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The Effect of Time Constraints on Value-Directed Long-Term Memory in Younger and Older Adults

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We often encounter more information than we can remember, making it critical that we are selective in what we remember. Being selective about which information we consolidate into our long-term memory becomes even more important when there is insufficient time to encode and retrieve information. We investigated whether older and younger adults differ in how time constraints, whether at encoding (Experiment 1) or retrieval (Experiment 2), affect their ability to be selective when remembering important information that they need to recall later. In Experiment 1, we found that younger and older adults exhibited similar selectivity, and the participants remained selective when rushed at encoding. In Experiment 2, older adults maintained their selectivity when given insufficient time at retrieval, but younger adults' selectivity was increased when given limited recall time. Altogether, the present experiments provide new support for negligible, and in some cases, even beneficial, effects of time constraints on older and younger adults' ability to selectively encode and retrieve the most valuable information. These findings may provide insight into a mechanism that allows older adults to use their long-term memory efficiently, despite age-related cognitive declines, even when faced with constraining encoding and retrieval situations.

Public Significance Statement

The present studies suggest that younger and older adults can selectively remember important information even when under suboptimal conditions such as time pressure. This is especially relevant in real-world scenarios where older adults may be hurried, such as in situations involving scams. Importantly, these insights shed light on the potential mechanisms that enable older individuals to harness their memory resourcefully, even amidst the challenges posed by age-related cognitive decline.

Keywords: aging, memory, selectivity, rushing, encoding

Decades of research have explicated how limited time impacts how much people remember. Overarchingly, less study time results in the worse recall, and this is true for the recall of digits presented visually (Mackworth, 1962) and orally (Posner, 1964) and lists of words (Hogan & Kintsch, 1971; Murdock, 1962; Roberts, 1972). This effect of study time on recall has been replicated consistently through the years (see Unsworth, 2016), and this effect may be even more pronounced in older adults whose slower processing speed (Salthouse, 1996) already lessens their ability to elaboratively encode to-be-remembered items when given sufficient time (Craik, 1983, 1986, 2002). Insufficient retrieval time can also adversely affect recall. This is likely because effective retrieval strategies do not have time to be implemented, which may have important consequences for older adults' recall performance as less strategy usage (Kahana et al., 2002) due to associative memory deficits (Naveh-Benjamin et al., 2004) and slower processing speed (Salthouse, 1996, 2000, 2019) likely contributes to older adults' impaired retrieval.

Although prior work provides some insight into how time constraints can affect the quantity of words remembered, few studies have looked at the effect of these constraints on younger and older adults' memory for valuable information. The prioritization of information based on item value or importance has been referred to as value-directed remembering (VDR; Castel, 2008; Castel et al., 2012; Knowlton & Castel, 2022; Murphy et al., 2021). In typical VDR studies, participants are asked to remember words that are paired with point values, and they receive these points when the associated words are later recalled. To emphasize the importance of value, participants are incentivized to remember the words with the highest point values so that they will receive a higher score. Both younger and older adults are generally selective such that they remember words with the

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highest point values more than those with lower point values (e.g., Castel et al., 2002; for a review, see Knowlton & Castel, 2022).

The mechanisms of VDR can be understood through both strategic and automatic cognitive processes (Knowlton & Castel, 2022). Strategic processing involves the deliberate use of encoding strategies to enhance the later recall of valuable information (Dunlosky, 1998; Hertzog et al., 2008). For example, people may generate sentences, create a mental image, or preferentially rehearse the highest valued items while engaging less in these behaviors for the lowest valued information (Hennessee et al., 2019; Stefanidi et al., 2018). These strategies are employed to prioritize the most important information and facilitate its storage in memory. However, the effects of value on memory can also operate more automatically. Rewarding or valuable information tends to be more salient compared to low-value information, leading to better memorability (Gruber et al., 2016; for a review, see Schultz, 2015). These automatic effects of value on memory occur without intentional engagement in strategic processing.

When given insufficient time for studying or retrieving information, it is especially important to engage in VDR to compensate for the resulting overall recall deficit accompanying limited time. From a mechanistic perspective, time constraints at encoding may not affect the ability to automatically process the most valuable information due to its subconscious and effortless nature; however, it is likely that time constraints would impact the strategic processing of value. For example, prior work has found that performing a divided attention task while engaging in value-directed encoding eliminated the effect of value on recognition memory (Elliott & Brewer, 2019; see also Murphy & Castel, 2022b; Murphy et al., 2023). This may be because implementing desired strategies requires time and effort (Elliott & Brewer, 2019; Stoff & Eagle, 1971). Stefanidi et al. (2018) found that one technique that younger adults use to selectively recall high-value items is by rehearsing the highest valued items more than low-value items; however, rehearsing these words takes time. If under time constraints at encoding, there may not be sufficient time to preferentially rehearse high-value items or to rehearse any words at all, much less employ more elaborative encoding strategies (e.g., sentence generation or mental imagery). Such findings suggest that strategic processing in VDR requires executive functioning and the recruitment and usage of cognitive resources such that when these resources are depleted (e.g., due to divided attention), VDR is impaired.

To provide insight into the effect of time pressure on younger adults' recall of valuable information, Middlebrooks, Murayama, and Castel (2016) manipulated study time when encoding information that varied in value. The researchers allocated 5 s of study time per word to some participants, whereas others were given only 1 s per word. The researchers found that, although having 1 s of study time led to worse recall than those who had 5 s of study time, younger adults were similarly selective in their memory for high-value words, such that those with 1 s of study time and the others with 5 s of study time both remembered more high-value words than low-value words. These findings suggest that contrary to our previous hypothesis, VDR may be preserved under time constraints at encoding in younger adults, although it is unclear whether this is because strategic processing was unaffected by the limited time or if automatic processing may have compensated for any impairments in strategic processing caused by the time constraints.

Limited research has been done on the effects of rushing at encoding on older adults' prioritization of high-value information in long-term memory. Older adults may have a different response to limited study time than younger adults due to the cognitive declines and structural changes in the brain that accompany aging (for review, see Anderson & Craik, 2017; Craik, 2002; Hasher & Zacks, 1988; Hess, 2005; Krueger & Salthouse, 2011). For example, previous research has found that memory, reasoning, and processing speed tend to decline as people age (Salthouse, 1996, 2000, 2019). In addition, executive control mechanisms essential for information processing may diminish with age (Craik, 2002; Hasher & Zacks, 1988; Hess, 2005; Krueger & Salthouse, 2011), as may associative binding (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000) and inhibitory processes (Hasher & Zacks, 1988; Zacks & Hasher, 2006).

The roles of automatic and strategic processing in VDR may also undergo changes as individuals age, as younger adults tend to engage more in automatic processing, whereas older adults shift toward employing strategic processing (e.g., Knowlton & Castel, 2022; Samanez-Larkin et al., 2014). This transition has been hypothesized to occur due to age-related alterations in the brain's reward system, potentially reducing the significance of valuable information for older adults (Chowdhury et al., 2013; Halfmann et al., 2016). Consequently, their ability to automatically process such valuable information might be impaired. To compensate for this deficit, older adults may rely on more effortful strategic processing when dealing with important information, allowing them to prioritize and remember it better (see Bowen et al., 2020; Schwartz et al., 2023). However, if older adults rely more on strategic processing to engage in VDR, time constraints at encoding may affect them differently than younger adults. For example, because the strategic processing of value is effortful and cognitively demanding (Elliott & Brewer, 2019), when rushed, there may not be sufficient time or resources to be intentionally selective in their encoding of the most valuable information. Although younger adults may be able to compensate with automatic processing, without the aid of automatic processing, older adults may struggle to devote their already limited cognitive resources to strategically processing value, resulting in impaired VDR under time constraints.

Despite the generally negative cognitive effects of aging, researchers have found that healthy older adults seem to become more selective in how they expend their resources (Baltes & Baltes, 1990; Hess, 2014; Riediger & Freund, 2006). This is reflected in their selectivity for valuable information during the study, which has been found to be comparable with that of younger adults (Castel et al., 2012, 2013; Middlebrooks, McGillivray, et al., 2016). This trend appears across multiple memory domains with older adults benefitting from value in visuospatial and verbal associative long-term memory (Ariel et al., 2015; Hennessee et al., 2018; Siegel & Castel, 2018) and visual working memory (Allen et al., 2021). In fact, Allen et al. (2021) manipulated encoding time and found that older adults were just as effective at prioritizing the high-value items as younger adults, regardless of encoding time (500 ms vs. 1,000 ms). Thus, because older and younger adults exhibit comparable selectivity for high-value information under normal conditions and maintain this selectivity regardless of encoding time with visual working memory (Allen et al., 2021), it is possible that older adults will show the same pattern of preserved VDR with long-term memory when faced with time constraints at encoding as younger adults.

Time constraints at encoding may potentially enhance older adults' ability to better remember high- rather than low-value information. Prior work suggests that, when given sufficient time at encoding, older adults are selective in their memory for the highest valued items (for recent reviews, see Castel, 2023; Knowlton & Castel, 2022), potentially in part due to older adults' metacognitive awareness and experience with memory limitations which may prompt them to strategically encode words based on their value (Siegel & Castel, 2019). However, when constrained by time limitations at encoding, older adults' metacognitive awareness of their low recall ability (especially given these circumstances) may be enhanced, causing them to adapt their already selective encoding strategy to focus only on a few of the most valuable words. By narrowing their attention to a small amount of the most valuable information, older adults could forego allocating cognitive resources to encoding more words, leaving additional resources to implement their selective strategy. Although only a few words would be recalled, these words would be the most valuable, resulting in time constraints for encoding and enhancing older adults' selectivity.

Retrieval of valuable information is another process that may be affected by limited time and may yield age-related differences in performance. In typical VDR studies without time constraints, younger and older adults tend to initiate recall with high-value items rather than low-value items (Murphy & Castel, 2022b; see also Murphy et al., 2023; Stefanidi et al., 2018), likely contributing to their overall selective recall by value. However, if given only a limited amount of time at retrieval, organizing recall for the high-value items first becomes even more important because all remembered words may not be outputted in time. However, it is possible that time constraints may affect one's ability to implement this retrieval strategy.

Indeed, Craik et al. (1996) theorized that retrieval processes require even more substantial cognitive resources than encoding processes based on the evidence of slower retrieval times and worse secondary task performance when under divided attention at retrieval (Johnston et al., 1972). Other work has also shown interference effects at retrieval when the two tasks overlap in terms of information similarity (Fernandes & Moscovitch, 2000). These attentional demands of retrieval have been found to be even greater as we age (Anderson et al., 1998; Hou et al., 2022) and combined with older adults' diminished working memory capacity, which has been found to negatively affect the ability to use strategies at recall (Unsworth et al., 2012), time constraints may produce even greater decrements on older adults' selectivity when rushed. For example, when rushed, older adults may not have the time they need to implement a retrieval strategy that prioritizes value such as outputting the most valuable words first. Without such a strategic retrieval organization, older adults may output lower valued words but run out of time before they can output the more valuable words. This would mean that time constraints at retrieval worsen selectivity for older adults due to insufficient time and available cognitive resources to engage in selective remembering strategies (see the strategic use of value in Knowlton & Castel, 2022).

However, it is also possible that older adults' selectivity may not be affected by time constraints at retrieval. Older adults' preserved selectivity under normal conditions could be attributed to their retrieval organization such that, like younger adults, they tend to output high-value items before low-value items. In addition, prior work has found that the average value of older adults' first recalled word was even greater than younger adults (Murphy & Castel, 2022b). These retrieval strategies may be the result of older adults' adeptness at using memory strategies to offset memory loss in daily life (Hertzog & Dunlosky, 1996; Swirsky & Spaniol, 2019). If this is true, even though retrieval processes may be more cognitively demanding than encoding (Craik et al., 1996), older adults' expertise with compensatory memory strategies may allow for a preserved, or perhaps even enhanced, ability to remember the most valuable information when under time constraints at retrieval.

The Present Study

The present work investigated the effects of time constraints on VDR in younger and older adults. In two experiments, older and younger participants were either under time constraints at encoding (Experiment 1) or retrieval (Experiment 2) to see whether participants' tendency to remember high-value words at the expense of low-value words was impacted when short on time.

Experiment 1

In Experiment 1, participants studied 12 lists of 20 words. Each word from these lists was randomly associated and presented with a point value ranging from 1 to 10. Thus, each list had two words assigned to every point value. The incentive structure was such that if a participant recalled a word during the test phase, they earned its associated point value. Participants were prompted to remember as many words as they could while aiming to maximize their score. Following the presentation of each list, participants immediately underwent a free recall test. After each test, participants received feedback on their score for that list out of a maximum of 110 points. To probe the effects of time constraints during encoding on memory selectivity, participants were split into two conditions: "constant slow" and "rushed." Those in the "constant slow" condition were allocated 5 s per word for the first eight lists. In contrast, the "rushed" group had 5 s for the initial four lists and just 1 s per word for Lists 5–8. For the last four lists (9–12), all participants self-paced their study time for each word. For analysis, the 12 lists were segmented into three groups: Segment 1 (Lists 1–4), Segment 2 (Lists 5–8), and Segment 3 (Lists 9–12).

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 at https://osf.io/p9fdq/?view_only=5587c1c099394a1c813a07de7abfc391. Data were analyzed using JASP, and all information needed to reproduce the analyses is available. This study's design and its analysis were not preregistered. Informed consent was acquired, and the study was completed in accordance with the University of California Los Angeles (UCLA) Institutional Review Board (Memory, Attention, Emotion, and Aging: IRB No.12-000617).

Participants

Younger adults were recruited from the UCLA Human Subjects Pool and completed the experiment in 2021. They were tested online and received course credit for their participation. Because younger adults were tested online, they were excluded from analysis if they admitted to cheating (e.g., writing down answers) in a posttask questionnaire (they were told they would still receive credit if they cheated). This exclusion process resulted in five exclusions. Older adults were recruited from the Los Angeles area via fliers posted throughout the community and through the UCLA Cognition and

Aging Laboratory participant pool. The older adults participated in person from 2015 to 2017 and received monetary compensation at a rate of $10 per hour. Our sample size (younger adults: $n = 58$; older adults: $n = 47$) was based on prior work with a similar design (see Murphy & Castel, 2022a). Demographic information for Experiments 1 and 2 is provided in Table 1.

Materials

Stimuli consisted of 12 lists with 20 words per list. Each word was randomly paired with a point value ranging from 1 to 10, such that two words in each list had the same point value (consistent with prior work; see Middlebrooks, Murayama, & Castel, 2016). The 240 words that each participant saw were randomly selected without replacement from a word bank of 280 words to avoid potential item effects (Murayama et al., 2014). All the words were nouns or verbs and their lengths ranged from 4 to 7 letters. Collectively, the words averaged 8.81 ($SD = 1.57$) on the log-transformed hyperspace analog to language frequency scale (Lund & Burgess, 1996) and ranged from 5.48 to 12.65. The words also averaged 5.22 ($SD = 0.78$; range: 2.71–7.76) on the emotional valence scale used in Warriner et al. (2013), which measured the emotional valence of words on a scale of 1 (*very positive*) to 9 (*very negative*) with 5 indicating neutral valence.

Procedure

Participants were told that they would be shown 12 lists of 20 words, and each word would be randomly paired with a point value between 1 and 10 such that each point value was shown twice in each list. For example, in each list, two words out of the 20 words in a list would be worth 10 points if correctly recalled at test, and this was true for the rest of the point values (i.e., 1–9) such that two words in each list would worth the same value. The value of a given word varied randomly across participants such that for one participant "bunch" could be worth 3 points, for another participant "bunch" could be worth 9 points, and some participants may not see the word "bunch" at all.

Participants were informed that if they remembered a word on the test, which occurred immediately after the presentation of each list, they would receive the points paired with the word. Participants were instructed to remember as many of the words in each list as possible while also striving to achieve a maximal score. Participants were told that the words would be presented on the screen one at a time and they were told how long they would have to study each word before each list. After the words in each list were presented, participants engaged in a free recall test where they had to spend a minimum of 30 s on the test before a button appeared that allowed them to move on to the next list when they were ready. We set a minimum time in efforts to prevent participants from simply clicking through the test. Participants could spend a maximum of 90 s to recall remembered words; however, once 90 s had passed, the task automatically moved on to the next list which is consistent with prior VDR work (e.g., Middlebrooks, Murayama, & Castel, 2016). Participants recalled words by typing them into an on-screen text box. To account for typographical errors in participants' responses, we employed a real-time textual similarity algorithm where responses with at least 75% similarity to the correct answer were counted as correct. Immediately following the recall test, participants were told the score they received out of a total of 110 possible points

Table 1
Demographic Information for Experiments 1 and 2

Demographic categories	Experiment 1		Experiment 2	
	YAs	OAs	YAs	OAs
n	58	47	94	91
Gender				
Female	39	28	72	57
Male	19	19	22	33
Other	0	0	0	1
Age				
Average age	20.41 (1.64)	71.48 (7.42)	20.12 (1.54)	72.11 (5.68)
Age range	18–27	60–88	18–27	60–87
Race/ethnicity				
American Indian/Alaskan Native	0	0	1	0
Asian/Pacific Islander	21	4	35	1
Black	2	3	4	5
Hispanic	13	2	23	2
White	18	39	24	83
Other/unknown	4	1	7	0
Education				
Some high school	0	n/a	1	3
High school graduate	12	n/a	14	19
Some collegiate education (no degree)	30	n/a	57	21
Associate's degree	3	n/a	17	9
Bachelor's degree	13	n/a	5	21
Graduate degree (master's, doctorate, etc.)	0	n/a	0	18
Fluent in English	58	n/a	94	91

Note. Standard deviations for the mean ages are in parentheses. For the category "race/ethnicity," participants could choose one or more categories. YAs = younger adults; OAs = older adults; n/a = not collected information.

(i.e., with 20 words per list and each value appearing twice in the list, the total possible score would be 10 + 10 + 9 + 9 … 1 + 1 = 110).

To manipulate the experience of feeling rushed at encoding, participants were randomly assigned to one of two conditions: constant slow ($n = 29$ younger adults, $n = 24$ older adults) or rushed ($n = 29$ younger adults, $n = 23$ older adults). In the constant slow condition, to allow for sufficient time to elaboratively rehearse and encode the words, participants were given 5 s to study each word (e.g., Castel et al., 2007; Middlebrooks, Murayama, & Castel, 2016) for the first eight lists. In the rushed condition, participants were allotted 5 s of study time per word for the first four lists and then were given 1 s of study time per word for the next four lists (Lists 5–8). For Lists 9–12, all participants were allowed to self-pace their study time such that they decided for how long they wanted to study each word. For analysis and clarity purposes, the 12 lists were broken down into three segments: Segment 1 (Lists 1–4), Segment 2 (Lists 5–8), and Segment 3 (Lists 9–12).

Results

Recall

A 2 (age: young, old) × 2 (study rate: constant slow, rushed) × 3 (segment: 1, 2, 3) mixed analysis of variance (ANOVA) revealed a main effect of age, $F(1, 102) = 42.56$, $p < .001$, $\eta_p^2 = .29$, such that younger adults recalled a greater proportion of words ($M = .44$, $SD = 0.18$) than older adults ($M = .25$, $SD = 0.10$). There was no main effect of study rate, $F(1, 102) = .90$, $p = .346$, $\eta_p^2 < .01$; however, there was a main effect of segment, Mauchly's $W = .91$, $p = .009$; Huynh–Feldt corrected results: $F(1.87, 190.74) = 19.76$, $p < .001$, $\eta_p^2 = .16$, such that recall in Segment 1 ($M = .36$, $SD = 0.17$) and Segment 3 ($M = .38$, $SD = 0.21$) was significantly greater than recall in Segment 2 ($M = .31$, $SD = 0.18$; both $p_{\text{holm}} < .001$). In addition, the analysis found an interaction between segment and study rate, Huynh–Feldt corrected results: $F(1.87, 190.74) = 21.11$, $p < .001$, $\eta_p^2 = .17$, and post hoc analyses revealed that the constant slow condition remembered significantly more words in Segment 2 than the rushed condition in Segment 2 ($p_{\text{holm}} = .013$). The effect size, as measured by Cohen's d, was $d = .65$, indicating a medium–large effect. However, there was no significant interaction between age and study rate, $F(1, 102) = 1.20$, $p = .275$, $\eta_p^2 = .01$, or age and segment, Huynh–Feldt corrected results: $F(1.87, 190.74) = 1.47$, $p = .232$, $\eta_p^2 = .01$, and there was no three-way interaction among age, study rate, and segment, Huynh–Feldt corrected results: $F(1.87, 190.74) = .21$, $p = .794$, $\eta_p^2 < .01$. A sensitivity analysis indicated that with our sample size, we had an 80% chance of detecting a *medium* (Cohen's $d = .550$) difference between younger and older adults. In addition, when assuming $\alpha = .05$ and power = .80 and a Huynh–Feldt nonsphericity correction of .935 with an actual correlation of $r = .833$ between repeated measures, our study design could detect a *small* effect size (Cohen's $d = .167$) for an interaction between age (young, old), study rate (constant slow, rushed), and segment (1–3). These findings are consistent with previous literature that has found that older adults experience impairments in recall compared with younger adults (Salthouse, 1996, 2000, 2019) and confirm that having less time to encode the words during the study phase has a detrimental effect on recall. Younger and older adults' average recall performance for each segment (along with their average recall performance in Experiment 2) is provided in Table 2.

Table 2
Average Recall Performance in Experiments 1 and 2

Condition	Younger adults		Older adults	
	M	*SD*	*M*	*SD*
Experiment 1				
S1—constant slow	0.456	0.202	0.247	0.103
S1—rushed	0.439	0.139	0.281	0.116
S2—constant slow	0.464	0.22	0.251	0.1
S2—rushed	0.322	0.133	0.186	0.076
S3—constant slow	0.478	0.223	0.24	0.118
S3—rushed	0.461	0.196	0.283	0.16
Experiment 2				
Unhurried	0.39	0.16	0.321	0.158
Rushed	0.307	0.075	0.144	0.057

Note. S1 = Segment 1, S2 = Segment 2, and S3 = Segment 3.

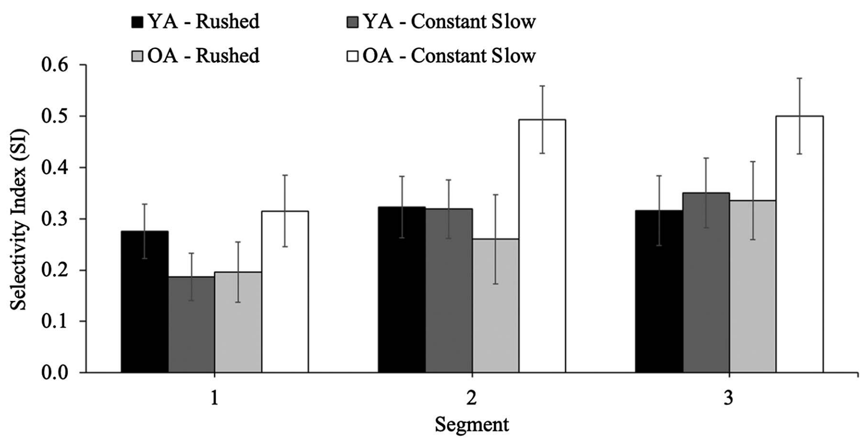
Recall Selectivity

To measure whether participants remembered the high-value words better than the low-value words, we utilized a selectivity index. The selectivity index is a metric that looks at a given participant's score in relation to their ideal and chance scores. A participant's ideal score is the score the participant would have received if they recalled only the highest valued words. For example, if a participant remembered three words, then ideally those words would be paired with the three highest values (10, 10, 9). Thus, the ideal score in this scenario would be 29. A participant's chance score is the average value of the points in the list (5.5) multiplied by the number of recalled words. If a participant only recalled words paired with the highest values, then their score would be equivalent to the ideal score and their resulting selectivity score would be 1. However, if a participant only recalled words paired with the lowest values, then their resulting selectivity score would be −1. Scores close to 0 indicate that a subject was not sensitive to the point values and was not selective (for more details, see Castel et al., 2002).

Participants' selectivity, as measured by the selectivity index, as a function of age, study rate, and segment is shown in Figure 1. We conducted a 2 (age: young, old) × 2 (study rate: constant slow, rushed) × 3 (segment: 1–3) mixed ANOVA. This analysis revealed that there was no main effect of age, $F(1, 100) = .89$, $p = .347$, $\eta_p^2 = .01$, such that there were no significant differences in selectivity between younger ($M = .28$, $SD = 0.28$) and older adults ($M = .35$, $SD = 0.33$). There was also no main effect of study rate, $F(1, 100) = 1.73$, $p = .191$, $\eta_p^2 = .02$; however, there was a main effect of segment, $F(2, 200) = 14.03$, $p < .001$, $\eta_p^2 = .12$, and post hoc analyses indicated that participants were significantly more selective in Segments 2 and 3 than Segment 1 (both $p_{\text{holm}} < .001$). The effect sizes, as measured by Cohen's d are .318 and .396, respectively, indicating small–medium effects. Furthermore, there was no significant interaction between age and study rate, $F(1, 100) = 2.75$, $p = .100$, $\eta_p^2 = .03$, or study rate and segment, $F(2, 200) = 2.05$, $p = .131$, $\eta_p^2 = .02$, and there was no three-way interaction between age, study rate, and segment, $F(2, 200) = .53$, $p = .589$, $\eta_p^2 < .01$. In addition, a sensitivity analysis indicated that with our sample size, assuming $\alpha = .05$ and power = .80, we had an 80% chance of detecting a medium (Cohen's $d = .552$) effect size for the interaction between age and study rate. Furthermore, a sensitivity analysis for the interaction between age (young, old), study rate (constant slow, rushed), and segment (1–3), with an actual correlation of $r = .688$ between

Figure 1

Recall Selectivity, as Measured by the Selectivity Index, as a Function of Age, Study Rate, and Segment in Experiment 1



Note. Error bars reflect the standard error of the mean. YA = younger adults; OA = older adults.

repeated measures, our study design could detect a small-to-medium effect size (Cohen's d = .234) for the interaction.

As shown in Figure 1, it is surprising that we did not find the interaction between age and study rate to be significant. Thus, to further probe this null effect, we computed Bayes factor (a ratio of the marginal likelihood of the null model and a model suggesting that there are group differences; Love et al., 2019) compared with the null model and found that BF_{01} = 1.27. We used BF_{01} because our prior inferential statistics favored the null hypothesis. Based on Lee and Wagenmakers (2014) guidelines for Bayes factor interpretations, we interpret that values greater than 3 would provide support for the lack of effect, whereas values less than .33 would provide support for the effect. Thus, with our BF_{01} of 1.27, we have ambiguous support for a lack of an interaction between age and study rate; however, given the ambiguous support and our study design only having enough power to detect a medium effect size for this interaction, it is possible that there may be a small interaction but our study did not have enough power to detect it. Altogether, these findings support previous literature that older adults either have preserved or enhanced selectivity compared with younger adults (Castel et al., 2002; Murphy & Castel, 2022a) and that selectivity improves with task experience (McGillivray & Castel, 2011).

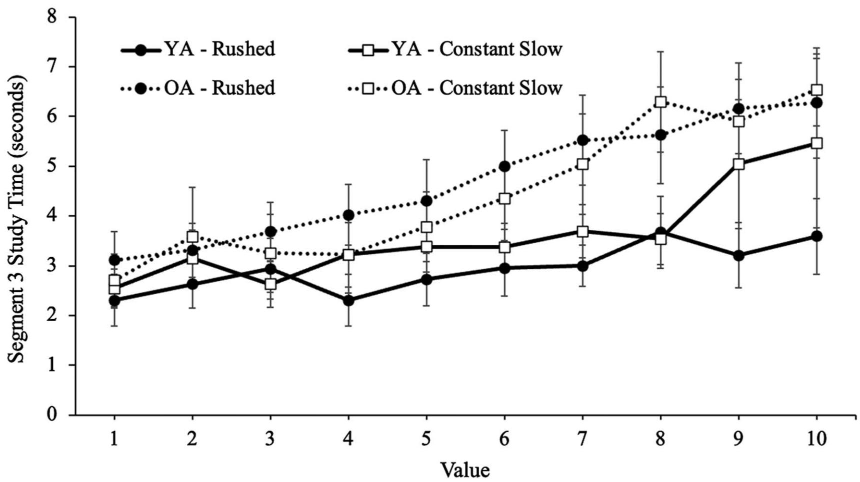
Recall Order

In addition, we conducted a 2 (age: young, old) × 2 (study rate: constant slow, rushed) × 10 (point value: 1, 2, 3, … 10) mixed ANOVA on the average output order of the recalled words in Segment 2 (e.g., the first word that a participant correctly recalls would have an output order value of 1, whereas the fourth correctly recalled word would have an output order value of 4) to investigate whether time constraints at encoding and/or age affected the role that value may play in recall output. Critically, we only used the data from Lists 5–8 (Segment 2) because this was the only segment where time constraints at encoding were manipulated. The analysis revealed no main effects of age, $F(1, 31) = 1.06, p = .310, \eta_p^2 = .033$, or study rate, $F(1, 31) = 2.83, p = .102, \eta_p^2 = .084$. Furthermore, we found no significant interaction between age and study rate, $F(1, 31) = .27, p = .610, \eta_p^2 = .008$. We did not find a significant main effect of point value on output order, $F(9, 279) = 1.35, p = .213, \eta_p^2 = .042$. In addition, we did not find significant interactions between age and point value, $F(9, 279) = .99, p = .446, \eta_p^2 = .031$, or study rate and point value, $F(9, 279) = 1.62, p = .108, \eta_p^2 = .050$. However, there was a significant three-way interaction with point value, age, and study rate, $F(9, 279) = 2.07, p = .032, \eta_p^2 = .063$, but none of the post hoc tests (with a Holm correction) reached significance. A sensitivity analysis indicated that with our sample size, assuming $\alpha = .05$ and power = .80, and an actual correlation of $r = .654$ between repeated measures, our study design could detect a small effect size (Cohen's d = .178) for an interaction between age (young, old), study rate (constant slow, rushed), and value (1, 2, 3 … 10).

Self-Regulated Study Time

Average study time per word in Segment 3 as a function of age, (prior) study rate, and point value is shown in Figure 2. We conducted a 2 (age: young, old) × 2 (study rate: constant slow, rushed) × 10 (point value: 1, 2, 3, … 10) mixed ANOVA. The analysis revealed a main effect of age, $F(1, 102) = 4.91, p = .029, \eta_p^2 = .05$, such that the older adults (M = 4.58 s, SD = 3.09) spent more time studying the words in Segment 3 than the younger adults (M = 3.27 s, SD = 2.96), ($p_{holm} = .029, d = .338$). There was no main effect of previous study rate, $F(1, 102) = .14, p = .713, \eta_p^2 < .01$, suggesting that starting off with 5 s of study time and then being reduced to 1 s of study time did not significantly influence later self-regulated study decisions. There was a main effect of point value, Mauchly's $W < .01, p < .001$; Huynh–Feldt corrected results: $F(3.12, 318.05) = 14.38, p < .001, \eta_p^2 = .12$, such that the highest valued words (8–10) were studied for a greater duration of time than the lowest valued words (1–3; all $p_{holm} < .001$, all $d > .415$). There was no significant interaction between age and prior study rate, $F(1, 102) = .58, p = .448, \eta_p^2 < .01$, age and point value [Huynh–Feldt corrected results: $F(3.12, 318.05) = 1.85, p = .136$,

Figure 2
Self-Regulated Study Time in Segment 3 as a Function of Age, Value, and Prior Study Rate in Experiment 1



Note. Error bars reflect the standard error of the mean. YA = younger adults; OA = older adults.

$\eta_p^2 = .02$, or point value and prior study rate, Huynh–Feldt corrected results: $F(3.12, 318.05) = .75$, $p = .528$, $\eta_p^2 < .01$. There was no significant interaction between age and prior study rate, $F(1, 102) = .58$, $p = .448$, $\eta_p^2 < .01$. There was also no three-way interaction between age, prior study rate, and point value, Huynh–Feldt corrected results: $F(3.12, 318.05) = .76$, $p = .525$, $\eta_p^2 < .01$. A sensitivity analysis indicated that with our sample size, assuming $\alpha = .05$ and power = .80, and with a Huynh–Feldt nonsphericity correction of .346 and an actual correlation of $r = .623$ between repeated measures, our study design could detect a small-to-medium effect size (Cohen's $d = .260$) for an interaction between age (young, old), prior study rate (constant slow, rushed), and value (1, 2, 3 … 10). Although the three-way interaction between age, prior study rate, and point value (range: 1–10) was not statistically significant, there was a lot of variability in the data, and it may be valuable to conduct a focused analysis targeting the extreme point values to better understand any potential shifts in study time allocation as a function of age and prior study rate. By examining how study time allocation changes specifically for low- and high-value words, we can assess whether older adults allocate more study time to high-value items and whether this effect is influenced by the time constraints experienced during encoding.

To examine how study time for the extremes of low value (e.g., 1 and 2 points) and high value (9 and 10 points) and how they are modulated by age and prior study rate, we conducted a 2 (value: low [1 and 2 points], high [9 and 10 points]) × 2 (age: young, old) × 2 (study rate: constant slow, rushed) mixed ANOVA. Results indicated that there was a main effect of value, $F(1, 102) = 25.48$, $p < .001$, $\eta_p^2 = .20$, indicating that younger and older adults spent more time studying the highest valued words (9 and 10 points) than the lowest valued words (1 and 2 points; $p_{\text{holm}} < .001$, $d = .542$). Unlike the previous analysis that included the entire range of point values, there was no significant main effect of age group, $F(1, 102) = 2.89$, $p = .092$, $\eta_p^2 = .03$. In addition, there was no significant main effect of prior study rate, $F(1, 102) = .59$, $p = .446$, $\eta_p^2 < .01$, and no significant interactions between value and prior study rate, $F(1, 102) = .68$, $p = .410$, $\eta_p^2 < .01$, value and age, $F(1, 102) = 2.15$, $p = .146$, $\eta_p^2 = .02$, and age and condition, $F(1, 102) = .65$, $p = .420$, $\eta_p^2 < .01$. There was also no significant three-way interaction between value, prior study rate, and age, $F(1, 102) = .56$, $p = .454$, $\eta_p^2 < .01$. A sensitivity analysis indicated that with our sample size, assuming $\alpha = .05$ and power = .80, and with an actual correlation of $r = .491$ between repeated measures, our study design could detect a small-to-medium effect size (Cohen's $d = .332$) for an interaction between age (young, old), study rate (constant slow, rushed), and value (low, high). Although the interaction between value and age was not significant, we further probed this effect to look specifically at whether study time allocation between younger and older adults differed for the highest valued words; however, this difference was not significant ($p_{\text{holm}} = .082$, $d = .434$). These additional analyses suggest that older adults do not allocate significantly more study time to the highest valued items compared with the lowest valued items than younger adults, and this remains true regardless of prior experience with time constraints at encoding.

Discussion

To examine whether there are age-related differences in how time constraints at encoding affect selectivity, we tasked younger and older adults with remembering words paired with point values and manipulated their study time for the words to induce the experience of being rushed. Although older adults displayed age-related declines in overall recall compared with younger adults, their selectivity was preserved. We also found that older adults appeared to compensate for their age-related processing efficiency deficits (Salthouse, 1996) by spending more time studying the words than younger adults when they had control of their study time in Segment 3. Further analyses revealed that despite more overall study time, older adults spent a similar amount of time studying the highest valued words as younger adults, suggesting that this compensation was not selectively allocated to the most valuable words. Collectively, these findings show that, even when short on time, older adults remain selective and may even use compensatory mechanisms to mitigate age-related cognitive deficits to remember more information (although this may not be influenced by value).

Experiment 2

The results from Experiment 1 support previous findings that selectivity is preserved with age (Castel et al., 2012, 2013; Middlebrooks, McGillivray, et al., 2016) and present new evidence for this ability remaining intact even under time pressures during encoding. However, prior work indicates that encoding and retrieval differentially contribute to memory selectivity (Murphy et al., 2023). In addition, the retrieval process may be more attentionally demanding than encoding (Craik et al., 1996; Johnston et al., 1972) and may affect younger and older adults' selective recall of the most valuable information. For example, in Experiment 1 and prior work (e.g., Murphy & Castel, 2022b; Stefanidi et al., 2018), younger and older adults organize their output such that the higher valued words tend to be outputted before lower valued words. However, if given insufficient time to recall all remembered words, this selective retrieval strategy may not have the time to be implemented (e.g., participants may recall any words that readily come to mind, irrespective of their value, simply to secure some points), resulting in reduced selectivity. On the other hand, time constraints during recall may enhance metacognitive awareness of the limited number of words that can be outputted, engaging selective retrieval strategies sooner and preserving or even enhancing selectivity. Altogether, it is unclear whether selectivity is affected by time pressure at retrieval. In Experiment 2, we examined whether time constraints at retrieval affect younger and older adults' ability to selectively recall valuable information and potential age-related differences in this effect. Specifically, participants studied each word for 3 s and after studying each list, participants either had a "rushed" retrieval time of 15 s, accompanied by a visible count-down clock, or an "unhurried" retrieval time of 1 min without a visible clock.

Method

Participants

Younger adults were recruited from the UCLA Human Subjects Pool. They were tested online and received course credit for their participation in 2021. Older adults from the United States were recruited from Amazon's Cloud Research (Chandler et al., 2019) and were paid to participate in 2021. Participants were excluded from analysis if they admitted to cheating (e.g., writing down answers) in a posttask questionnaire (they were told they would still receive credit if they cheated). This exclusion process resulted in one exclusion from the younger adult group and nine exclusions from the older adult group. With our sample size (younger adults: $n = 94$; older adults: $n = 91$) which we based on prior work with a similar design (Murphy & Castel, 2022a), we had an 80% chance of detecting a medium difference between younger and older adults and a medium effect size (both Cohen's $d = .414$) for the interaction between age (young, old) and retrieval time (rushed or not rushed), assuming $\alpha = .05$.

Materials and Procedure

The materials used were identical to those of Experiment 1. In Experiment 2, due to the time restrictions of online data collection on Cloud Research, we adapted the materials to consist of six lists of words with all participants having 3 s to study each word. As in Experiment 1, participants were instructed to remember as many of the words in each list as possible while also striving to achieve a maximal score. To study the effect that time constraints at retrieval had on selectivity, we split participants into two conditions: rushed ($n = 47$ younger adults, $n = 47$ older adults) and unhurried ($n = 47$ younger adults, $n = 44$ older adults). In the rushed condition, participants had 15 s after each list was presented to recall as many words from the just-shown list as they could remember. In addition, to increase feelings of being rushed, during the retrieval test, a clock counting down from 15 s was present at the top of the screen. In the unhurried retrieval condition, participants had 1 min during the retrieval tests and no clock was present. In both conditions, after the allotted retrieval time (15 s or 1 min) was up, their score was given. Participants were told how much time they would have for the retrieval test immediately prior to each test.

Results

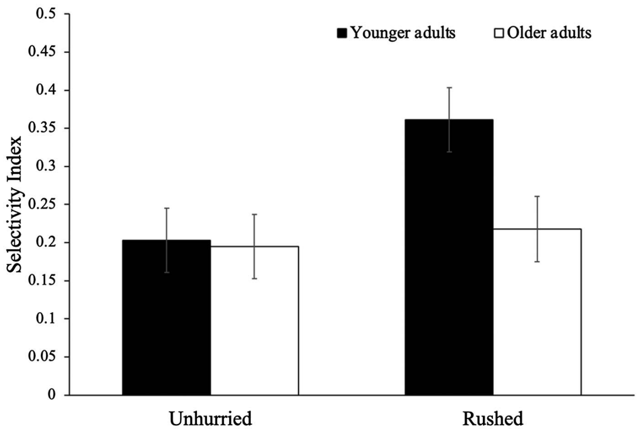
Recall

We investigated recall performance as a function of age and retrieval time via a 2 (age: young, old) × 2 (retrieval time: rushed, unhurried) mixed ANOVA. Results revealed a main effect of age, $F(1, 181) = 42.29$, $p < .001$, $\eta_p^2 = .19$, such that younger adults recalled a greater proportion of words ($M = .35$, $SD = 0.13$) than older adults ($M = .23$, $SD = 0.15$). In addition, there was a main effect of retrieval time, $F(1, 181) = 53.18$, $p < .001$, $\eta_p^2 = .23$, such that participants who had 1 min to recall the words (i.e., unhurried; $M = .36$, $SD = 0.16$) recalled a greater proportion of words than those who only had 15 s at retrieval (i.e., rushed; $M = .23$, $SD = 0.11$). There was an interaction between age and retrieval time, $F(1, 181) = 6.82$, $p = .010$, $\eta_p^2 = .02$, such that for both younger and older adults, the unhurried retrieval group had better recall than the rushed retrieval group; however, the magnitude of this effect (recall deficits from the reduced retrieval time) was less pronounced for younger adults ($p_{\text{holm}} = .003$, $d = .689$) than older adults ($p_{\text{holm}} < .001$, $d = 1.457$) as measured by Cohen's d. A sensitivity analysis indicated that with our sample size, assuming $\alpha = .05$ and power = .80, our study design could detect a medium effect size (both Cohen's $d = .414$) for the interaction between age (young, old) and retrieval time (rushed, unhurried). This suggests that older adults' output was more negatively affected by rushing at retrieval compared with the younger adults.

Recall Selectivity

To investigate whether selectivity differed among participants as a function of age and retrieval time (see Figure 3), we conducted a 2 (age: young, old) × 2 (retrieval time: rushed, unhurried) mixed ANOVA on participants' selectivity scores. The analysis revealed a main effect of retrieval time, $F(1, 180) = 5.10$, $p = .025$, $\eta_p^2 = .03$, indicating that participants who were given less time at retrieval had significantly higher selectivity scores ($M = .28$, $SD = 0.32$) than the unhurried participants ($M = .19$, $SD = 0.24$). There was also a main effect of age, $F(1, 180) = 4.40$, $p = .037$, $\eta_p^2 = .02$, such that older

Figure 3
Recall Selectivity, as Measured by the Selectivity Index, as a Function of Age and Retrieval Time in Experiment 2



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

adults were less selective ($M = .19$, $SD = 0.30$) than younger adults ($M = .27$, $SD = 0.26$). Importantly, the results indicated an interaction between age and retrieval time, $F(1, 180) = 5.40$, $p = .021$, $\eta_p^2 = .03$, with post hoc tests indicating that the younger adult participants who were given less time at retrieval had significantly higher selectivity scores than the younger adult participants with more retrieval time ($p_{\text{holm}} = .008$, $d = .676$), whereas older adults in both the unhurried and rushed retrieval groups were similarly selective ($p_{\text{holm}} > .999$, $d = .010$). In addition, post hoc tests further revealed that unhurried younger adults had selectivity comparable with the unhurried older adults ($p_{\text{holm}} > .999$, $d = .033$) as well as the older adults who were given less time at retrieval ($p_{\text{holm}} > .999$, $d = .024$).

Recall Order

In addition, we conducted a 2 (age: young, old) × 2 (retrieval time: rushed, unhurried) × 10 (point value: 1, 2, 3, … 10) mixed ANOVA on the average output order of the recalled words to investigate whether time constraints and/or age affected the role that value may play in retrieval. The analysis revealed main effects of value, $F(9, 6394) = 3.24$, $p < .001$, $\eta_p^2 = .005$, age, $F(1, 6394) = 151.02$, $p < .001$, $\eta_p^2 = .023$, and retrieval time, $F(1, 6394) = 576.18$, $p < .001$, $\eta_p^2 = .083$. Furthermore, we found a significant interaction between age and retrieval time, $F(1, 6394) = 53.23$, $p < .001$, $\eta_p^2 = .008$, which aligns with our analysis of recall performance that participants who had less retrieval time outputted less words than those with 1 min at the recall test (which is reflected in a lower average output order value) and that reduced retrieval time had a more detrimental effect on recall performance for older adults ($p_{\text{holm}} < .001$, $d = .883$) than younger adults ($p_{\text{holm}} < .001$, $d = .471$) as measured by Cohen's d. Interestingly, there was also a significant interaction between retrieval time and value, $F(9, 6394) = 2.09$, $p = .027$, $\eta_p^2 = .003$, with post hoc tests revealing that participants who had 1 min to recall the words outputted the highest valued words before the lowest valued words ($p_{\text{holm}} < .001$, $d = .348$) while value did not seem to have a significant influence on the output order of words for participants who had only 15 s at retrieval ($p_{\text{holm}} > .999$, $d = .079$). Last, we did not find a significant interaction between value and age, $F(9, 6394) = .79$, $p = .620$, $\eta_p^2 = .001$, or a three-way interaction with value, age, and retrieval time, $F(9, 6394) = 1.11$, $p = .353$, $\eta_p^2 = .002$. A sensitivity analysis indicated that with our sample size and an actual correlation of $r = .580$ between repeated measures, while assuming $\alpha = .05$ and power = .80, our study design could detect a small effect size (Cohen's $d = .146$) for an interaction between age (young, old), retrieval time (unhurried, rushed), and value (1, 2, 3 … 10).

Discussion

In Experiment 2, we investigated whether limited time at retrieval affects younger and older adults' ability to selectively recall high-value words. Results revealed that participants who were only given 15 s at retrieval recalled fewer words than participants who were given 1 min at retrieval, and older adults recalled fewer words overall than younger adults. Interestingly, although less retrieval time negatively impacted recall for both younger and older adults, this discrepancy was more severe for the older adult participants, suggesting that having less retrieval time may have a more detrimental impact on older adults' memory than for younger adults.[1] This aligns with prior work that has found that the retrieval process is more attentionally demanding for older adults which may have affected their ability to recall all the words they remembered (Anderson et al., 1998). Alternatively, this effect could be explained by older adults generally having a slower typing speed than younger adults (Krampe & Ericsson, 1996; Salthouse, 1984). This would mean that reduced retrieval time had a more detrimental effect on older adults' recall than younger adults because of age-related motor impairments (Welford, 1977) rather than because of retrieval limitations differentially affecting the cognitive processes of younger and older adults.

When looking at participants' ability to selectively remember the high-valued words, the younger adults who were given less time at retrieval were more selective than the younger adults in the unhurried condition as well as both older adult groups (i.e., rushed and unhurried). Regarding the older adults, the rushed and unhurried groups were similarly selective to each other as well as to the younger adults who were given 1 min at retrieval (i.e., unhurried). This suggests that the time pressure did not significantly impact older adults' selectivity despite the quantity of words recalled being less.

Last, we found that the order in which participants under time constraints in Experiment 2 recalled words was not significantly influenced by the value of the words and this was true for both younger and older adults. In contrast, younger and older adults who

[1] In Experiment 1, a 2 (age: young, old) × 2 (study rate: constant slow, rushed) mixed ANOVA on the average amount of time participants spent on each recall test revealed a main effect of age, $F(1, 102) = 12.65$, $p < .001$, $\eta_p^2 = .110$, such that older adults ($M = 60.5$ s, $SD = 24.0$) spent more time on each recall test than younger adults ($M = 48.5$ s, $SD = 20.5$; $p_{\text{holm}} < .001$, $d = .694$). This is consistent with the finding in Experiment 2 that less retrieval time had a greater negative effect on recall for older adults than younger adults because when able to self-regulate their retrieval time, the older adults took more time to recall the words than the younger adults. This analysis did not find a significant main effect of study rate, $F(1, 102) = 2.19$, $p = .142$, $\eta_p^2 = .021$, or an interaction between age and study rate, $F(1, 102) = 1.75$, $p = .189$, $\eta_p^2 = .017$.

had 1 min at the recall test had a similar tendency to output the highest valued words before the lowest valued words. Thus, our findings suggest that the ability to output remembered words based on value may be hindered by time constraints at retrieval for both younger and older adults.

General Discussion

For important decisions, such as whether to get a medication that has severe side effects or whether to give money to a potential scammer, it is essential that older adults, as well as anyone making an important decision, pay attention to and remember the most critical information (e.g., red flags), particularly when short on time. However, it was previously unclear how time constraints affected older adults' ability to selectively encode and remember valuable information. As such, the present studies had both younger and older adults participate in a typical VDR task such that they were instructed to remember words that were paired with point values and participants were either rushed at encoding (Experiment 1) or retrieval (Experiment 2).

In Experiment 1, we investigated how selectivity may differ based on study time and age when rushed at encoding by manipulating the amount of time participants had to study each word (5 s vs. 1 s). We found that selectivity did not significantly differ when rushed or when given sufficient study time for younger or older adults. In addition, the older and younger adults exhibited similar selectivity, suggesting that selectivity is a cognitive function that may be preserved with aging even under adverse conditions. Thus, the findings of Experiment 1 align with previous literature that has found that younger adults' selectivity is preserved even when rushed (Middlebrooks, Murayama, & Castel, 2016) and with past research that has found that younger and older adults have comparable selectivity (Castel et al., 2012, 2013; Middlebrooks, McGillivray, et al., 2016; for a recent review, see Castel, 2023). This could be because preserved metacognitive awareness and prior experience with compensating for age-related memory changes may mitigate the possible detrimental effects of limited encoding time on older adults' selectivity (e.g., not sufficient time or resources to engage in strategic processing).

Ultimately, older adults' preserved selectivity when rushed at encoding compared with younger adults indicates that the processes older adults use to engage in VDR do not seem to require what we previously viewed as "sufficient" encoding time. One might have thought that less encoding time would disproportionately impair older adults' ability to be selective due to older adults having limited cognitive resources to engage in strategic processing without the aid of automatic processing of value; however, our findings suggest that the selective strategies that older adults may use when engaging in VDR may not be as resource demanding as hypothesized and instead can be implemented very quickly. This would allow older adults to decide immediately whether they want to elaboratively encode the presented item and, if not, reallocate the time for deeper encoding of previously presented higher valued words. On the other hand, it is also possible that older adults automatically process value as well as younger adults which may make "sufficient" encoding time and time-consuming strategies unnecessary; however, more research is necessary to investigate this theory.

In Experiment 2, we examined how selectivity would be affected by time pressures at retrieval such that older and younger adult participants had either 1 min or 15 s to recall the words from each list. We found that although both younger and older adults recalled fewer words overall when given only 15 s to retrieve the studied words, older adults had a steeper decline in retrieval performance when rushed compared with younger adults. This makes sense given age-related motor impairments (Seidler et al., 2010), which likely manifest in slower typing speeds that would disproportionately impair older adults' ability to output remembered words in time. In addition, older adults tend to need more time to retrieve target information from long-term memory potentially due to slower processing speed (Salthouse, 1996, 2000, 2019) as well as interference from other irrelevant information in memory (inhibition deficit theory of cognitive aging; Hasher & Zacks, 1988) which may also explain their steeper decline in recall than younger adults.

We also found that older adults were similarly selective when given 1 min or 15 s to recall the words and exhibited selectivity comparable with the younger adults who were given 1 min to recall the words. Older adults' similar selectivity to the unhurried younger adults aligns with the findings of Experiment 1 and prior literature that has found that selectivity for valuable information is preserved with age. In contrast, we found that the younger adults who were rushed at retrieval exhibited enhanced selectivity compared with the other groups. The younger adults' selectivity, but not the older adults', may have benefitted from time constraints at retrieval because the rushed older adults may have struggled to update their VDR strategy (for a relevant review, see Gajewski et al., 2018) due to age-related impairments in executive control and monitoring (see Bieman-Copland & Charness, 1994; Bouazzaoui et al., 2010; Hultsch et al., 1988) and cognitive flexibility (Braver & West, 2008). Younger adults may have been able to update their VDR strategy when they realized that they would not be able to output all the words they remembered, whereas the rushed older adults may have simply maintained the same strategy that they would use without the time constraints at retrieval, resulting in preserved but not enhanced selectivity. Prior experience and metacognitive awareness of their memory limitations may enable older adults to engage in VDR but age-related impairments in executive functioning may prevent them from exhibiting enhanced selectivity when rushed at retrieval like the younger adults in Experiment 2.

When younger and older adults were rushed at retrieval, value did not play a significant role in their output order. We originally thought that strategic retrieval organization would be especially necessary when there are time constraints at retrieval compared with at encoding given the importance of outputting the highest valued words in the limited time to maximize their scores. However, the output order of the younger and older adults who were only given 15 s at recall was not significantly influenced by value, yet both these groups were at least as selective as the unhurried younger and older adults who did engage in strategic retrieval organization. It seems that selectivity when rushed at retrieval is more dependent on the value of the words that the participants choose to selectively encode rather than any strategies used at retrieval.

Overall, the findings of the two experiments differed regarding the effects of time constraints at encoding versus retrieval for younger adults', but not older adults', selectivity. Specifically, regardless of when the time constraints occurred, older adults maintained their selectivity; however, although younger adults also maintained their selectivity when rushed at encoding in Experiment 1, when rushed at retrieval in Experiment 2, younger adults showed enhanced selectivity.

Younger adults' enhanced selectivity in Experiment 2 but not in Experiment 1 seems somewhat counterintuitive given that the boost in selectivity when rushed at retrieval did not seem to be due to strategic retrieval organization but rather implementing a selective strategy during the encoding process. Perhaps this is due to younger adults having more experience with being rushed at retrieval resulting in the insufficient time at retrieval activating metacognitive awareness of the need to be more selective in which words they preferentially encode. If they realized that they can dedicate the cognitive resources that they would normally dedicate to boosting their recall to do a better job encoding just the highest valued words, this would likely contribute to their enhanced selectivity. This could also explain why they did not show much strategic retrieval organization because if they only outputted high-value items then value would not need to play as large of a role with output order.

Older adults may not have used this same strategy as effectively or at all because they likely have less experience with being rushed when retrieving information than younger adults who have probably taken timed tests in the recent past (e.g., standardized testing). Even so, older adults likely have experienced many instances when they do not have the time that they need to sufficiently encode all the information they want to remember. Thus, in Experiment 1, the older adults, regardless of time constraints, may have successfully been able to use the selective strategies that they have used in prior instances when overwhelmed by too much information to remember. However, in Experiment 2, the rushed older adults may not have had the experience necessary to update this strategy like the rushed younger adults, resulting in these older adults maintaining their selectivity but not benefitting from the time constraints like the younger adults. Thus, greater recent experience with time constraints when retrieving information that varies in value may be able to explain (at least partly) the age-related difference in the effect of time constraints at retrieval in Experiment 2 but no age-related difference in selectivity when rushed at encoding in Experiment 1. This explanation is speculative and would benefit from further research to directly examine how experience impacts age-related differences in rushing during encoding and retrieval.

It is also possible that older adults' selectivity may not benefit from less time at retrieval because of age-related cognitive impairments. For example, older adults have a smaller working memory capacity than younger adults which Schelble et al. (2012) have found to be an important factor that diminishes strategy use at retrieval. In addition, older adults have reduced processing speed (Salthouse, 1996, 2000, 2019) which may make it more difficult for older adults to use the strategies that they need to be selective in the limited time allocated for recall (for age differences in retrieval tendencies, see Murphy & Castel, 2022b). It is also possible that age-related changes in strategy updating may be a possible explanation for only the younger adults' selectivity, but not the older adults', benefitting from the time constraints at retrieval in Experiment 2. Older adults often struggle to retrieve information quickly from long-term memory (e.g., Brod et al., 2013; Burke & Shafto, 2004), perhaps due to older adults' large knowledge base which may cause high-value remembered words to be less accessible in memory than for younger adults (e.g., Brown & Nix, 1996; Dahlgren, 1998). In Experiment 2, the extra cognitive demands of retrieving remembered words under time constraints may have reduced the time and resources that older adults need to update their VDR strategy like the younger adults potentially did to boost their scores (and selectivity).

Together, the present two experiments show how healthy older adults can selectively optimize recall under various study and test conditions, in line with theories that emphasize how selectivity can lead to an efficient way to compensate for declines in cognitive function in older age such as the selective optimization with compensation theory (e.g., Baltes & Baltes, 1990; Hess, 2014; Riediger & Freund, 2006). In the present task, compensation may be achieved via longer self-regulated study time (see also Castel et al., 2013), and optimization can be achieved by focusing on fewer items but remembering these higher value items (e.g., Baltes & Baltes, 1990; Freund & Baltes, 2002). Although optimization and compensation play a connected role, the present task emphasizes how selectivity may engage these other processes. Thus, situations of rushing or limited encoding time may in fact engage selectivity by encouraging older adults to focus on fewer items and ensure that these words are recalled which would prioritize how their memory can be used.

Although the present studies' findings provide insight into how time constraints affect selectivity, there are limitations of the present work that may affect the interpretations we can make. For example, future research could examine how different operationalizations of rushing affect selectivity. We defined rushing as being under time constraints; however, the phenomenological experience of being rushed may involve more than limited time such as stress, emotion, and surprise, which may differentially affect older and younger adults' selectivity. This is particularly important to study when applying this research to real-life situations (e.g., scams) because it is likely that emotions and stress along with, and potentially caused by, time constraints may play a role in the detrimental effect that rushing has on decision making.

We note that the older adults who were tested had a much wider age range (60–88 years) than the younger adults (18–27 years), and thus there might be some important individual differences to consider in the older adult group (Zelinski & Stewart, 1998). In addition, we did not administer a formal screening procedure for dementia or self-report of neurocognitive conditions, and thus it is possible that some older adults who participated in the present experiments may have conditions that could influence performance (see Plassman et al., 2008). Future research could address how older adults of different ages perform in the present task and control for neurodegenerative conditions that may influence performance under time constraints.

In addition, in the present experiments, we explicitly instructed participants to try to maximize their scores, thus encouraging them to remember the high-value words compared with the lower valued words; however, outside of the laboratory, there are not always external cues that emphasize being selective in their memory for the most important information. We also collected data online for both Experiments 1 and 2 and although we excluded participants who reported cheating, it is possible that the data quality may be worse than in-person data collection and thus not reflect what actually occurs in daily life (for an overview of potential advantages and disadvantages of online data collection, see Greene & Naveh-Benjamin, 2022). Future studies may want to include additional data quality measures such as using attention check questions and supplementing the online data collection with in-person data. This may be especially important in the present area of research given that the rewards in VDR tasks (and in the present study) are typically hypothetical such that participants' compensation is not affected by their scores (see Horn & Freund, 2022).

In summary, the present study investigated whether being short on time affects our ability to selectively encode and recall valuable information and whether this differs between younger and older adults. Such research is essential because remembering high-value information can be imperative for one's quality of life or even mortality, such as choosing health treatments and considering financial opportunities (e.g., scams and fraud; Holtfreter et al., 2014; Ross et al., 2014). In many of these situations, people do not have sufficient time to encode or retrieve all the information that they would like to remember. Thus, it is critical to know how people can encode and/or retrieve the information that is most important for making efficient and informed decisions. Ultimately, the present work generally indicated that selective memory is preserved in both younger and older adults when short on time at encoding and retrieval, providing preliminary insight into a cognitive ability that is maintained under adverse conditions despite age-related cognitive declines.

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