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Selecting Valuable Information to Remember: Age-Related Differences and Similarities in Self-Regulated Learning

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It is often necessary to selectively attend to important information, at the expense of less important information, especially if you know you cannot remember large amounts of information. The present study examined how younger and older adults select valuable information to study, when given unrestricted choices about how to allocate study time. Participants were shown a display of point values ranging from 1–30. Participants could choose which values to study, and the associated word was then shown. Study time, and the choice to restudy words, was under the participant's control during the 2-minute study session. Overall, both age groups selected high value words to study and studied these more than the lower value words. However, older adults allocated a disproportionately greater amount of study time to the higher-value words, and age-differences in recall were reduced or eliminated for the highest value words. In addition, older adults capitalized on recency effects in a strategic manner, by studying high-value items often but also immediately before the test. A multilevel mediation analysis indicated that participants strategically remembered items with higher point value, and older adults showed similar or even stronger strategic process that may help to compensate for poorer memory. These results demonstrate efficient (and different) metacognitive control operations in younger and older adults, which can allow for strategic regulation of study choices and allocation of study time when remembering important information. The findings are interpreted in terms of life span models of agenda-based regulation and discussed in terms of practical applications.

Keywords: metamemory, memory, aging, self-regulated study, value-directed remembering

We are often presented with more information than we can actually remember, and we need to rely on the ability to selectively attend to goal-relevant information. Thus, the ability to selectively encode and later retrieve valuable information is essential when trying to maximize memory performance in situations when we cannot remember all of the presented information. Previous research (Ariel, Dunlosky, & Bailey, 2009; Castel, 2008a; Castel, McGillivray, & Friedman, 2012; Soderstrom & McCabe, 2011) has shown that people can selectively remember high-value information and that this ability is preserved or even more pronounced in older adults (Castel et al., 2011). Ariel, Dunlosky, and Bailey's (2009) agenda-based regulation model of study time allocation suggests that control processes (such as the allocation of study time, and restudy choices) are affected by one's agendas, or goals. Specifically, they showed that reward (point values) superseded item difficulty as the basis for selecting items for study, as learners (younger adults) allocated greater study time to high-value items. This model has important theoretical and pedagogical implications but has yet to be fully examined with respect to age-related similarities or differences in agenda-based self-regulated learning. The present study examines how younger and older adults select valuable information to study, when given unrestricted choices about how to allocate study time, in a novel self-regulated learning paradigm. Given that older adults have memory deficits in various learning environments (Kausler, 1994), we were especially interested in whether older adults would selectively study high-value information in the interest of achieving optimal memory performance.

While *self-paced study* typically involves allowing people to determine how long they will study certain information, *self-regulated study* conditions allow people to also choose what information to study, in addition to how long to study it (see Bjork, Dunlosky & Kornell, in press, for a recent review). In the real world, how we learn new information is often under our own control (and involves self-regulated learning), suggesting that we have to monitor our memory (e.g., determine how well we know the target information) before we stop studying this information and turn to other information. In terms of self-paced study time, older adults may spend less than the necessary or optimal amount of time studying information that differs in difficulty (e.g., Froger, Bouazzaoui, Isingrini, & Taconnat, in press; Murphy, Sanders,

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Gabriesheski & Schmitt, 1981; Souchay & Isingrini, 2004). Thus, additional study time could potentially enhance learning and reduce age-related deficits in memory performance (Kausler, 1994). However, Dunlosky and Connor (1997) have shown that age differences in study time allocation can account for age differences in memory performance, suggesting that self-regulated learning, if implemented successfully, could enhance older adults' memory performance (see also Froger et al., in press).

In regard to self-regulation of study, Dunlosky and Hertzog (1997) examined younger and older adults' restudy selections of word pairs that varied in terms of difficulty of learning, after participants had studied and made initial judgments of learning for these pairs. Although older adults displayed poorer overall memory for the word pairs, both younger and older adults selected to restudy the word pairs that they had rated as least-well learned, demonstrating significant improvements in memory performance for these restudied items. Thus, both age groups had metacognitive awareness of the necessity to restudy information that was not well learned used additional study time to optimize learning. These results are consistent with a discrepancy-reduction hypothesis, in that people seek to restudy information that has yet to reach the desired level of learning. In addition, with task experience and sufficient training, older adults can learn to effectively study and test themselves such that they allocate necessary restudy to appropriate information (Dunlosky, Kubat-Silman, & Hertzog, 2003).

While previous research has examined age-related differences in self-paced learning in terms of item difficulty, very little work has examined age-related differences in self-regulated learning when item importance is manipulated. That is, can older adults strategically focus on remembering high-value or important information, given overall memory deficits? Price, Hertzog and Dunlosky (2010) found that both younger and older adults choose to study easier items first, relative to more difficult items, although this effect was reduced when more difficult items were assigned higher rewards for recall, consistent with both the region of proximal learning (Metcalfe & Kornell, 2005) and agenda-based regulation models of metacognitive control (Ariel, Dunlosky, & Bailey, 2009). Self-regulated learning typically involves a less constrained learning environment, where people can choose what, and how long, to study information for a later test (see also Bjork et al., in press). Under these conditions, older adults may need to be especially considerate of how many items should be studied in order to achieve optimal memory performance, if they are aware of their own memory constraints. In addition, efficient self-regulated learning strategies may be critical when encountering large amounts of information that vary in terms of importance to remember. Thus, to thoroughly study self-regulated learning and aging, it is important to consider the learning environment, value of the to-be-remembered items, and the metacognitive factors that can influence memory performance in younger and older adults.

Theoretical frameworks regarding selectivity and aging have stated that older adults engage in "selective optimization with compensation," allowing older adults to selectively focus on important goals and functions, at the expense of other tasks and activities (Baltes & Baltes, 1990; see also Bäckman & Dixon, 1992). As suggested by Riediger and Freund (2006), a more general form of "motivational" selectivity may involve *focusing* on high value/important information while also *restricting* access to lower value or more peripheral information. The ability to be selective can also enhance learning and metacognitive monitoring in older adults, consistent with the value-directed remembering framework (Castel, 2008a; Castel et al., 2011). Specifically, older adults can selectivity remember high-value information, and this involves the use of metacognitive monitoring regarding how much information can be remembered, feedback about performance and task experience (Castel, Benjamin, Craik, & Watkins, 2002; Castel et al., 2011). Using a selectivity index, in which memory efficiency can be measured in terms of remembering high-value words relative to lower-value words, older adults often show comparable levels of selectivity, despite recalling fewer words, relative to younger adults (e.g., Castel et al., 2002; Castel et al., 2009; see also Castel et al., 2011). Furthermore, McGillivray and Castel (2011) have shown that older adults can learn to selectively choose to remember high-value items in a manner that maximizes both memory performance and metacognitive accuracy, in the context of needing to selectively and strategically bet (as opposed to simply making less consequential predictions of learning) that they will remember these items. Thus, despite memory deficits, under some conditions older adult can efficiently learn to employ metacognitive strategies to enhance recall of selected information.

The present study examined how younger and older adults chose to study information that varied in value, to determine how self-regulated study could lead to efficient memory performance. Older adults may have a deficit in self-regulated learning if they are not aware of how to direct sufficient study time to enhance memory for higher-value words. We used a novel value-based encoding task, in which participants were presented with a matrix-like display that consisted of 30 point value place-holders (see Figure 1). Once a participant chose a point value to study, the associated word was displayed for the participant to view for as long as they liked. After participants had viewed the word, they were free to view other words by selecting the value on the screen, making this a value-guided selection process. Participants were free to choose as many value-word pairs to study during a two-minute period, and could also revisit items, before an immediate free recall test. After recalling the words, participants were informed of their score based on the value of the words recalled, and then engaged in five additional study-test sessions with new words.

We were most interested in whether younger and older adults could successfully engage in self-regulated learning, by choosing high-value items, directing more study time toward these items, and to also potentially sample these items more often (and especially immediately prior to the test), relative to lower-value items. Although older adults would likely remember fewer items overall (reflecting typical episodic memory impairments), more *strategic processes* that involve metacognition, such as studying an appropriate number of words and allocating sufficient time for high value words in order to facilitate later recall, may be aspects of self-regulated learning that are not impaired in old age. Thus, we were especially interested in whether older adults would focus selectively on fewer items to study, but more high-value items, demonstrating metacognitive knowledge about how to optimize memory performance in light of reduced recall ability. In contrast, younger adults may choose to study more items for relatively less time to maximize overall recall. The novel learning environment used in the present study allows for various measures of how people self-regulate study, such as time spent studying each word (the allocation of study time as a function of value), and if and

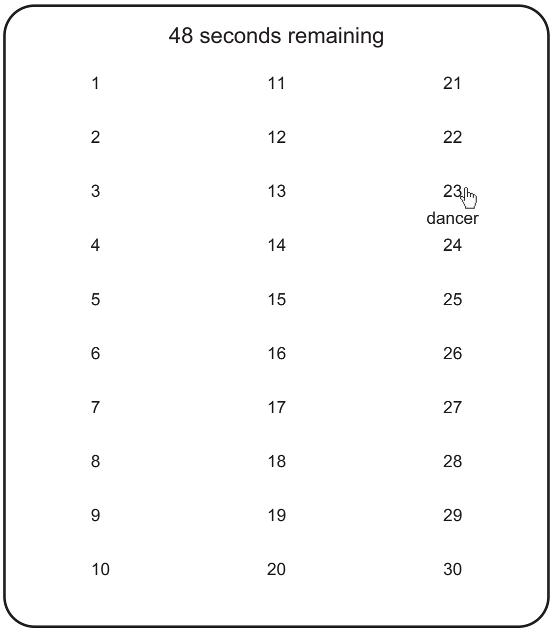

Figure 1. A sample display from the self-regulated learning task, in which participants could select any value-word pairs to study during the two-minute study session. When the participant selected the point value (by clicking on the value with the mouse), the word appeared until the participant selected a new value. In this example screenshot, the participant selected the 23-point word to study, which revealed the word "dancer", and 48 seconds were remaining in the study session.

when participants selected to restudy certain words. For example, recency effects can occur with immediate free recall such that participants remember the last few words that were studied, by maintaining these words in a short-term memory (STM) store (Murdock, 1962). Although recency effects are robust phenomena that can enhance memory (e.g., Murdock, 1962), only under certain circumstances are participants aware of the memorial benefits associated with recency items (Castel, 2008b; Crowder, 1969). We were specifically interested in whether younger and older adults might be aware of the benefits of studying high-value items immediately before the test (by monitoring the time-clock present on the display, see Figure 1) to capture the potential "high-yield" benefits of recency effects (see also Crowder, 1969), given that recency effects are often intact in older adults (Craik, 1994; Howard, Kahana, & Wingfield, 2006). In addition, we examined memory performance in terms of the mean value of the recalled items, to determine whether younger and older adults selectively remember high-value words relative to lower-value words, despite lower levels of recall by older adults (e.g., Castel et al., 2002; Castel, Balota & McCabe, 2009; Castel et al., 2011). Finally, we present a mediation analyses that attempts to illustrate how certain strategic factors (e.g., study time allocation to high value words and studying high-value words near the end of the study session) mediates value-directed remembering in younger and older adults. The examination of potential similarities and differences for younger and older adults on these measures of selectivity and self-regulated study were of direct interest, given predicted age-related differences in overall memory performance.

Method

Participants

The participants were 24 older adults (17 females, 7 males; average age = 73.9 years old) and 24 younger adults (21 females, 3 males; average age = 20.3 years old). Older adults were living independently in the Los Angeles area and recruited through community flyer postings as well as through the UCLA Cognition and Aging Laboratory Participant Pool. The older adults had good self-reported health ratings (M = 8.7 on a scale of 1–10 with 1 indicating *extremely poor health* and 10 indicating *excellent health*) and had 16.8 years of education. All older adults were proficient with using a computer mouse, and reported regular use of computer. Older participants were paid $10 an hour for their time and reimbursed for parking expenses. Younger adults were all University of California, Los Angeles undergraduates and received course credit for their participation.

Materials

One hundred eighty nouns, five to seven letters in length, were used as stimuli (e.g., paddle, flight, scale). The log mean hyperspace analog to language (or HAL, a model of semantics which derives representations for words from analysis of text; Burgess & Lund, 1997) average frequency of the words was 9.8 (range = 7.02–12.42), as obtained from the elexicon.wustl.edu Web site (Balota et al., 2007). The words were randomly assigned into one of six different lists, and each list contained 30 words. Within each list, words were randomly assigned a point value from 1 to 30. Each point value was only used once within a list. All stimuli were displayed on a computer.

Procedure

Participants were tested individually in private rooms, seated in front of a computer. Participants were told that they would be presented with six different lists of words, one list at a time, and that each list contained 30 words. They were informed that each word was paired with a number (a point value), and that this number indicated how much the word was "worth." They were told that the values ranged from 1–30. They were told that if they were later able to remember the words on an immediate free recall test, they would receive the points that were associated with those words. Participants were told that the goal was to try to get as many points as possible, and were encouraged to maximize their score (for a similar selectivity task and procedure, see Castel et al., 2002; Castel et al., 2009; Castel et al., 2011).

Once the experiment began participants were presented with three columns of numbers arranged by value (from 1–30) on the computer screen. Participants used the computer mouse to click on a number/point value of their choice, and a word then appeared directly below the number (see Figure 1 for an example). This word remained on the screen until the participant clicked on another value, at which point the previous word disappeared and the next word was displayed below its corresponding value. Thus, participants could view each word (one at a time) for as long as they liked and were not required to study all of the words. Furthermore, participants could restudy the words as many times as they chose. Participants had two minutes to study as many words as they wanted, in any order, and a timer indicating the amount of time remaining was displayed at the top of the screen during the task. At the end of the two minutes the participants were given one minute to verbally recall as many words as they could from the list (they did not need to recall the point values). Their responses were recorded by an experimenter. Immediately after this recall period, participants were informed of their score for the list but were not given feedback about specific items. Scores were calculated by summing the points associated with the words participants successfully recalled. The next list began after the scores were calculated and the feedback was provided (approximately 30 seconds later). The procedure was repeated until all six lists had been completed.

Results

The present experiment provided several important observations of how aging influences self-regulated learning in the context of remembering important information. We first present the amount of time participants spent studying each value (Figure 2A) and the proportion of words recalled as a function of value (Figure 2B) to show the overall picture of the results. We also summarized a variety of key statistics to compare the basic and strategic study behavior and performance of younger and older adults in more detail (see Table 1). Finally, we conducted a multilevel mediation analysis to disentangle the multivariate relationship between strategic behavior and recall performance. In the following analysis, the reported statistics are aggregated across the six lists, but all the possible list effects are incorporated and explored in the final mediation analysis. Effect size involving mixed model analysis of variance (ANOVA) was reported based on generalized eta squared statistics (η^2_G; Olejnik & Algina, 2003).

Study Time and Point Value

The mean study time as a function of point value for younger and older adults is displayed in Figure 2A. In this and the following analysis on study time, when an item was studied more than once, we computed the sum of study time for these multiple attempts. In the following ANOVAs, we binned the point values into groups of three, to reduced specific item effects and for clarity of presentation, consistent with prior research (e.g., Castel, Farb, & Craik, 2007; Soderstrom & McCabe, 2011). A 2 (Age Group) × 10 (Point Value) mixed-model ANOVA revealed a significant Age Group × Point Value interaction, $F(9, 414) = 4.60$, $MSE = 60.48$, $p < .01$, $\eta^2_G = .09$, as well as a significant main effect of Point Value, $F(9, 414) = 85.59$, $MSE = 60.48$, $p < .01$, $\eta^2_G = .65$. Post hoc tests revealed that whereas younger adults studied medium-value items (values 16–18, 19–21) significantly longer than older adults, $t(46) > 2.3$, $p < .05$, $d = 0.67$, older adults spent more time studying high value items (values 25–27, 28–30) than younger adults, $t(46) > 2.60$, $p < .05$, $d = 0.75$. These results indicate that younger adults distributed their study time across medium to high point values while older adults allocated a greater amount of study time toward the highest valued items.

We also conducted a supplementary analysis examining the number of restudy attempts as a function of point value. A 2 (Age Group) × 10 (Point Value) mixed-model ANOVA revealed a significant main effect of Age Group, $F(1, 46) = 32.41$, $MSE = 67.93$, $p < .01$, $\eta^2_G = .17$, and Point Value, $F(9, 414) = 84.28$, $MSE = 17.57$, $p < .01$, $\eta^2_G = .56$. These main effects were qualified by a significant Age Group × Point Value interaction, $F(9, 414) = 2.67$, $MSE = 17.57$, $p < .01$, $\eta^2_G = .04$. Post hoc tests revealed that younger adults restudied low- or medium-value items (values 1–3, 4–6, 7–9, 10–12, 13–15, 16–18, 19–21, and 22–24) more than older adults (ps $< .05$), but the age difference was not statistically significant for high-value items (values 25–27, 28–30;

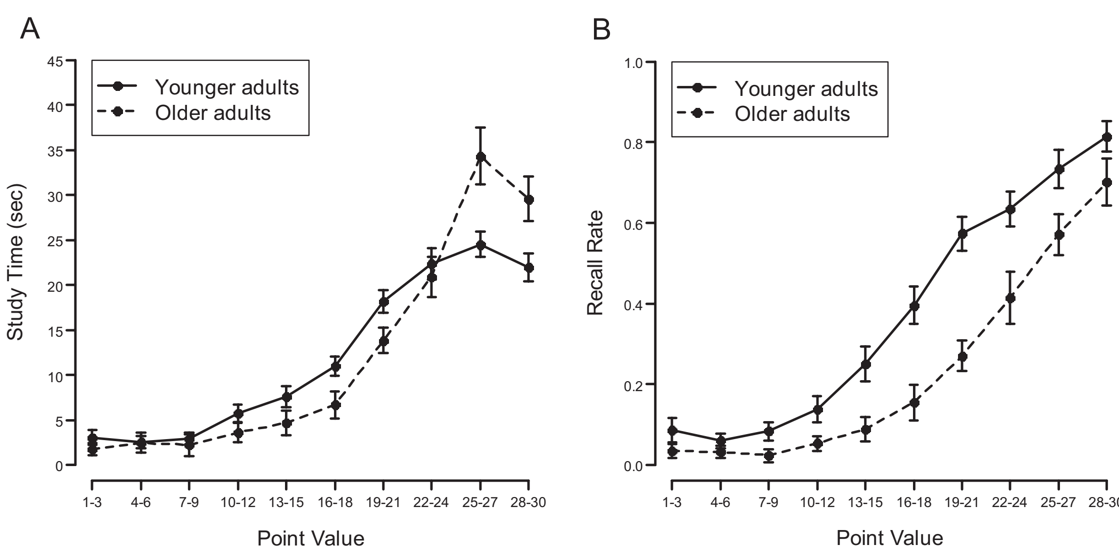

Figure 2. A, left panel: Mean study time (in seconds), averaged across lists, as a function of binned point values for younger and older adults. B, right panel: Mean proportion recalled, averaged across lists, as a function of binned point values for younger and older adults

Table 1
Study Behavior and Performance for Younger and Older Adults

	Basic study behavior and performance			Strategic behavior and performance				
	# Studied items	# Recalled items	Total point value	Average study time per item (in seconds)	Average point value per studied items	Percentage of studied items recalled	Average point value per recalled item	Point value of the last three studied items
Younger adults	**21.5 (6.6)**	**11.3 (2.6)**	**245.5 (54.8)**	6.3 (2.2)	19.5 (3.2)	0.58 (0.17)	21.9 (2.7)	19.9 (2.9)
Older adults	12.3 (4.2)	7.0 (2.1)	165.5 (52.7)	**11.3 (4.3)**	**22.4 (3.5)**	0.63 (0.17)	23.4 (3.6)	**22.7 (3.5)**

Note. Standard deviation is presented in parentheses. Bolded values indicate significant age-related differences ($p < .05$).

ps > .05). These results indicate that, like study time, younger adults distributed their restudy attempt across low to high point values whereas older adults restricted their restudy attempts more toward the highest valued items.

Recall Rate and Point Value

The proportion recalled as a function of point value for younger and older adults is presented in Figure 2B. A 2 (Age Group) × 10 (Point Value) mixed model ANOVA revealed a significant interaction, $F(9, 414) = 3.04$, $MSE = 0.03$, $p < .01$, $\eta^2_G = .05$, as well as the significant main effects of Point Value, $F(9, 414) = 104.51$, $MSE = 0.03$ $p < .01$, $\eta^2_G = .65$ and Age Group, $F(1, 46) = 41.06$, $MSE = 0.06$, $p < .01$, $\eta^2_G = .13$. Post hoc tests revealed that, whereas younger adults recalled medium-value items (values 7–9, 10–12, 13–15, 16–18, 19–21, 22–24, 25–27) more than older adults, $ts(46) > 2.15$, $ps < .05$, $ds = 0.62–1.56$, these significant differences were not present for the lowest-valued (1–3, 4–6) and the most valued items (values 28–30) items, $ps > .10$. In addition, the frequency of intrusions (recalling words from prior lists) was extremely low for both groups (Older Adults: $M = 0.24$, $SD = 0.28$; Younger Adults: $M = 0.17$, $SD = 0.21$), $t < 1$. In summary, although younger adults generally showed better overall memory performance, older adults selectively remember highest-valued items to the same extent as younger adults (see also Castel et al., 2002; Castel, 2008a). However, in the present study, older adults spent a significantly greater amount of time studying the highest point values to achieve comparable performance to that of younger adults for only the highest valued items, and this may represent adaptive allocation of attention to compensate for declines in memory.

Recall Performance and Strategic Behavior Between Younger and Older Adults

To examine age differences in recall performance and strategic behavior in more detail, we computed several key summary statistics for younger and older adults (see Table 1). As can be seen from the table, younger adults studied more items (in this and the following analysis on the number of studied items, items that are studied more than once are counted as one), $t(46) = 5.73$, $p < .01$, $d = 1.65$, recalled more items, $t(46) = 6.41$, $p < .01$, $d = 1.85$, and obtained higher point scores, $t(46) = 5.16$, $p < .01$, $d = 1.49$. However, on indices representing more strategic behavior and performance, older adults either did not differ or performed more strategically than younger adults. Specifically, older adults invested significantly more time to study each item, $t(46) = 5.05$, $p < .01$, $d = 1.46$, and studied the items with higher point values longer (consistent with the observation in Figure 2A), $t(46) = 2.96$, $p < .01$, $d = 0.85$, than younger adults. As a result, despite superior overall recall performance by younger adults, both older and younger adults recalled a similar percentage of the items that they studied ($p = .32$) and showed the same average point value of the recalled items ($p = .12$). In addition, the average point value of the last three items participants studied was significantly higher in older adults than in younger adults $t(46) = 3.04$, $p < .01$, $d = .88$. This indicates that older adults were more likely to strategically study highly valued items at the end of the study session to exploit the recency effect (greater likelihood of recalling the most recently studied items). Note, however, that this result does not mean that older adults waited to study the high-value items until the end of the study period. When we computed the frequency of study attempt for these items before being studied at the end, the mean number of study attempt was significantly higher than 0 for both younger ($M = 4.04$, $SD = 2.27$) and older ($M = 3.55$, $SD = 2.29$) adults ($ps < .01$). The age difference was not significant, $t(46) = 0.75$, $p = .46$. Therefore, the selective rehearsal in late study may reflect participants' attempt to revisit the high value items right before the test, rather than a mere attempt to take advantage of the STM storage. Indeed, for recall output, younger and older adults did not differ in terms of the mean value of the first three recalled items ($p = .95$).

Mediation Analysis of Self-Regulated Learning

In the previous analysis, we focused on the univariate or bivariate relationships in the strategic and mnemonic aspects of self-regulated learning (e.g., study time, recall performance).

To better understand the process by which younger and older adults strategically remember valued items, we conducted a mediation analysis to disentangle the multivariate relationship between such strategic and mnemonic aspects (MacKinnon, Fairchild, & Fritz, 2007). Specifically, we examined whether the relationship between point value and recall performance observed in the previous analysis (as shown in Figure 2B) can be explained by participants' study time allocation and strategic exploitation of recency effect (see Figure 3). Age group and study lists were included in the model to investigate possible age difference and list effects in those relationships.

Given that the data represent a nested structure, we conducted multilevel modeling (Raudenbush & Bryk, 2002) to investigate the mediational process (level 1: items, $n = 8640$, level 2: lists, $n = 288$, level 3: participants, $n = 48$). This analysis allows us to appropriately model the within-person relationship of the variables

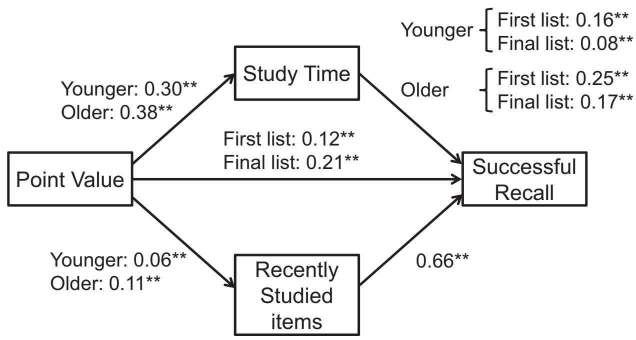

Figure 3. Mediation analyses using the interaction between point value, study time, recently study items, and successful recall in the first list and final list for younger and older adults. The estimated (unstandardized) path coefficients are presented separately for younger and older adults, and first and final lists, or grouped when no age-group/list differences were present (** $p < .01$).

of interest by making use of the full information contained in the data. All the analyses were performed by HLM 6 (Raudenbush, Bryk, & Congdon, 2004).

Multilevel mediation modeling takes three steps (Kenny, Bolger, & Korchmaros, 2003; Krull & MacKinnon, 2001). First, we regressed recall performance (1 = *recalled*, 0 = *not recalled*) on point value of the items to investigate whether items with high point values were well remembered. The full version of the model equation takes the following form:

Level 1 (item level):

$$\eta_{ijk} = \pi_{0jk} + \pi_{1ji}\left(Value\right)_{ijk} + e_{ijk}$$

Level 2 (list level):

$$\pi_{0jk} = \beta_{00k} + \beta_{01k}\left(List\right)_{jk} + r_{0jk},$$

$$\pi_{1jk} = \beta_{10k} + \beta_{11k}\left(List\right)_{jk}$$

Level 3 (person level):

$$\beta_{00k} = \gamma_{000} + \gamma_{001}\left(Age\right)_{k} + u_{00k},$$

$$\beta_{01k} = \gamma_{010} + \gamma_{011}\left(Age\right)_{k},$$

$$\beta_{10k} = \gamma_{100} + \gamma_{101}\left(Age\right)_{k},$$

$$\beta_{11k} = \gamma_{110} + \gamma_{111}\left(Age\right)_{k} \quad (1)$$

where $(Value)_{ijk}$ is value point of the *i*th item in the *j*th list of the *k*th participant anchored at the mid value point (15.5; group-mean centering), $(List)_{jk}$ is list number of the *j*th list of the *k*th participant anchored at the first list, and $(Age)_k$ is the age group of the *k*th participant anchored at the younger adults (i.e., younger adults = 0; older adults = 1). η_{ijk} is the log odds of successful recollection of the *i*th item in the *j*th list of the *k*th participant,

$$\eta_{ijk} = \log\left(\frac{\phi_{ijk}}{1 - \phi_{ijk}}\right),$$

with ϕ_{ijk} being the (population) probability of successful recollection. The variables are unstandardized. Accordingly, the coefficients (γs) can be interpreted as the change in the log odds of successful recall for unit change in the independent variable. For example, if $\gamma_{100} = 0.15$, this indicates that items with point value $X + 1$ are $\exp(0.15) = 1.16$ times as likely as items with point value X to be recalled. If $\gamma_{101} = 0.20$, this indicates that such log odds ratio for successful recall between the items with point $X + 1$ and X is 0.20 higher in older adults than younger adults (for coefficients in Age, positive effect means that older adults are associated with higher likelihood than younger adults). Given the complexity of the model and inherent difficulty in dealing with random slopes in multilevel mediation (Kenny et al., 2003), random effects are posited only for intercepts (r_{0jk} and u_{00k}). Consistent with the observation in Figure 2B, the results showed a significant effect of point value on successful recall ($\gamma_{100} = 0.13$, $p < .01$), indicating that items with higher values were significantly better recalled than items of lower value. In addition, the analysis also showed that this association between point value and recall performance became larger in later lists ($\gamma_{110} = 0.02$, $p < .01$), suggesting that participants (both younger and older adults) learned to remember high valued items with task experience (see also Castel, 2008a; McGillivray & Castel, 2011).

In the second and the third steps, we ran separate models to estimate the path coefficients in the mediation model (Figure 3; for detailed results, see Tables in Appendix). The models in the second step were almost the same as the previous equations (1), but the dependent variable was replaced by a mediator. Two mediators were considered: study time and last three items that participants studied within a list (recently studied items: *studied* = 1, *not studied* = 0). Because study time is not a binary variable (unlike successful recall), η_{ijk} is replaced by Y_{ijk}, the study time (with seconds as the unit with the unit of second) of the *i*th item in the *j*th list of the *k*th participant. The model in the third step was almost the same as the pervious equations (1) but included study time and recently studied items as additional predictors (both are group-mean centered). The estimated path coefficients for the mediation model are summarized in Figure 3. For each path, different path coefficients are noted when the effect of age group or list was significant ($p < .05$). The results indicated that the association between point value and successful recall is partially explained by participants' strategic behavior. That is, items with higher point values were allocated more study time (as shown in the "Point Value → Study Time" path) and studied at the end of the list (as shown in the "Point Value → Recently Studied Items" path), which in turn positively predicts successful recall (the "Study Time → Successful Recall" path and the "Recently Studied Items → Successful Recall" path).

Importantly, there were three significant effects of age group on the path analyses shown in Figure 3. First, consistent with the observation in Figure 2A, the relationship between point value and study time allocation was significantly stronger for older adults ($\gamma = 0.38$, $p < .01$) than for younger adults ($\gamma = 0.30$, $p < .01$), suggesting that older adults tried to compensate for poorer memory abilities by prioritizing and allocating more study time toward high value items. Second, consistent with Table 1, older adults strategically remembered the items with higher point values for the last three items ($\gamma = 0.11$, $p < .01$) more so than younger adults ($\gamma = 0.06$, $p < .01$). Third, the benefit of study time on successful recall is greater for older adults ($\gamma = 0.25$, $p < .01$ for the first list and $\gamma = 0.17$, $p < .01$ for the final list) than younger adults ($\gamma = 0.16$, $p < .01$ for the first list and $\gamma = 0.08$, $p < .01$ for the final list).

This may reflect the fact that younger adults can recall items fairly well relatively irrespective of study time, whereas older adults may need to strategically allocate longer study time to remember the items (cf., Craik & Rabinowitz, 1985; Dunlosky & Connor, 1997). Finally, the effect of point value on successful recall was still significant ($\gamma = 0.12$ for the first list and $\gamma = 0.21$ for the final list) even after controlling for study time and recently studied items. That is, even if two items were studied for the same amount of time and both items were studied at the end (or not studied at the end) of the list, the item with a higher point value was better remembered (and this effect was invariant across age groups). In sum, the multilevel mediation analysis indicated that participants strategically remembered items with higher point values, and older adults showed similar or even stronger strategic processes that may help to compensate for poorer memory.

Discussion

The results from the present study yielded several important insights regarding how aging and value influence self-regulated learning, and how strategic and compensatory processes may allow older adults to engage in efficient self-regulated learning, despite memory deficits. In general, both younger and older adults were highly sensitive to value, spending more time studying high-value items, and recalled more high value items, relative to lower value items. However, older adults spent considerably more time studying the higher value items, studied fewer items overall, and recalled fewer items relative to younger adults. Importantly, age-differences in recall were reduced or eliminated for the highest value words. In addition, older adults capitalized on recency effects in a strategic manner, by studying high-value items often but also immediately before the test, to ensure recall of these items. These findings are consistent with the agenda-based regulation model (Ariel, Dunlosky & Bailey, 2009), extending this model to the domain of cognitive aging and demonstrating that older adults engage in agenda-based regulation by allocating additional study time to high-value items relative to younger adults. The mediation analyses support the notion that participants strategically remembered the items with higher point values, with older adults exhibiting similar or even stronger strategic processes that may compensate for poorer memory. These finding are consistent with the notion that older adults engage in "selective optimization with compensation" (Baltes & Baltes, 1990), by selectively focusing on high value information at the expense of lower value items.

In the present task, both younger and older adults used value to guide self-regulated study, indicative of similar agendas for achieving a goal (in this case, a high score). We suggest that two processes guide self-regulated learning in the context of value-directed remembering. One is purely *mnemonic* in nature and allows younger adults to remember more words, despite studying words for a short period of time, relative to older adults. This reflects the typical episodic memory impairments in older adults that are well-documented (e.g., Craik, 1994). However, a second process that can allow for efficient self-regulated learning involves metacognitive awareness that one needs to select a certain number of items and study them for an appropriate amount of time, to maximize one's memory efficiency. Such metacognitive processes may be particularly important for older adults who are aware of age-related memory impairments. This metacognitive awareness allows for *strategic processes,* such as studying an appropriate number of words, spending enough time to facilitate later recall of higher value words, and studying and/or revisiting high-value words toward the end of the study session, are all aspects of self-regulated learning that do not appear to be impaired in older adults and may be used to combat age-related changes in overall memory performance.

The allocation of study time toward higher value information by older adults may reflect a strategic compensatory function to enhance memory for high value information in light of declines in memory capacity in old age. In the present study, we show that older adults can compensate for global memory impairments by allocating additional study time toward high-value items to enhance recall and engage in efficient value-directed remembering. This could reflect adaptive metacognitive awareness but also potentially inefficiencies if this additional study time does not yield sufficient returns in memory performance, relative to a fixed-paced study time (e.g., labor-in-vain effects). Stine-Morrow, Miller, and Hertzog (2006) have provided an adult developmental model of self-regulated language processing, in which the "allocation policy" with which a learner studies reading material is driven by declines in processing capacity, growth in knowledge-based processes, and age-related shifts in reading goals (see also Stine-Morrow, Miller, Gagne, & Hertzog, 2008). Although the present study focused on memory and does not address reading goals or language processing, there are some parallels in terms of age-related differences in the allocation policy. Older adults in the present study viewed fewer words, but studied them for a longer period of time, to enhance recall of high value items. This may serve to compensate for age-related declines in episodic memory and highlights critical strategic aspects necessary for effective self-regulated learning in older adults (cf., Craik & Rabinowitz, 1985; Dunlosky & Connor, 1997). Given that many life span developmental theories of self-regulation suggest that perceived control decreases in older adults (e.g., Heckhausen & Schulz, 1995; Lachman, 2006), the present task may empower older adults given that they have complete control over the learning environment (in terms of item selection, study duration, and ability to revisit high-value items prior to recall). Thus, the unique control aspects in the present task may allow older adults to effectively use mechanisms of selective optimization and compensation (e.g., Bäckman & Dixon, 1995; Baltes & Baltes, 1990) to engage in efficient goal- or value-directed remembering.

It is interesting to note that both younger and older adults restricted the amount of information they studied in the present task (i.e., did not study all of the potential to-be-remembered words), and that this was most pronounced for older adults. Whereas younger adults sampled a greater distribution of values, older adults chose a more limited number of values but studied these items for a longer period of time. One might expect that perfect efficiency would involve studying the exact number of items that one might later recall, but it appears that both groups were aware of the rapid forgetting that might occur after the study session (e.g., Halamish, McGillivray & Castel, 2011; Rawson, Dunlosky, & McDonald, 2002). Both age groups recalled approximately half of the words they studied, suggesting that list length effects (greater number of words recalled but lower proportion of words recalled as number of words in a list increases) are involved in participants choice of number of words to study (cf. Tauber & Rhodes, 2010). Alternatively, the fact that both groups studied considerably more words than they actually recalled could also reflect some form of general overconfidence (cf., Rast & Zimprich, 2009, but see Tauber & Rhodes, 2012). One could also speculate that choosing an optimal number of items to study involves taking into account interference and forgetting effects, especially when revisiting high-value items before the test. Future research could examine how providing more specific feedback regarding efficiency (e.g., you studied 20 words and recalled 10 words) or the need to achieve a certain goal (e.g., try to improve your score by 10 points or by 30 on the next list) could alter (either enhance or disrupt) self-regulated processes in younger and older adults (e.g., West, Thorn, & Bagwell, 2003). It would also be of interest to determine how item difficulty and value potentially might interact (e.g., Price, Hertzog, & Dunlosky, 2010; Soderstrom & McCabe, 2011), such as when remembering more difficult items receives a higher pay-off or reward, possibly leading to a change in the allocation of study time policy that may be fixed and less dynamic when all items are of equal difficulty.

While previous work has shown that older adults often allocate less study time than necessary or optimal when studying information (e.g., Murphy, Sanders, Gabriesheski & Schmitt, 1981; Souchay & Isingrini, 2004), the present study shows that older adults can use additional study time to enhance learning of high-value items. The learning environment in the present study provided a strong cue (point value) to guide study behavior, and the goal to accumulate points may be sufficiently salient for older adults to engage in efficient (and possibly compensatory) study time allocation for high-value items. Future work could assess how honoring or dishonoring participants' item selection could influence memory efficiency (e.g., Tullis & Benjamin, 2012) and how memory performance is influenced when item selection and presentation time is not under the participants' direct control, or is in fact dictated by a non–self-generated algorithm (e.g., if the study choices and schedule that younger adults use must also be followed by older adults, or vice versa).

It may be that older adults require a learning environment that emphasizes the priority of learning specific information, to engage effective control operations that can ultimately enhance retrieval of high-value information. This could have implications for learning in more real-world contexts. For example, if examining a long list of side effects of a specific medication, one would most likely need to later remember only certain important or severe side effects. Also, often learning to use new technology (e.g., new cellular phone or digital camera) involves reading/studying a lengthy instruction manual, but often only a few critical steps are of most importance when first learning to use the new device. Thus, prioritizing to-be-learned information may help older adults remember important information in self-guided learning situations. The present work illustrates a situation in which older adults can effectively remember important information when study choice and study time allocation is completely under the learner's control. While aging can lead to declines in overall memory performance, strategic components of self-regulated learning can be well-used to remember important information.

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Appendix

Detailed Results From the Mediation Model

Three-level Hierarchical Linear Model of Study Time as a Function of Point Value, List, and Age

Fixed effects	
Intercept (γ_{000})	3.99**
Predictors of intercept	
Age (person-level) (γ_{001})	0.00
List (list-level) (γ_{010})	−0.00
Age × List interaction (γ_{011})	0.00
Value (γ_{100})	0.30**
Predictors of value	
Age (γ_{101})	0.08**
List (γ_{110})	0.01
Age × List interaction (γ_{111})	0.00
Random effects	**Variance**
Intercept (list-level) (r_{0jk})	0.00
Intercept (person-level) (u_{00j})	0.00

Note. The dependent variable is study time (in seconds) for each item. Random effect variances are negligible because overall study time is virtually constant across participants and lists (see Methods).
$^{*} p < .05$. $^{**} p < .01$.

Three-level Hierarchical Generalized Linear Model of the Last Three Studied Items Predicted by Point Value, List, and Age

Fixed effects	
Intercept (γ_{000})	−2.35**
Predictors of intercept	
Age (person-level) (γ_{001})	−0.21
List (list-level) (γ_{010})	−0.01
Age × List interaction (γ_{011})	−0.03
Value (γ_{100})	0.06**
Predictors of value	
Age (γ_{101})	0.05**
List (γ_{110})	0.00
Age × List interaction (γ_{111})	0.00
Random effects	**Variance**
Intercept (list-level) (r_{0jk})	0.00
Intercept (person-level) (u_{00j})	0.00

Note. The dependent variable is the last three items studied coded as 0 (not studied) or 1 (studied). Logit link function was used to address the binary dependent variable. Random effect variances are negligible as the number of last studied items was fixed at three across all participants and lists.
$^{*} p < .05$. $^{**} p < .01$.

(*Appendix continues*)

Three-level Hierarchical Generalized Linear Model of Recall Performance Predicted by Point Value, Study Time, Last Three Items Studied, List and Age

Fixed effects	
Intercept (γ_{000})	−0.65**
Predictors of intercept	
Age (person-level) (γ_{001})	1.51**
List (list-level) (γ_{010})	0.03
Age × List interaction (γ_{011})	0.04
Value (γ_{100})	0.12**
Predictors of value	
Age (γ_{101})	−0.01
List (γ_{110})	0.02**
Age × List interaction (γ_{111})	−0.00
Study time (γ_{200})	0.16**
Predictors of Study time	
Age (γ_{201})	0.08**
List (γ_{210})	−0.02*
Age × List interaction (γ_{211})	0.01
Last studied three items (γ_{300})	0.66**
Predictors of last studied three items	
Age (γ_{301})	0.26
List (γ_{310})	0.02
Age × List interaction (γ_{311})	0.06
Random effects	**Variance**
Intercept (list-level) (r_{0jk})	0.00
Intercept (person-level) (u_{00j})	0.45**

Note. The dependent variable is recall performance coded as 0 (not recalled) or 1 (recalled). Logit link function was used to address the binary dependent variable.
* $p < .05$. ** $p < .01$.

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