated that words in the first and last serial positions were recalled first more frequently than words in

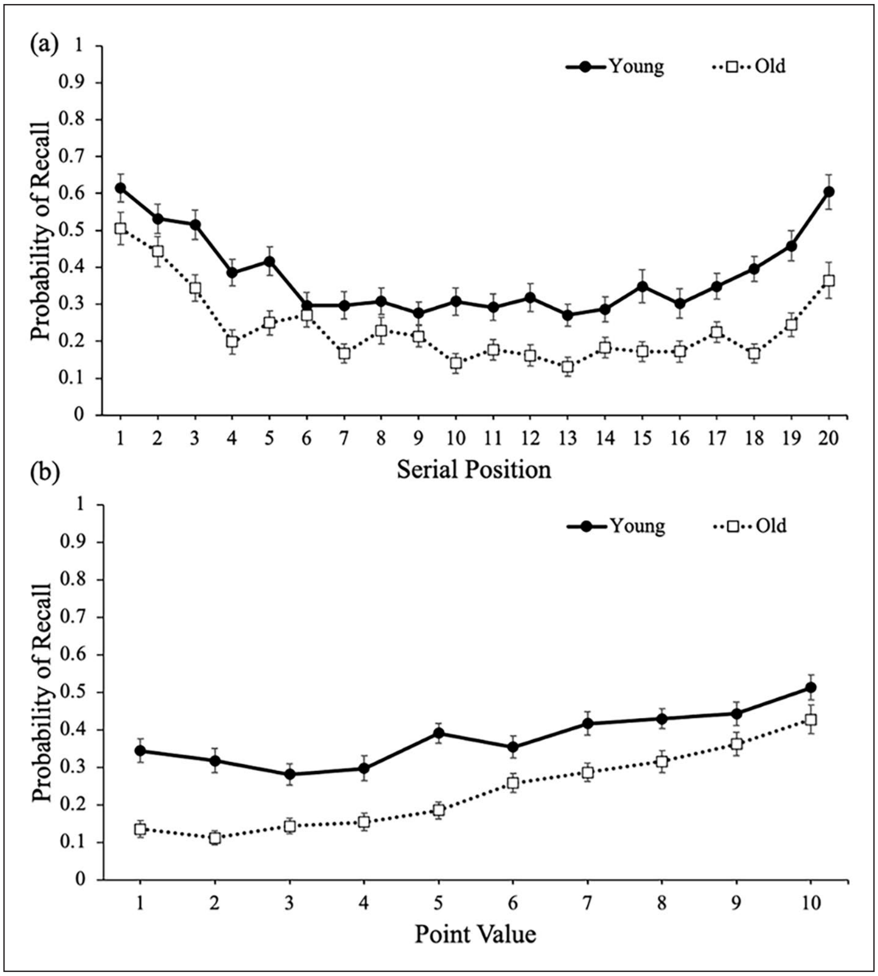

Figure 4. Probability of recall as a function of (a) serial position and age as well as (b) value and age in Study 2. Error bars reflect the standard error of the mean.

other serial positions (all $p_{\text{bonf}} < .001$). However, serial position did not interact with age—$F(5.02, 472.03) = 2.18$, $p = .055$, $\eta^2 = .02$.

To investigate whether the PFR differed as a function of value (see Figure 5b), a repeated-measures ANOVA with value (10 levels) as a within-subjects factor and age as a between-subjects factor revealed a main effect of value—Mauchly's $W = .35$, $p < .001$; Huynh-Feldt corrected results: $F(7.82, 735.16) = 7.84$, $p < .001$, $\eta^2 = .08$, suggesting that participants tended to begin recall with higher valued words. Specifically, post hoc comparisons indicated that the 10 point words were recalled first more frequently than the words paired with values 1–6 (all $p_{\text{bonf}} < .002$). However, value did not interact with age—$F(7.82, 735.16) = 1.29$, $p = .246$, $\eta^2 = .01$. Together, these results suggest that, irrespective of the age, participants tend to initiate recall with the first or last presented word, or the highest valued word.

To determine whether the average value of participants' first recalled word differed between younger and older adults, we computed an independent samples *t*-test. Results revealed that the average value of the first recalled word for older adults ($M = 7.01$, $SD = 6.18$) was greater than the average value of the first recalled word for younger adults ($M = 6.18$, $SD = 1.55$), $t(94) = 2.44$, $p = .017$, $d = .50$. Thus, initiating recall with higher valued words than younger adults likely contributes to older adults' greater selectivity.

Retrieval organisation. To determine how participants organised the retrieval of items of various values, we again computed a Pearson's correlation between output position and the corresponding item's value for each participant. Across participants and age groups, this relationship was significant ($r = -.12$, $p < .001$), suggesting that participants tended to recall valuable words before low-value words. Next, we converted each participant's correlation using Fisher's *z*-transformation. These values (young: $M = -.05$, $SD = .24$; old: $M = -.08$, $SD = .36$) served as the dependent variable in a 2 (age) × 4 (list) repeated-measures ANOVA. However, results did not reveal a main effect of list—$F(3, 240) = 0.55$, $p = .649$, $\eta^2 = .01$, there was not a main effect

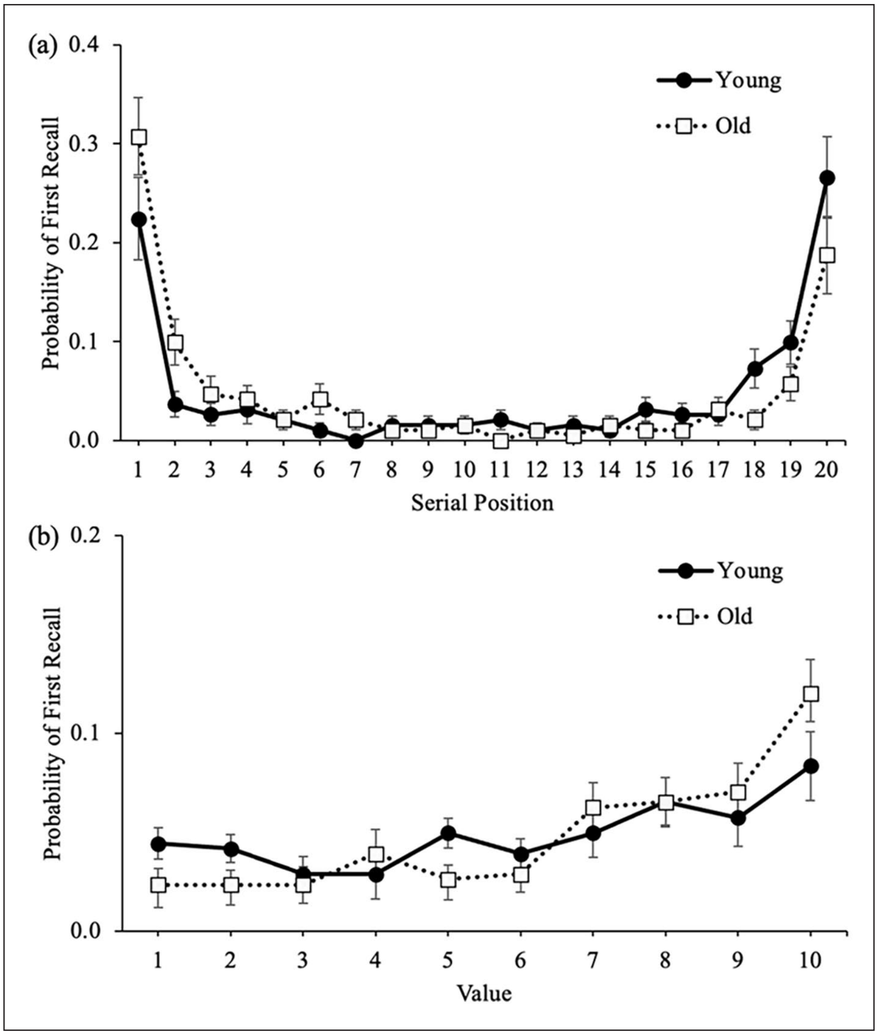

Figure 5. Probability of first recall (PFR) as a function of (a) serial position and age as well as (b) value and age in Study 2. Error bars reflect the standard error of the mean.

of age—$F(1, 80)=0.25$, $p=.618$, $\eta^2<.01$, and list did not interact with age—$F(3, 240)=1.30$, $p=.276$, $\eta^2=.02$, consistent with Castel et al. (2013).

Lag-CRP. To investigate age-related differences in the lag-recency effect (see Figure 6), a 5 (lag: 1–5; within-subjects factor) × 2 (direction: forward vs. backward) × 2 (age) repeated-measures ANOVA revealed a main effect of age—$F(1, 94)=6.84$, $p=.010$, $\eta^2=.07$—such that younger adults demonstrated stronger lag-recency effects than older adults. Furthermore, participants showed a forward preference for the direction of transitions—$F(1, 94)=47.35$, $p<.001$, $\eta^2=.33$, but this did not differ as a function of age—$F(1, 94)=2.48$, $p=.119$, $\eta^2=.02$. In addition, participants showed strong adjacency effects—Mauchly's $W=.59$, $p<.001$; Huynh-Feldt corrected results: $F(3.13, 294.60)=61.61$, $p<.001$, $\eta^2=.39$, but lag did not interact with age—$F(3.13, 294.60)=1.64$, $p=.179$, $\eta^2=.01$. There was an interaction between direction and lag—Mauchly's $W=.69$, $p<.001$; Huynh-Feldt corrected results: $F(3.43, 322.57)=19.97$, $p<.001$, $\eta^2=.17$—such that participants showed a stronger preference for items of 1 lag in the forward direction, but there was not a three-way interaction between direction, lag, and age—$F(3.43, 322.57)=1.66$, $p=.169$, $\eta^2=.01$. Collectively, these patterns suggest that a recalled item typically follows an item from a nearby input position and age affects this pattern such that younger adults use accompanying temporal and contextual information as a cue to continue the search for items more so than older adults.

Correlations. The relationships between recall, selectivity, the average value of participants' first recalled word, organisation of retrieval, and the lag-recency effect are shown in Table 2. As can be seen, the average value of participants' first recalled word was related to selectivity such that the greater the value of the first word participants recalled, the more selective they tended to be.

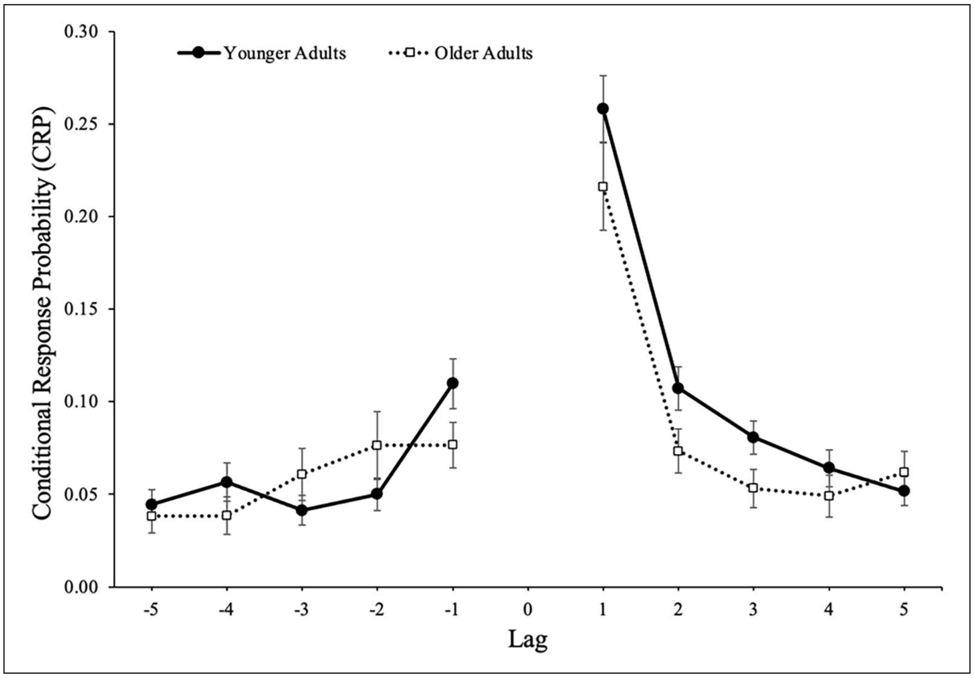

Figure 6. Conditional-response probability (CRP) functions for forward and backward transitions as a function of lag and age in Study 2. Error bars reflect the standard error of the mean.

Table 2. Pearson's (*r*) correlations between the primary variables of interest (collapsed across age groups) in Study 2.

Measure	1	2	3	4	5
1. Recall	–				
2. Selectivity	–.194	–			
3. Average value of first recalled word	–.150	.706***	–		
4. Output Position × Value of Pearson's *r*	–.147	–.036	–.463***	–	
Exponential fit of lags +1 through +5	–.138	.056	.140	.003	–

**p* < .05; ***p* < .01; ****p* < .001.

Furthermore, the average value of participants' first recalled word was also related to the organisation of recall such that participants who initiated retrieval with higher valued words were more likely to organise the rest of their retrieval according to value. However, the organisation of recall according to value was not related to selectivity. Finally, similar to Study 1, the lag-recency was not related to PFR, the organisation of recall, or selectivity.

Discussion

In Study 2, we examined age-related differences in the dynamics of free recall in a similar value-directed remembering paradigm as in Study 1. Overall, younger adults recalled more words but older adults were more selective. In addition to serial position effects, younger and older adults also demonstrated an elevated PFR for the first and last presented items, similar to typical free recall tasks (Howard & Kahana, 1999), contributing to the observed primacy and recency effects. However, participants were also more likely to initiate recall with high-value items rather than low-value items (consistent with Stefanidi et al., 2018) and the average value of older adults' first recalled word was greater than that of younger adults, likely contributing to their greater selectivity for high-value words.

We also investigated whether the use of temporal-contextual information to recall items is impacted by healthy ageing when words are paired with point values. Results revealed adjacency effects for items sharing contextual features with others, but these effects were more pronounced in younger adults, consistent with prior work suggesting that older adults encode less contextual information than younger adults and that the rate of contextual change is slower in older adults (Balota et al., 1989). Together, Study 2 indicates that, compared with word lists that do not contain any point values, similar principles govern younger and older adults' retrieval processes when using value to guide remembering, but older adults may achieve greater selectivity by initiating retrieval with higher-valued words.

General discussion

While reward-based learning involves strategic encoding processes (e.g., Hennessee et al., 2019), it also involves strategic retrieval to prevent the rapid forgetting of valuable information. In the present study, we evaluated the retrieval dynamics in value-directed remembering tasks to determine attentional and age-related differences in how participants initiate and organise recall as well as how they transition between items. In two data sets (Middlebrooks et al., 2017; Siegel & Castel, 2019), younger (divided or full attention) and older adults were presented with lists of words paired with point values, with their goal being to maximise their point scores (the sum of recalled item values).

Results revealed that older adults, as well as younger adults under divided attention during encoding, recalled fewer words than younger adults under full attention. However, selectivity was better in older adults than in younger adults and preserved in younger adults when their attention was divided. While these findings, in addition to previous work using value-directed remembering tasks, reveal much about learning processes, most work has limited their analyses to recall as a function of value and emphasised strategic encoding processes (e.g., Ariel et al., 2015; Castel et al., 2002; Griffin et al., 2019; Nguyen et al., 2019; Robison & Unsworth, 2017; Wong et al., 2018), leaving much of the dynamic retrieval process unknown.

Although pairing to-be-remembered words with point values influences recall probability (Castel et al., 2002), many of the systematic retrieval tendencies observed when participants recall to-be-remembered items that are not paired with point values are preserved in value-directed remembering tasks (Stefanidi et al., 2018). Specifically, in both Study 1 and Study 2, participants still demonstrated serial position effects, increased PFR for primacy and recency items, and lag-recency effects. However, participants also initiated recall with high-value words and tended to recall valuable words before low-value words. Although there were no significant differences in the value of the first word recalled or lag-recency effects as a function of attention at encoding, older adults not only initiated recall with higher valued words than younger adults but also demonstrated decreased lag-recency effects compared with younger adults.

Generally speaking, older adults display deficits in retrieval processes and in utilising effective retrieval strategies (e.g., Touron & Hertzog, 2004). This is especially pronounced when older adults attempt to remember associative information more explicitly, and may or may not use an effective strategy at encoding (such as imagery or creating a mediator to link word pairs), leading to a deficit during retrieval and failure to use cues from encoding to facilitate retrieval operations (Hertzog et al., 2013). In the present work, we examined item-based encoding and retrieval, such that the items were paired with values, which may engage metacognitive processes (see Murphy, Agadzhanyan, et al., 2021) that encourage older adults to focus on high-value words and also prioritise these words during retrieval, leading to their increased selectivity.

A reduced attentional resource account of cognitive ageing posits that younger adults under divided attention may be comparable to older adults under full attention (Castel & Craik, 2003; Craik, 2006; Craik & Byrd, 1982; Healey & Kahana, 2016), but the associative memory deficit (Old & Naveh-Benjamin, 2008) may account for the reduced lag-recency effects in older adults. In light of these theories that emphasise reduced attentional processing resources in older age, we were also interested in how younger adults under divided attention during encoding may be comparable to older adults under full attention. Similar to older adults, younger adults under divided attention recalled fewer words but selectivity was preserved (although there is some evidence that divided attention impairs selectivity in recognition tasks, see Elliott & Brewer, 2019), likely attributable to strategic retrieval operations like initiating recall with high-value words and recalling valuable information before low-value words.

Again, participants were generally selective in their recall and often initiated retrieval with high-value words. Specifically, older adults initiated retrieval with higher-valued words than younger adults and this tendency was associated with better selectivity, perhaps the result of reduced output interference—the decreased recall probability as a function of later serial position in a testing sequence (Bäuml, 1998; Roediger, 1974; Roediger & Schmidt, 1980). Older adults generally experience greater output interference than younger adults (Smith, 1971, 1974), and the retrieval process may lead to output interference that reduces selectivity, especially if one initially recalls a mixture of both high- and low-value items. Thus, older adults' tendency to initiate recall with higher-valued items than younger adults benefits their task performance and can help older adults compensate for overall recall deficits.

In sum, when presented with more information than can be remembered, people tend to selectively remember valuable information, but most prior work has attributed this to strategic encoding processes and has not provided an account of strategic retrieval operations. However, when selectivity occurs in free recall paradigms, the present study revealed that selectivity may be the product of both strategic encoding and then strategic retrieval to output high-value items before they are forgotten. Specifically, despite impairments in contextual binding, strategic retrieval plays an important role for older adults such that strategic retrieval operations can increase selectivity, possibly as a result of decreased output interference. Thus, the initiation and organisation of retrieval may be an important factor in selectivity for valuable information, and older adults can potentially maximise recall operations by using strategic retrieval processes despite displaying impairments in temporal binding during encoding. In addition to strategic encoding operations, future work should further investigate the understudied role of the strategic retrieval operations that contribute to the remembering of important information.

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Data accessibility statement

None of the experiments reported in this article were formally preregistered. Neither the data nor the materials have been made available on a permanent third-party archive; requests for the data or materials are available from the corresponding author upon reasonable request.

Notes

1. We did not use participants in the music conditions (see Middlebrooks et al., 2017).
2. Participants in the various divided attention conditions did not differ in selectivity—$F(2, 69)=0.55$, $p=.578$, $\eta^2=.02$, but there were differences in the proportion of words recalled—$F(2, 69)=3.99$, $p=.023$, $\eta^2=.10$—such that the one-back group recalled fewer words than participants tasked with identifying whether the two tones played during a word's presentation were the same ($p_{\text{bonf}}=.046$), but there were no other pairwise differences (all $p_{\text{bonf}}>.082$]). Since we were primarily interested in the effects of fewer attentional recourses (compared with full attention) on the retrieval dynamics contributing to selectivity for valuable information, we collapsed these data across divided attention conditions.
3. When calculating lag-conditional-response probabilities (CRPs), the more items a participant recalls, the less likely it is that they can make certain types of transitions because they are subsequently constrained by which items remain to be recalled (Hintzman, 2015). Although Healey and colleagues (2019) developed an adjustment for calculating lag-CRPs, they argue against the usage of this correction in standard practice, especially when there are group differences in total recall (as seen in the present study).
4. When calculating the lag-CRPs, incorrect responses were included in participants' output. For example, if a participant recalled a correct item, followed by an error, then another correct item, this last item's output position would be third.
5. We only considered 5 lags in each direction for our analyses, and other transitions (e.g., a transition from the 1st item on the list to the 20th item) did not differ between attention groups in Study 1 or age groups in Study 2. Although it has been common to limit lag-CRP analyses to 5 lags, see Farrell and Lewandowsky (2008) for the limitations of this approach.
6. To examine whether the lag-recency effect was related to other variables of interest, we fit an exponential function for each participant with lags $+1$ to $+5$ as the inputs. This measure provides a reasonable summary of the tendency to recall in the forward direction and to recall adjacent items compared with more remote items; the more negative the exponential fit, the greater the lag-recency effect.

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