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Authors
Middlebrooks, Catherine D
Castel, Alan D

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Self-Regulated Learning of Important Information under Sequential and Simultaneous Encoding Conditions

Catherine D. Middlebrooks and **Alan D. Castel**
University of California, Los Angeles

Abstract

Learners make a number of decisions when attempting to study efficiently: they must choose which information to study, for how long to study it, and whether to restudy it later. The current experiments examined whether documented impairments to self-regulated learning when studying information sequentially, as opposed to simultaneously, extend to the learning of and memory for valuable information. In Experiment 1, participants studied lists of words ranging in value from 1-10 points sequentially or simultaneously at a preset presentation rate; in Experiment 2, study was self-paced and participants could choose to restudy. Although participants prioritized high-value over low-value information, irrespective of presentation, those who studied the items simultaneously demonstrated superior value-based prioritization with respect to recall, study selections, and self-pacing. The results of the present experiments support the theory that devising, maintaining, and executing efficient study agendas is inherently different under sequential formatting than simultaneous.

Keywords

memory; self-regulated learning; agenda-based regulation; value-directed remembering; selectivity

Deciding how to study, what to study, and for how long to study are critical to efficient learning and successful retrieval. Self-regulated learning, the intentional and strategic study of information, refers to any and all goal-oriented behaviors and cognitive processes in which a learner engages with the intention of minimizing the gap between one's present knowledge state and the ideal or goal-based state (Dunlosky & Ariel, 2011a; Nelson & Narens, 1990; Winne & Hadwin, 1998). The specific choices that learners make during study, however, are dependent upon a variety of factors, including item-based characteristics (e.g., item importance, ease of learning) and task-related conditions (e.g., time constraints), which can sometimes encourage efficient study and at other times thwart or mislead such efforts.

Prior work concerning difficulty-based self-regulated study indicates that the format in which to-be-remembered information is presented—namely, whether all at once (i.e., simultaneously) or single to-be-remembered units at a time (i.e., sequentially)—can notably

Please address all correspondence to Catherine D. Middlebrooks, Department of Psychology, University of California, Los Angeles, 1285 Franz Hall Box 951563, Los Angeles, CA 90095; (310) 206-9262; cmiddlebrooks@ucla.edu.

impact later memory and the efficiency of study behaviors. Generally speaking, learners tend to prioritize difficult items over easier ones, allocating more time during study to the difficult subset and electing to restudy them more often than easier items (Dunlosky & Connor, 1997; Le Ny, Denhiere, & Taillanter, 1972; Mazzoni, Cornoldi, & Marchitelli, 1990; Nelson & Leonesio, 1988; Thiede & Dunlosky, 1999). There are, however, circumstances in which learners will appropriately shift their prioritization to easier items, such as when assigned a low performance goal (Thiede & Dunlosky, 1999) or under conditions of limited study time (Dunlosky & Thiede, 2004; Metcalfe, 2002; Son & Metcalfe, 2000; Thiede & Dunlosky, 1999). Thus, in situations in which studying difficult items over easy items would be an unnecessary or likely unsuccessful expenditure of resources, learners adjust their study agenda in order to maintain study efficiency. When the to-be-remembered items are presented sequentially, however, learners display a detrimental and inefficient shift back to prioritizing more difficult items (Ariel, Dunlosky, & Bailey, 2009; Thiede & Dunlosky, 1999), even in cases in which the learner had previously demonstrated more optimal self-regulated study of similar materials (Dunlosky & Thiede, 2004).

The proposed explanation for such sub-optimal regulation under sequential study is that sequential formats require learners to keep not only their agenda in mind, but to also keep in mind previously studied items, upcoming items (e.g., how many are left?), their relevant characteristics (e.g., difficulty, importance), *and* previous study behaviors when determining how best to study the single item being presented at that moment (Ariel et al., 2009; Dunlosky & Ariel, 2011a; Thiede & Dunlosky, 1999). Simultaneous formatting, on the other hand, is thought to place less of a demand on the learner's central executive, as much of the agenda-relevant information is continually visible and so does not need to be held in working memory (or is at least held to a lesser extent). This theory is supported by findings that learners with high working memory spans are less influenced by presentation format than learners with lower spans (Ariel et al., 2009; Dunlosky & Thiede, 2004).

Evidence that sequential formatting impairs one's ability to efficiently execute optimal study agendas, though, would seem to conflict with literature suggesting intact prioritization of high-value information over low-value information during study despite sequential presentation. When tasked with remembering a set of items that exceeds one's memory capacity, learners have been shown to shift their attention and encoding efforts towards the more valuable subset so as to increase the probability that at least the most important items are remembered if all cannot be (e.g., Castel, Benjamin, Craik, & Watkins, 2002; Castel, Farb, & Craik, 2007). Moreover, learners become increasingly selective with continued task experience, recalling not only high-value items more often than low-value items, but strategically shifting their recall in favor of the highest values and away from the lowest (Castel, 2008; Castel, McGillivray, & Friedman, 2012). Such intentional prioritization on the basis of item value/importance has been termed value-directed remembering and, despite sequential formatting, has been consistently reported following both tasks in which prioritization is a consequence of unobservable shifts in attention (e.g., Ariel & Castel, 2014; Castel et al., 2002; DeLozier & Rhodes, 2015) and tasks in which learners have more direct control over study pacing and presentation (Middlebrooks, Murayama, & Castel, 2016; Robison & Unsworth, 2017).

One potential reason for this discrepancy may be that learners can learn to adopt and execute appropriate value-based study agendas under both presentation formats, but simply do so more effectively when the information is studied simultaneously. A direct comparison of sequential to simultaneous value-based study has not yet been conducted, but recent work suggests that individuals with lower working memory capacities are less likely to spontaneously adopt effective, value-based study strategies than those with greater working memory (Robison & Unsworth, 2017). Sequential formatting, relative to simultaneous formatting, may similarly stress the central executive and impair participants' ability to adopt and execute an optimally strategic agenda.

Another explanation concerns the “learn to adopt” aspect of value-directed remembering. Participants generally require task experience before demonstrating successful execution of a selective, value-based study strategy (Castel, 2008). Although participants are generally as likely to recall a low-value word after the first study block as a high-value word, the effect of value on participants' attention allocation during study and subsequent recall markedly increases with continued feedback across multiple study-test blocks (with each block consisting of novel items). If only the first study-test block were considered, it would certainly appear as though learners are *not* capable of prioritizing high-value information during study. It may be the same situation in other cases of agenda-based study, like that of easy and difficult information: perhaps learners would appropriately prioritize easy items over difficult items in light of time constraints or low performance goals, in spite of sequential formatting and in a manner comparable to simultaneous formatting, with continued task experience. Research to date has predominantly considered single trials when comparing presentation formatting effects (e.g., Ariel et al., 2009; Dunlosky & Thiede, 2004; Thiede & Dunlosky, 1999), yet the importance of task experience and feedback is widely acknowledged as critical to the adoption, modification, and improved execution of study strategies (Ariel, 2013; Broekkamp & Van Hout-Wolters, 2007; Nelson & Narens, 1990; Winne & Hadwin, 1998).

It may also be, however, that the demands of maintaining and executing a value-based study agenda are sufficiently low that additional stressors to the central executive, like the demands of sequential formatting, are less consequential to efficient study. When studying easy and difficult items, for instance, the dominant study behavior appears to be to devote more time to the information which is further from one's norm of study (Dunlosky & Hertzog, 1998; Le Ny et al., 1972; Metcalfe & Kornell, 2005; Thiede & Dunlosky, 1999), and it is only in certain circumstances, like constrained study time, that easy items take priority. Perhaps learners must override a more habitual response behavior in these cases, which in itself should be more executively taxing (Hasher, Lustig, & Zacks, 2007; Redick, Calvo, Gay, Engle, 2011), and the costs of doing so to learners' self-regulated study (Ariel, Al-Harthy, Was, & Dunlosky, 2011; Ariel & Dunlosky, 2013; Dunlosky & Ariel, 2011b) may be amplified by the more executively taxing nature of sequential formatting. In the case of low- and high-value information, however, it would make little sense to prioritize less important information over more important information (at least in the absence of other pertinent characteristics). There is not another reasonable, competing study agenda against which learners must choose, and so selecting and maintaining a value-based agenda may be simpler and less cognitively demanding than that of other study agendas.

The following experiments serve as an effort to understand why value-based study is consistently found following sequential study, despite prior findings that suggest such efforts should markedly suffer. Experiment 1 directly contrasts sequential and simultaneous formatting using an experimenter-paced task in which learners have no control over item presentation and any value-based study can be based only on shifts in attention. Experiment 2 also contrasts sequential and simultaneous formatting, but participants in this experiment chose how to distribute their allotted study time across items and were given opportunities for restudy.

Experiment 1

The aim of Experiment 1 was to directly compare sequential to simultaneous value-based study (Castel, 2008; Castel, Murayama, Friedman, McGillivray, & Link, 2013; Robison & Unsworth, 2017; Watkins &Bloom, 1999). It may be that learners can learn to adopt and execute a value-based agenda under either format, as evidenced by prior value-directed remembering research utilizing sequential formatting. It may also be, however, that learners are ultimately more selective when the valuable information is presented for study simultaneously, consistent with research concerning the impact that presentation format can have on the adoption and execution of optimal study agendas (Ariel et al., 2009; Dunlosky & Ariel, 2011a; Thiede & Dunlosky, 1999).

Method

Participants

Participants consisted of 48 undergraduate students (37 female)[1] from the University of California, Los Angeles, ranging in age from 17 to 27 years ($M = 19.96$, $SD = 1.60$). Participants received partial credit for a course requirement.

Materials

The study was designed and presented to participants via the Collector program (Gikeymarcia/Collector, n.d.). Stimuli consisted of 6 lists containing 20 novel words apiece. Each of the words were randomly assigned a value ranging from 1 to 10 points, with two words assigned to each value per list. The words in each list were randomly selected without replacement from a larger bank of 665 nouns, verbs, and adjectives. Within the larger bank, word length ranged from 4-6 letters and averaged to 7.52 ($SD = 1.02$) on the log-transformed Hyperspace Analogue to Language (HAL) frequency scale. The 120 studied words were randomly selected from this bank for each participant so as to avoid any potential item effects (Murayama, Sakaki, Yan, & Smith, 2014).

[1]The sample size per condition in Experiment 1 and Experiment 2 was based on prior research investigating value effects on memory and selectivity (Castel et al., 2013; Hayes, Kelly, & Smith, 2013; Middlebrooks et al., 2016; Middlebrooks, Kerr, & Castel, in press; Middlebrooks, Murayama, & Castel, 2017); value-directed remembering and selectivity effects have been repeatedly and robustly found with this conventional sample size.

Procedure

All participants were told that they would be studying a series of lists, each containing 20 different words that would range in value from 1 point to 10 points with two words per point value in each list. They were instructed to remember as many of the words in each list as possible while also aiming to achieve a maximal score, a sum of the points associated with each word correctly recalled at the end of the respective list's presentation. After recalling the words from a given list, participants were provided feedback about their performance in terms of the number of points they had earned out of 110 possible points before studying the next list. This study-recall-feedback procedure was completed for each of the six word lists.

Participants were randomly assigned to either the simultaneous study condition or the sequential study condition. Participants in the sequential condition were shown each of the word-value pairings within a given list one at a time for 3 seconds each. Participants in the simultaneous condition were shown all 20 of the words and their values within a given list for a total of 60 seconds in a 5 × 4 array (see Figure 1). The order of presentation in the sequential condition, and the arrangement of the items in the simultaneous presentation, was randomized for each participant.

Results

Overall Recall Performance

The proportion of items correctly recalled across the 6 lists are provided in Table 1. Initial analyses were conducted to determine whether the presentation format affected the total number of items that participants recalled, irrespective of their item values. A 2 (Condition: sequential, simultaneous) × 6 (List) repeated-measures ANOVA revealed a main effect of Condition, $F(1, 46) = 12.72$, $MSE = .05$, $\eta^2_G = .12$, $p = .001$, such that participants in the simultaneous condition recalled more items overall ($M = .46$, $SD = .09$) than participants in the sequential condition ($M = .36$, $SD = .09$).

There was also a main effect of List, $F(5, 230) = 2.55$, $MSE = .01$, $\eta^2_G = .03$, $p = .03$. A posthoc trend analysis suggested a small (Bakeman, 2005) quadratic trend in the total number of items recalled across lists, $F(1, 47) = 3.93$, $MSE = .01$, $\eta^2_G = .08$, $p = .05$. Although speculative, these changes in overall recall may reflect some combination of general acclimation to the experimental task demands and minor interference owing to continued study of and exposure to novel items.

Value-Directed Remembering and Selectivity

Recall performance as per item value and study condition throughout the task is presented in Figure 2a. Hierarchical linear modeling (HLM) was used to analyze recall as a function of an item's value, the list in which it was presented, and the format in which it was studied (Raudenbush & Bryk, 2002) in order to detect the use of value-directed remembering in studying the presented items and also to determine whether there were differences in attention to value (i.e., selectivity) based on whether the to-be-remembered information was presented sequentially or simultaneously.

HLM was used for two primary reasons. Firstly, HLM analyses maintain the continuous nature of the item values as they were studied, rather than treating each value point as a discrete entity (as would be the case in, for instance, an analysis of variance). By maintaining the continuity of the value spectrum, it is possible to identify whether there is a direct relationship between value and recall and, thus, to detect value-based study strategizing. Moreover, it is possible to examine whether such a value-recall relationship changes with continued task experience, as has been previously documented (Castel, 2008; Castel et al., 2013; Middlebrooks et al., in press; Middlebrooks et al., 2017). Secondly, and of particular importance, individuals likely differ in *how* they attend to value during study. A participant with high performance expectations, for example, might attend to items worth 5 or more points, while a participant with low expectations might limit attention to the few items worth 9 or 10 points. Both examples illustrate value-based study strategies devised as per metacognitive judgments of personal memory capacity and likely performance. Such between-subject variation in strategy application would be lost in simply comparing average recall across discrete value points. HLM accounts for within- and between-subject differences in strategy by first clustering the data within each participant and *then* considering potential study condition differences in value-directed remembering and selectivity, all while maintaining the continuous nature of the value scale as it was used in the task.

Item-level recall performance (based on a Bernoulli distribution, with 0 = *not recalled* and 1 = *recalled*; level 1 = items; level 2 = participants) was modeled as a function of each item's value, the list in which it was presented, and the interaction between value and list. Value and List were entered as group-mean centered variables, such that Value was anchored on the mean value point (5.50) and List on the mean list (3.5). The model further included the study conditions as a level-2 predictor of those level-1 effects (0 = *sequential* and 1 = *simultaneous*). Table 2 reports the tested model and its estimated regression coefficients. As the model is effectively a logistic regression model with a dichotomous dependent variable, the regression coefficients can be interpreted via their exponential (Raudenbush & Bryk, 2002). Specifically, exponential beta, e^B, is interpreted as the effect of the independent variable on the odds ratio of successful recall (i.e., the probability of recall items divided by the probability of forgetting them) (Murayama, Sakaki, et al., 2014). e^B of more than 1.0 indicates a positive effect of the predictor and less than 1.0 a diminished effect.

Value positively predicted recall performance in the sequential condition ($\beta_{10} = 0.18$, $p < .001$), and there was positive interaction between Value and Condition ($\beta_{11} = 0.11$, $p = .06$), indicating that the effect of value was greater when the items were presented simultaneously during study than sequentially. Thus, the odds of successfully recalling an item increased with increasing value. Participants in the sequential condition were $e^{0.18} = 1.19$ times more likely to recall an item for each one-unit increase in value than they were to forget it, while participants in the simultaneous condition were $e^{0.28} = 1.33$ times more likely.[2] In other

[2]The simple slope for the simultaneous condition can be directly calculated by adding the β_{10} and β_{11} coefficients (i.e., 0.176 + 0.108 = 0.284). To determine whether this simple slope is statistically significant, the Condition predictor in the model was recoded, such that 0 = *simultaneous* and 1 = *sequential* (Hayes, 2013). Note that this was also done to determine the significance of any reported simple slopes hereon.

words, the odds of participants in the sequential condition recalling a 10-point word were $e^{0.18*10}$ = 6.05 times greater than the odds of their recalling a 1-point word, but the odds of participants in the simultaneous condition recalling a 10-point word were $e^{0.28*10}$ = 16.44 times greater than the odds of their recalling a 1-point word.

There was also a small but statistically detectable List × Value interaction (β_{31} = 0.03, p = .03), such that participants became more selective with continued task experience, increasingly prioritizing high-value items over low-value items across lists, with no detectable differences as a function of presentation format during study (p = .72).

Value-Based Organization during Encoding and Retrieval

Participants in Experiment 1 could control nothing about the nature of the study presentation —they could not, for instance, self-pace their study or refrain from viewing less agenda-relevant items. Participants in the simultaneous study condition appeared to more optimally allocate their attention in a value-based manner than those in the sequential condition, but how or why they were able to do so remains unclear.

One possibility is that the simultaneous formatting better lends itself to associative encoding across the items, and participants in the simultaneous condition were thus more easily able to associate the most important items. For instance, a participant studying simultaneously could more quickly form an image or sentence associating the 9- and 10-point items—thereby increasing their chances of later recall—than a participant who studied sequentially and may have had to study (or at least view) several lower-valued items before being presented with the next high-value item.[3] In this case, value differences might be evident not just across the particular subset of items recalled, but in the *order* in which those items were recalled and the extent to which the items were recalled in value-based clusters.

In an initial analysis, a Pearson correlation was independently calculated for each participant between the value of each recalled item and the order in which it was recalled within each of the six lists. A 2 (Condition) × 6 (List) repeated-measures ANOVA was then conducted on these correlations, revealing a main effect of Condition, $F(1, 46)$ = 10.99, MSE = .34, $\eta 2G$ = .06, p = .002, such that the correlation between value and output order was detectably stronger in the simultaneous condition (M = -.31, SD = .25) than in the sequential condition (M = -.08, SD = .22); the correlation between item value and output order was not detectably different from zero in the sequential condition (p = .08). So, of the items remembered, participants in the simultaneous condition were more likely to recall the higher-valued items first, whereas participants in the sequential condition demonstrated no such tendency.

To further explore the nature of the item value-output order relationship and potential differences that may have arisen between the two conditions, each recalled item was placed into one of three value categories. A recalled item worth 1-3 points was categorized as low-value;4-7 points as medium-value; and 8-10 points as high-value. Once categorized, an adjusted-ratio-of-clustering (ARC) score and a modified ratio of repetition (MMR) score

[3]The authors thank John Dunlosky for raising this point about potentially enhanced organizational or associative encoding in the simultaneous condition relative to the sequential condition.

were calculated for each participant per list (Roenker, Thompson, & Brown, 1971; Senkova & Otani, 2012).[4] 2(Condition) × 6(List) repeated-measures ANOVAs were then conducted on each the ARC scores and the MMR scores. In neither analysis were there detectable differences in scores owing to Condition and/or List (*p*s > .08), suggesting that differences did not arise between conditions with respect to any value-based clustering as per the posthoc value categorizations.

Discussion

Participants who studied under sequential formatting in Experiment 1 not only recalled fewer items overall than those who studied simultaneously, but were also significantly less selective in their study. Though there was an effect of value in both formatting conditions—consistent with prior research (Castel, 2008; Castel et al., 2013; Hayes, Kelly, & Smith, 2013; Middlebrooks et al., 2016; Robison & Unsworth, 2017)—value had less impact on the likelihood of an item being later recalled when it was studied sequentially than simultaneously. Moreover, this difference was maintained across lists, despite evidence of improved selectivity with task experience: it was not the case that sequential formatting demands relative to simultaneous study were surmounted with continued practice. Thus, reported differences in the efficiency with which information is studied owing to presentation format (Ariel et al., 2009; Dunlosky & Thiede, 2004; Thiede & Dunlosky, 1999) do not appear to be simply a consequence of limited experience with the task.

In addition to differences between conditions in the value-based composition of participants' recall, there were further differences with respect to the order in which the items were recalled: Participants in the simultaneous condition were more likely to recall higher-valued items before recalling lower-valued items, but participants in the sequential condition demonstrated no such tendency. This is consistent with the supposition that there were fundamental, formatting-driven differences between how participants approached and organized the to-be-remembered information. Both groups of participants prioritized high-value information to some extent, but only in the simultaneous condition did value also influence output order. Thus, the manner in which participants allocated their attention when executing their agendas—again, in the absence of any overt control of item presentation—appears to have differed as per presentation formatting.

Exploratory analyses did not definitively reveal differences between the conditions in value-based clustering of the items during recall that could have reflected particular associative or organizational encoding tendencies. In light of the continuous nature of the value spectrum, however, and the fact that the value-based categorical partitions were entirely posthoc—such partitioning was never suggested to participants during their study—it is not possible to state conclusively that participants did or did not cluster by value in their study and recall in the current experiment.[5] Nevertheless, the correlation between item value and output order during recall in the simultaneous condition, but not the sequential condition, does suggest

[4]There is debate in the literature as to which of the multiple calculations available for determining categorical clustering in recall is appropriate in various circumstances, with each measure influenced by various "irrelevant characteristics of recall" (Roenker et al., 1971). As this was an exploratory analysis, the results of which would need to be interpreted with caution regardless of the outcome, it seemed prudent to consider multiple measures.

that further consideration should be given to the extent to which encoding behaviors differ owing to formatting-based limitations to executive resources and intentional, strategic approaches.

Experiment 2

The general effect of value in Experiment 1, irrespective of condition, indicates that participants recognized the wisdom of prioritizing study based on value, even if studying sequentially minimized the extent of such prioritization. When value-directed remembering can be executed via specific, overt behaviors—like choosing whether to study an item at all—rather than being fully reliant on internal attention control mechanisms, though, sequential formatting may be less detrimental. The opportunity to devise and exercise a specific strategy via self-pacing and (re)study selections might allow participants in a sequential study condition to compensate for any strain of the formatting itself.

Secondly, it is presently unclear what effect formatting may have on the relationships between item value, self-regulated learning choices, and subsequent recall. When given the opportunity, learners generally elect to study high-value words longer than low-value words whether studying sequentially (Middlebrooks et al., 2016; Robison & Unsworth, 2017) or simultaneously (Ariel, Price, & Hertzog, 2015; Castel et al., 2013). Without directly contrasting the two formats, however, it has yet to be determined whether self-regulated choices during sequential and simultaneous study are *similarly* driven by item value. The correlation between output order and item value in only the simultaneous condition in Experiment 1 suggests formatting-driven differences in organizational approaches to study and retrieval, but these differences may have arisen because participants had no other means of regulating their study and so were subject to inherent characteristics of the formatting (e.g., simultaneous arrangement might be more inherently conducive to associative encoding). Experiment 2 aims to disentangle the role of item importance/value from self-regulated study behaviors on learning and memory during sequential versus simultaneous study.

Method

Participants

Participants consisted of 48 undergraduate students (35 female, 1 unreported) from the University of California, Los Angeles, ranging in age from 18 to 26 years (M = 19.98, SD = 1.69). Participants received partial credit for a course requirement.

[5]Consider two participants who both recalled a 6-point word, followed by 10-point, 8-point word, and 3-point words. If Participant A considers anything worth more than 5 points to be of high-value and worthy of attention during study, then the first three recalled items appear clustered. If Participant B limits highvalue classification to only 9- or 10-point items, then there is no evidence of clustering at all. Furthermore, neither Participant A's nor Participant B's partitions would have aligned with the categorizations used in these analyses.

Materials & Procedure

The materials and procedure of Experiment 2 were identical to Experiment 1, except that study was self-regulated with respect to self-pacing and selecting items for both study and restudy.

In the sequential condition, participants were presented with each of the item values within a list individually. The participant could click on the presented value in order to study the associated item or elect not to study the item at all by simply pressing the spacebar to progress to the next value (see Figure 3a). Although participants were presented with all 20 values within a list at least once, they could advance as quickly as they liked past an item if they elected not to study it at all. Participants were also given the opportunity to select an item for later restudy while it was on the screen (Figure 3a). Items were not seen again if not selected for restudy during the initial presentation. If an item was selected, it was presented again after the participant had advanced through all 20 of the items/values. Participants were allowed to restudy an item as many times as they liked within the 60-second allotment; if selected for an additional restudy, that item was presented in the next presentation cycle within that list's 60-second study period.

During the initial list presentation, for example, a participant might select *bench*, *float*, *injury*, and *theme* to restudy. These items would then be presented again after the participant had first advanced through all 20 of the list's items (regardless of whether the participant selected to study any of the other 16 items or simply pressed the spacebar to advance past them). If during the restudy phase the participant decided to select *bench* and *float* for a second restudy, these two items would be presented at the conclusion of the first restudy phase (i.e., after the participant had advanced past *injury* and *theme*, as well). Restudy selections in the sequential condition could only be made while the item-value pair was on the screen.

In the simultaneous condition, participants also saw only the values of the items and were to specifically click on the value in order to study the associated word. As in the sequential condition, participants were able to spend as much or as little of the 60-second allotment on the individual words. Participants only studied one word at a time, but all value points were presented in 4 columns of 5 words (see Figure 3b); clicking on a different value to study a new word returned the previously studied word to its original hidden state. There was no limit to the number of times a participant could study a particular item-value pairing.

In both conditions, a timer was provided on the screen to indicate how much of the 60-second study period remained.

Results

General Study and Recall

A summary of statistics reflecting general study behaviors (e.g., self-pacing, item selections) is provided in Table 3 with statistically detectable differences between conditions indicated. The proportion of items correctly recalled (of all 20 items within a list, irrespective of study behaviors) and provisionally recalled (i.e., recall performance provided that the item was studied at all) across the 6 lists is provided in Table 1.

Value-Directed Remembering and Selectivity

As in Experiment 1, HLM analyses were used to analyze recall in Experiment 2 as a function of item value, the list in which the item was presented, and the format in which it was studied. Table 2 reports the tested model (which was the same as that used in Experiment 1) and its estimated regression coefficients. In Experiment 2, however, both recall of the full set of items and provisional recall was considered. Certainly, a participant's failure to recall an item that he/she never studied in the first place is a given and not an indication of forgetting. In analyzing provisional recall, it is possible to assess whether participants selectively prioritized the most valuable items within the subset of items that they elected to study, whether those selections differed as a consequence of presentation formatting, and how their study of this selected subset may (or may not) have deviated between conditions.

Recall of the list in its entirety, though, regardless of study behaviors, must also be considered because the goal of the task was to maximize one's recall of the complete, 20-item set of to-be-remembered material in each list. A perfectly selective participant would choose only the most valuable items to study—for instance, the six items worth 8-10 points—and subsequently recall (if not all of those studied items) only the most valuable of that most valuable subset (e.g., the 9- and 10-point items). If a participant selected the six items worth 1-3 points to study and later recalled the four most valuable of that relatively unimportant subset, provisional recall would still suggest perfect selectivity. To an extent, selectivity would indeed have been evident in this case, but that participant ultimately chose to prioritize 3-point items over (the unstudied) 10-point items and, in light of the larger set of to-be-remembered information, was rather unselective with respect to high-value items. Analyzing recall (of the full set of items) and provisional recall separately when determining the impact of value make it possible to distinguish between situations such as these. Figure 2b depicts recall performance as per item value and study condition throughout the task—regardless of study behavior—and recall performance provisional on having actually studied the item.

Value positively predicted provisional recall performance (β_{10} = 0.31, $p < .001$), with no statistically detectable differences between the simultaneous and sequential conditions (β_{11} = 0.09, $p = .37$). There was also a List × Value interaction (β_{30} = 0.06, $p = .002$), such that participants became more selective with continued task experience, increasingly prioritizing high-value items over low-value items across lists, again consistent between conditions ($p = .54$).

When considering recall of the full set of items, however, the simultaneous condition was significantly more selective (β = 0.50) than the sequential condition (β_{10} = 0.26), $p = .03$, as in Experiment 1. So, although participants who studied sequentially in Experiment 2 recalled the more valuable items of those that they had chosen to study—in a manner similar to that of the simultaneous condition—they were notably less selective when considering the complete set of to-be-remembered items. There was evidence of attention to value during study in the sequential condition, but study itself was relatively suboptimal compared with the simultaneous condition.

Mediation Analysis of Self-Regulated Learning

As in Experiment 1, the HLM analyses for Experiment 2 indicate that participants who studied simultaneously were more selective overall than those who studied sequentially. Given that participants' study in Experiment 2 was overtly self-regulated, though, the mechanism(s) by which such selectivity was realized can be more directly investigated. Based on the fact that participants who studied sequentially *did* study selectively when considering provisional recall, but not when considering the full set of items, there must have been differences in participants' item selections. The nature of these differences, though, is unclear from the previous analyses. Did those in the simultaneous condition better prioritize high-value information only when choosing which items to study, or did differences extend to how the selected subset of information was studied, as well, in terms of restudy choices and study time allocation?

Multilevel mediation analysis was conducted to clarify the contributory roles of item value, study time allocation, and the number of times items were studied on subsequent recall across the six lists (see Castel et al., 2013 for similar analyses). The first phase of the mediation analysis determined the total effect of value on recall; this step was conducted in the previous section (Model 1, see Table 2). The second and third phases of the analysis estimated the path coefficients of the model.

The second phase included two separate HLM models in which the outcome variable in Model 1 was replaced by total study time per item (in seconds) (Model 2a, Table 4) and the number of times the item was studied (Model 2b, Table 4), respectively.[6] The third phase of the analysis (Model 3) addressed the direct effect of item value on recall probability and the indirect effects of the study time allocation and study selection mediators. Model 3 was similar to Model 1, but included the total study time per item and number of study instances as group-mean centered predictors alongside value and the interactions between each predictor and list (Model 3, Table 5). As in Model 1, recall in Model 3 was separately considered both in terms of recall of the full set of to-be-remembered items (Figure 4a) and provisional recall (Figure 4b). This distinction resulted in similar patterns between conditions, so these coefficients are provided separately in Tables 3 and 4 and Figure 4 but are not further distinguished in-text for the sake of simplicity. The coefficients provided in-text reflect an analysis of the full set of items unless otherwise noted.

Value predicted study time allocation in both study conditions (Model 2a; $\beta_{10} = 0.21$, $p = .002$), but it was more predictive of allocation during simultaneous study than sequential ($\beta_{11} = 0.30$, $p = .002$), as shown in Figure 5. Value also predicted the number of times that an item was studied in the simultaneous condition (Model 2b; $\beta = 0.51$, $p < .001$)—with high-value items studied more frequently than low-value items—but not in the sequential condition (Model 2b; $\beta_{10} = 0.01$, $p = .87$)[7]. Thus, participants who studied the items

[6]Study time and number of study instances are not binary outcomes, so item-level performance was not based on a Bernoulli distribution, like recall was in Model 1, but rather a continuous (normal) distribution.

simultaneously were markedly more selective when self-pacing their study and in selecting which items to study/restudy—devoting significantly more resources to high-value items relative to low-value items—than those in the sequential condition.

Naturally, the likelihood of later recalling an item increased the longer it was studied (Model 3; β_{50} = 0.25, $p < .001$)—with no statistically detectable differences between conditions (β_{51} = -0.08, $p = .21$). The odds of recalling an item also increased as a function of the number of times that it was studied (Model 3; β_{30} = 3.75, $p < .001$), but the number of study instances had a greater effect on recall in the sequential condition than the simultaneous condition (β_{31} = -3.40, $p < .001$). This may seem surprising, but it is important to keep in mind that participants in the simultaneous condition had, on average, more individual study events per item (*M* = 4.16) than those in the sequential condition (*M* = 1.03) (see Table 3). Thus, an additional instance of study in the simultaneous condition was relatively less influential; if one has already studied an item three times, studying it one more time will logically have less of an impact on recall odds than studying an item again which has so far only been studied once, particularly when most of the other studied items were also studied only one time.

After controlling for the effects of self-pacing and the number of study instances, there remained a statistically detectable effect of value on provisional recall in the sequential condition (β_{10} = 0.12, $p < .001$) and, to a greater extent ($p = .05$), in the simultaneous condition (β = 0.22, $p < .001$). These condition differences in the effect of value (β_{10} = 0.21, $p < .001$), after controlling for differences in overt study behaviors, were not evident when considering recall of the full set of items ($p = .71$).

Presentation order—A particularly notable finding in the mediation analyses was that item value did not predict study frequency in the sequential condition, but participants in the sequential condition also rarely restudied (Table 3). Certainly, this difference in restudy tendencies between conditions is noteworthy, but it might also minimize the role of value in making study selections in the previous analyses. As depicted in Figure 6a, though, value continued to be remarkably irrelevant to the sequential condition when examining simply whether an item was studied or not at all.

If participants in the sequential condition did not base their decision of whether or not to study an item (let alone restudy it) on its value, the only remaining logical factor on which they might have based it would appear to be the order in which it was presented. Part of what is thought to make sequential formatting demanding is that the order of presentation during study is more a factor with which a learner must contend rather than one which facilitates the execution of a study agenda, and it is a factor which is absent in simultaneous study as all to-be-remembered items are visible at once.

Multilevel mediation analyses were again conducted on the sequential condition alone, considering both item value and order of presentation as predictors rather than item value

[7]Note that this very small Value effect was detected (p = .06) in the sequential condition when considering only items that were studied at least once.

alone; the results of this analysis are provided in Figure 6b and Table 6.[8] Order predicted which items participants in the sequential condition chose to study, with the odds of studying an item decreasing the later that it was presented in the list. Order also predicted study time, effectively to the same extent that did Value: the further along the list an item was presented, the less time it received. After controlling for study time and whether or not an item was studied at all, Value was more predictive of recall than was Order—a 10-point item, for instance, was more likely to be recalled than a 1-point item that was studied for the same amount of time—but the contribution of both factors to recall likelihood was statistically detectable.

Reflecting on the previous results, Value had much less of an effect on self-regulated study and subsequent recall in the sequential condition than the simultaneous condition; it would appear that at least some of this difference was a consequence of a complete neglect of value by the sequential condition in determining what to study in the first place. Once selected, participants in the sequential condition did appear to apply some element of a value-based strategy, demonstrating selectivity on more of a local level—considering each presented item in turn—rather than applying a global value-based strategy across the entirety of the list.[9]

Discussion

As in Experiment 1, participants in the simultaneous condition were significantly more selective in their study and consequent recall than participants in the sequential condition, even though participants in Experiment 2 could decide for how long and how often to study the items. Critically, the sequential condition relied on presentation order—not value—when determining whether or not to study an item, meaning that even similar attendance to value within the studied subset of items in the sequential condition relative to the simultaneous condition was still demonstrative of less strategic study overall. Participants in the sequential condition did not study the most valuable of the full, to-be-remembered set of items. Although both conditions demonstrated adherence to a generally value-based study agenda to varying extents, item value was thus a consistently greater determinant of self-regulated study and recall in the simultaneous condition than in the sequential condition, consistent with prior research (Ariel et al., 2009; Dunlosky & Thiede, 2004; Thiede & Dunlosky, 1999).

General Discussion

According to the agenda-based regulation model of self-regulated learning, decisions during study, like electing to restudy and determining for how long to study, are generally made with the intention of studying in an efficient manner, of maximizing the return for one's cognitive expenditure (Dunlosky & Ariel, 2011a; Dunlosky, Ariel, & Thiede, 2011). Under

[8]Note that provisional analyses were not considered because they would have excluded unstudied items, thereby preventing any determination of the impact of presentation order versus item value on participants' study selections.

[9]There is evidence to suggest an influence of reading habits on item selections in simultaneous presentations, wherein left-to-right reading habits (or right-to-left, as applicable) can disrupt agenda execution during study (Ariel et al., 2011; Ariel & Dunlosky, 2013; Dunlosky & Ariel, 2011b), but there were no apparent effects of column assignment on any of the self-regulated study predictors or recall in the simultaneous condition (i.e., items in the left-most columns were not prioritized over items in the rightmost columns). These results are available upon request.

this model, a learner's study is guided by an agenda—constructed based on not only performance goals, but also various personal- and task-related factors. This agenda is maintained and enacted during study via the central executive of working memory, excess stress to which is predicted to lead to suboptimal study (Dunlosky et al., 2011; Dunlosky & Ariel, 2011a; Dunlosky & Thiede, 2004). The way in which to-be-remembered information is presented during study—viz. sequentially or simultaneously—has been identified as one such stressor to the central executive: relative to simultaneous study, learners tasked with studying sequentially demonstrate less efficient study (e.g., allocating more of their study to difficult items than easy items despite time limits) (Dunlosky & Thiede, 2004; Thiede & Dunlosky, 1999). The current experiments were designed to assess whether this same format-based impairment to study efficacy and efficiency extends to the strategic study of valuable information.

Experiment 1 directly contrasted sequential and simultaneous presentation during study to determine the effect of formatting on value-directed remembering and selectivity when the means of executing a value-based agenda were based on attention control mechanisms, while Experiment 2 examined the formatting effects on selective self-regulated study behaviors and, thus, recall. Evidence of value-directed remembering was found in both experiments regardless of the presentation format, with participants ultimately recalling more high-value items than low-value. This is consistent with prior reports that learners can and will prioritize high-value information over low-value information during sequential study when the quantity of information exceeds encoding capacity (Ariel & Castel, 2014; Castel et al., 2012; Robison & Unsworth, 2017), even in spite of stressors like constrained study time (Middlebrooks et al., 2016) and divided attention (Middlebrooks et al., in press). Importantly, however, participants in the simultaneous condition were *more* selective than those who studied sequentially. This difference supports prior research concerning formatting effects on the study of easy and difficult information (Ariel et al., 2009; Thiede & Dunlosky, 1999) and may help to explain instances in which sequential, value-based study has *not* been detected (DeLozier & Dunlosky, 2015). It further supports the agenda-based regulation model's position that the central executive is responsible for maintaining and executing study agendas and, as such, agenda maintenance/execution is susceptible to factors, like presentation formatting, stressful to the central executive (Dunlosky et al., 2011; Dunlosky & Ariel, 2011a).

That the agendas adopted by participants in the simultaneous and sequential conditions were value-based in Experiment 2, however, may have been the extent of their similarity. Participants in the simultaneous condition were not only more selective in their recall relative to the sequential condition, but were also more selective in their study selections, with the subset of items which they chose to study of greater value than that chosen by the sequential condition. Importantly, value did not appear to motivate item selections in the sequential condition at all. Rather, participants studied the presented items in order, regardless of their value, despite having been explicitly told that they could choose not to study items entirely if they so wished. In fact, order was just as predictive of self-pacing as was item value within the sequential condition (see Figure 6). If considering a whole textbook, participants in the simultaneous condition were metaphorically more likely to study and remember the most important information overall; participants in the sequential condition were somewhat more likely to remember the most important than less important information, but only in the first couple of chapters. Even a perfect study strategy is relatively useless if inappropriately applied.

The present results suggest that participants who studied simultaneously were not simply better able to execute the agenda, but that they devised a more efficient value-based study agenda in the first place. Participants in the simultaneous condition not only studied the high-value items for more time overall, but they divided this longer study into shorter, more frequent study events than did participants who studied sequentially (see Figure 7), essentially spacing their study.[10] For the most part, participants in the sequential condition, however, did not take advantage of the opportunity to restudy items and instead massed their study of an item into a single instance, suggesting that what appears to be the most effective schedule to learners could be (at times inappropriately) influenced by the format in which the information is originally presented. Future research should query participants on what they consider to be the most optimal study strategy in light of the task goals (in the current case, to attain as many points as possible) so as to determine whether evident differences in strategic study differ between presentation formats owing to differences in beliefs about the optimal strategy, or whether the optimal strategy professed by participants in fact differ from their behaviors.

The studied materials in the current experiments were discrete items, but future research should also consider materials in which the individual units of information are conceptually related, as in text passages and textbook chapters. It may be that the benefits of simultaneous study over sequential when presented with discrete items do not extend to situations in which learners must actually discretize the information into important and less important subsets when the less important information is, nevertheless, related to the important. On the other hand, one feature of simultaneous formatting is that it should encourage relative judgments/comparisons across items or informational units (Wells, 1984; Wells, Steblay, & Dysart, 2011), potentially highlighting differences in item importance. Participants in the current experiments were not tasked with evaluating the importance of the to-be-remembered items—value was explicitly noted. The effect of formatting on more realistic, conceptual materials may depend on whether the learner must first evaluate importance before applying a value-based strategy.

Conclusion

The current experiments examined whether previously reported impairments to strategic study following sequential presentation relative to simultaneous are similarly evident in the study of and memory for valuable information. Participants generally prioritized high-value over low-value information, irrespective of the manner of presentation during study, but those presented with all of the to-be-remembered information simultaneously demonstrated greater value-based prioritization in allocating their attention (Experiment 1) and overtly

[10]Note that, although speculative, the short, but frequent study events demonstrated by participants in the simultaneous condition—in contrast with the lengthier but generally singular study instances in the sequential condition—are consistent with the idea explored in Experiment 1 that simultaneous formatting may be more conducive to (or instigate) more associative or organized encoding than sequential formatting.

self-regulating their study (Experiment 2). These results are consistent with the theory that devising, maintaining, and executing an efficient study agenda is inherently more demanding under sequential formatting relative to simultaneous (Dunlosky & Thiede, 2004; Dunlosky & Ariel, 2011a; Thiede & Dunlosky, 1999).

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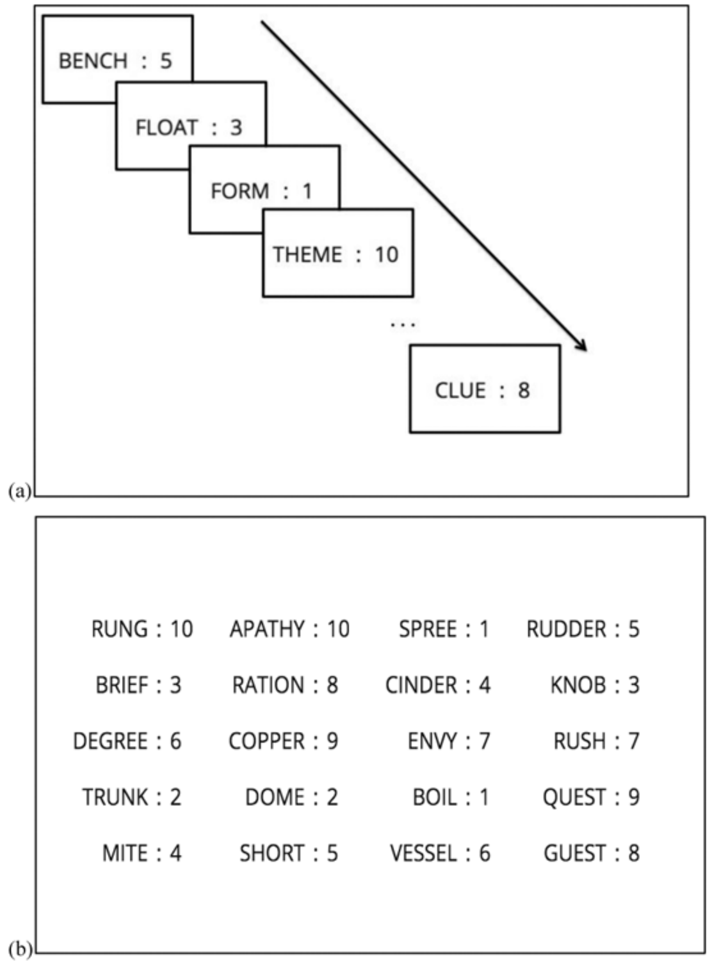


Figure 1.

An example of the (a) sequential and (b) simultaneous presentation of the 20 items within a list during study in Experiment 1. The items within a list were presented each for 3 seconds in the sequential condition or all at once for 60 seconds in the simultaneous condition before participants progressed to the recall test, after which they were told their score (the sum of the points associated with correctly recalled items).

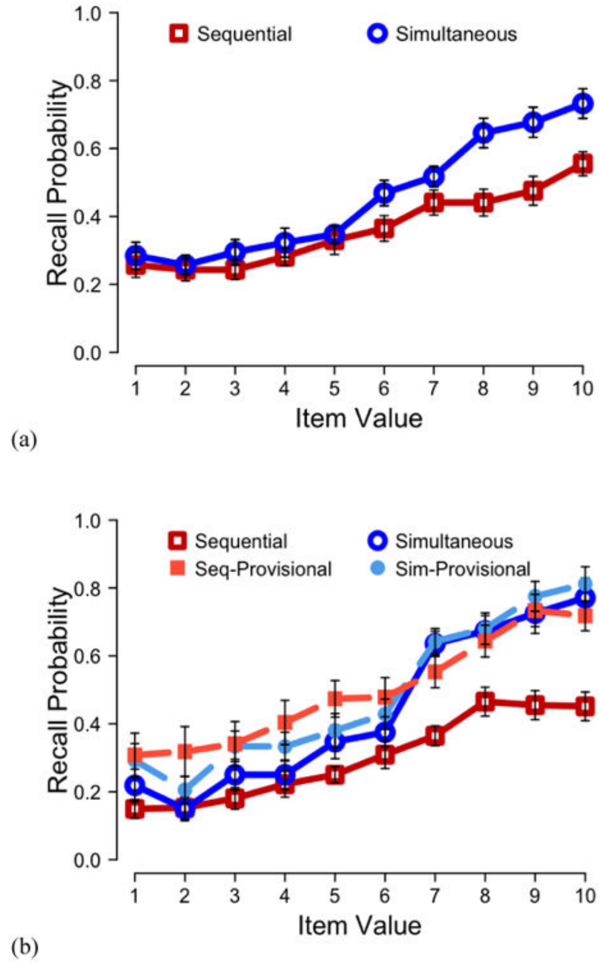


Figure 2.

Recall probability, averaged across lists, as a function of item value and assigned study condition in (a) Experiment 1 and (b) Experiment 2. “Sequential” and “Simultaneous” in Figure 2b refer to the probability of recalling all items (studied and not studied) within a list. “Seq-Provisional” and “Sim-Provisional” refer to the probability of recalling an item provided that the participant chose to study it in the first place.

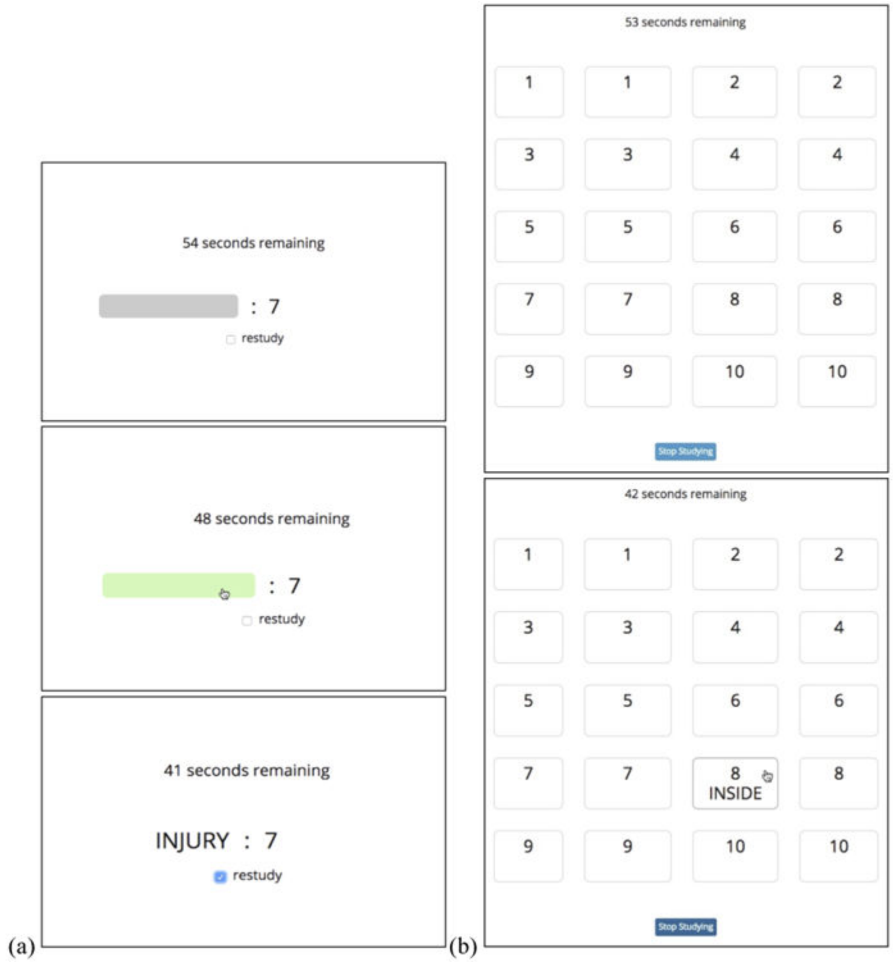


Figure 3.

An example of the (a) sequential and (b) simultaneous displays during study in Experiment 2. Participants were to click on a given value point to see the associated word. They could study only one word at a time, but were free to study as many or as few items as they wished as often as they liked. A timer was provided at the top of the screen to indicate how many of the 60 seconds remained for studying the 20 items in the list. They could also elect to stop studying the list before the 60-second study period had finished if they were so inclined. Participants completed a recall test after studying each list, after which they were told their score (the sum of the points associated with correctly recalled items).

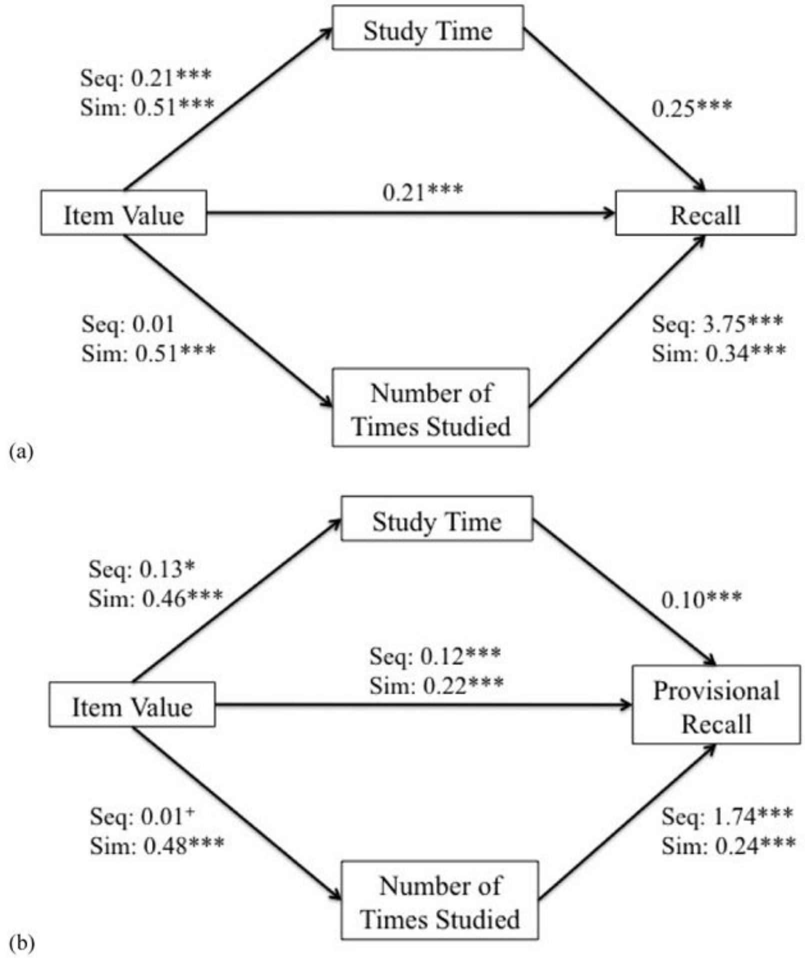


Figure 4.

Mediation analyses using the interaction between an item's value, the total time it was studied, and the number of times it was studied to determine the likelihood of (a) recall (when considering the full set of items within each list) and (b) provisional recall (considering only those items which the participant chose to study) by participants assigned to the sequential (seq) and simultaneous (sim) study conditions. The estimated (unstandardized) path coefficients are presented separately when statistically detectable differences arose between conditions. $^{+}p < .10$ $*p < .05$ $**p < .01$, $***p < .001$

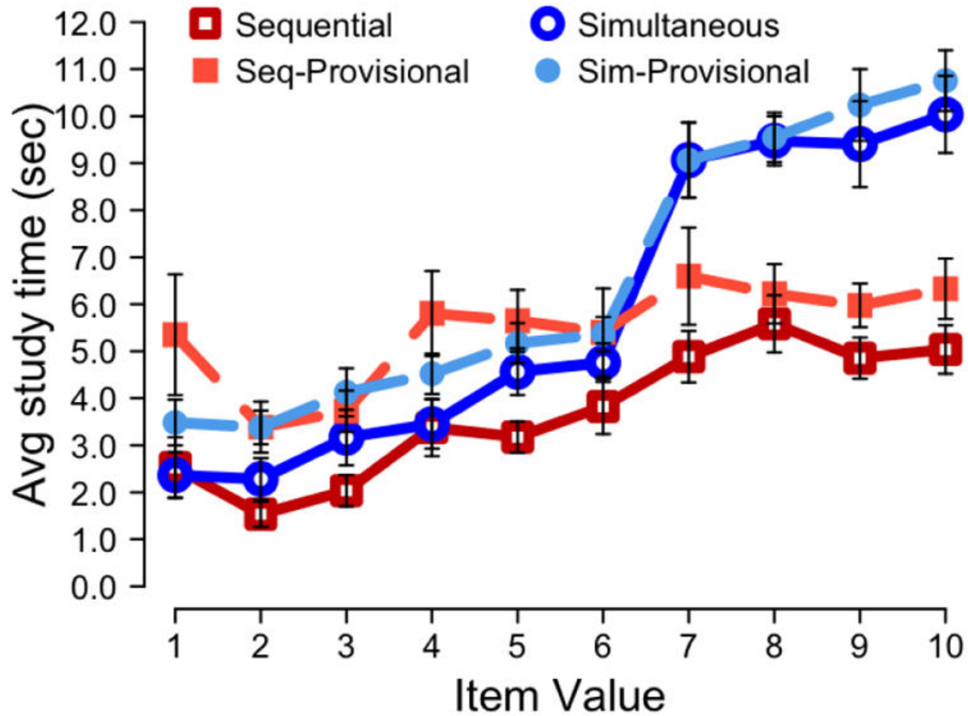


Figure 5.

Average study time (in seconds) of self-paced study time allocated to each item as a function of item value and assigned study condition across lists in Experiment 2. "Sim-Provisional" and "Seq-Provisional" refer only to items that were studied at least one time in the simultaneous and sequential conditions, respectively.

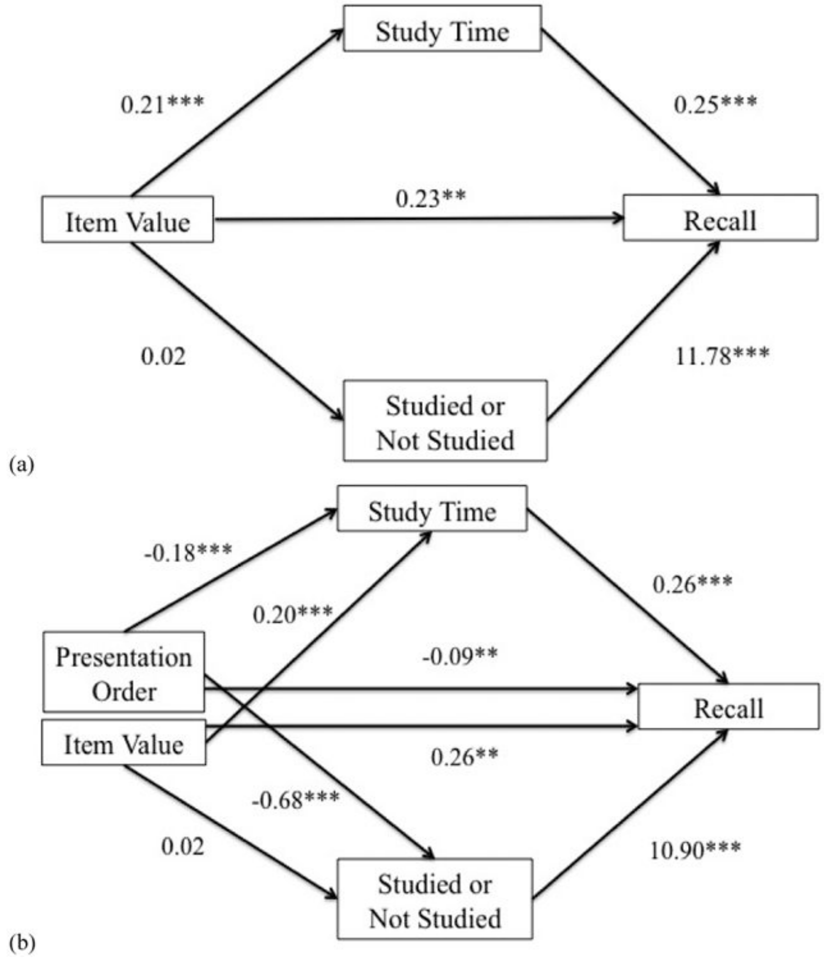
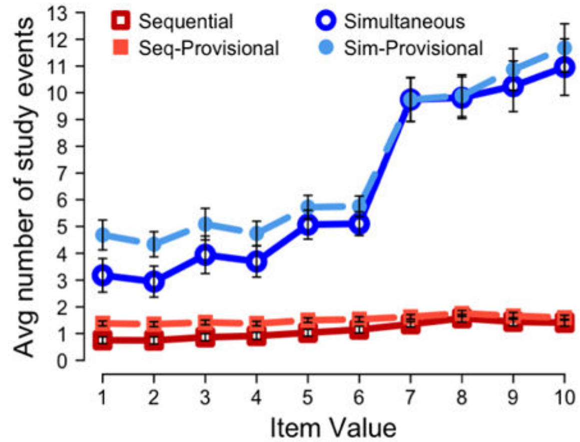
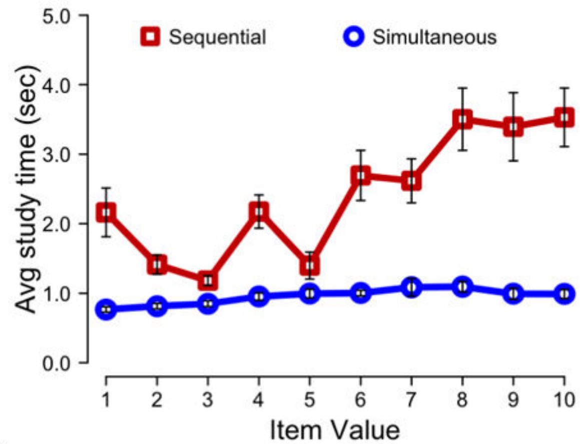


Figure 6.

Mediation analysis using the interaction between (a) an item's value and (b) the order in which it was presented, the total time it was studied, and whether or not it was studied (0 = *not studied*, 1 = *studied*) to determine its likelihood of being recalled by participants assigned to the sequential condition. As opposed to Figure 4, the separate presentation of the estimated (unstandardized) path coefficients for Value and Order does not reflect statistically detectable differences between the two predictors. *$p < .05$ **$p < .01$, ***$p < .001$



(a)



(b)

Figure 7.

(a) Average number of times an item was studied and (b) the average study time *per* study instance, in seconds, as a function of item value and assigned study condition across lists in Experiment 2. Note that Figure 7b cannot depict items that were not studied at all.

Table 1

Recall probability as a function of study condition and list in Experiments 1 and 2

	Condition	List 1	List 2	List 3	List 4	List 5	List 6	Average
Experiment 1	Sequential	.35 (.11)	.30 (.11)	.37 (.13)	.40 (.16)	.40 (.13)	.35 (.14)	.36 (.09)
	Simultaneous	.41 (.16)	.46 (.11)	.46 (.10)	.46 (.12)	.47 (.13)	.46 (.11)	.46 (.09)
Experiment 2	Sequential	.27 (.10)	.27 (.09)	.30 (.11)	.31 (.08)	.33 (.07)	.32 (.08)	.44 (.06)
	Simultaneous	.44 (.14)	.41 (.11)	.43 (.12)	.44 (.15)	.45 (.10)	.46 (.13)	.30 (.09)
	Sequential- Provisional	.59 (.28)	.57 (.22)	.53 (.24)	.45 (.21)	.51 (.22)	.47 (.23)	.52 (.19)
	Simultaneous- Provisional	.57 (.18)	.52 (.17)	.53 (.17)	.58 (.20)	.63 (.23)	.66 (.24)	.58 (.14)

Note. Standard deviations are presented in parentheses. “Sequential-Provisional” and “Simultaneous-Provisional” in Experiment 2 reflect the probability of recalling an item provided that the participant chose to study it in the first place.

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Table 2

Two-level hierarchical generalized linear model of recall performance predicted by item value, list, and study condition (Model 1)

Fixed effects	Experiment 1	Experiment 2	Experiment 2: Provisional recall
Intercept (β_{00})	-0.63 ***	-1.07 ***	-0.23
Predictors of intercept Condition (β_{01})	0.41 **	0.59 **	0.15
Value (β_{10})	0.18 ***	0.26 ***	0.31 ***
Predictors of value Condition (β_{11})	0.11 +	0.24 *	0.09
List (β_{20})	0.03	0.02	-0.11 *
Predictors of list Condition (β_{21})	-0.01	-0.04	0.14 *
List × Value (β_{30})	0.03 *	0.05 **	0.06 **
Predictors of list × value Condition (β_{31})	0.01	0.05 +	0.02
Random effects	**Variance**	**Variance**	**Variance**
Intercept (person-level) (r_0)	0.14 ***	0.29 ***	0.62 ***
Value (r_1)	0.03 **	0.36 ***	0.31 ***
List (r_2)	0.01 +	0.10 **	0.03 ***
List × Value (r_3)	0.002 ***	0.08 ***	0.01 ***

Note. The dependent variable is recall performance coded as 0 (*not recalled*) or 1 (*recalled*). Provisional recall analyses in Experiment 2 were based only on items that a participant had chosen to study. Logit link function was used to address the binary dependent variable. Level 1 models were of the form $\eta_{ij} = \pi_{0j} + \pi_{1j}$ (Value) + π_{2j} (List) + π_{3j} (List × Value). Level 2 models were of the form $\pi_{0j} = \beta_{00} + \beta_{01}$ (Condition) + r_{0j}, $\pi_{1j} = \beta_{10} + \beta_{11}$ (Condition) + r_{1j}, $\pi_{2j} = \beta_{20} + \beta_{21}$ (Condition) + r_{2j}, $\pi_{3j} = \beta_{30} + \beta_{31}$ (Condition) + r_{3j}. The Condition predictor was anchored on the sequential study condition (i.e., 0 = *sequential*, 1 = *simultaneous*).

+ $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 3

Summary statistics of self-regulated study in Experiment 2

	Sequential	Simultaneous
Avg # items studied per list	10.70 (4.27)	**16.15 (3.56)**
Avg value of studied items	6.31 (1.04)	6.25 (0.99)
Avg # items recalled per list (out of 20)	6.00 (1.29)	**8.79 (1.88)**
Avg proportion of studied items recalled per list	.52 (.19)	.58 (.14)
Avg total study time per studied item (sec)	4.14 (2.27)	3.84 (1.06)
Avg # of study events per studied item	1.03 (0.09)	**4.16 (1.31)**
Avg study time per study event (sec)	**5.19 (6.66)**	1.01 (0.31)

Note. Standard deviations are presented in parentheses. Bolded values indicate statistically detectable differences between conditions ($p < .05$), with the greater of the two conditions bolded.

Table 4

Two-level hierarchical generalized linear model of study time allocation (Model 2a) and (re)study selections (Model 2b) predicted by item value, list, and study condition in Experiment 2

Fixed effects	Model 2a: Total study time	Model 2a: Total study time, provisional	Model 2b: Number of times studied	Model 2b: Number of times studied, provisional
Intercept (β_{00})	1.84***	4.58***	0.71***	1.03***
Predictors of intercept Condition (β_{01})	1.09***	-1.16	2.53***	2.59***
Value (β_{10})	0.21***	0.13*	0.01*	0.01+
Predictors of value Condition (β_{11})	0.30**	0.33***	0.50***	0.48***
List (β_{20})	-0.03	-0.71+	0.05***	0.01
Predictors of list Condition (β_{21})	0.04*	0.77+	-0.05	0.04
List × Value (β_{30})	0.03*	0.04	0.001	0.004
Predictors of list × value Condition (β_{31})	0.003	-0.01	0.03+	0.01
Random effects	**Variance**	**Variance**	**Variance**	**Variance**
Intercept (person-level) (r_0)	0.01	8.35***	0.30***	0.29***
Value (r_1)	0.09***	0.07***	0.10***	0.09***
List (r_2)	0.0003	1.78***	0.02***	0.04***
List × Value (r_3)	0.003***	0.01***	0.003***	0.01***

Note. The dependent variable in Model 2a is the total time an item was studied (in seconds) and, in Model 2b, the number of times an item was studied. Provisional analyses consider only those items that were studied at all. Level 1 of both models were of the form $Y_{ij} = \pi_{0j} + \pi_{1j}$ (Value) + π_{2j} (List) + π_{3j} (List × Value). Level 2 of both models were of the form $\pi_{0j} = \beta_{00} + \beta_{01}$ (Condition) + r_{0j}, $\pi_{1j} = \beta_{10} + \beta_{11}$ (Condition) + r_{1j}, $\pi_{2j} = \beta_{20} + \beta_{21}$ (Condition) + r_{2j}, $\pi_{3j} = \beta_{30} + \beta_{31}$ (Condition) + r_{3j}. The Condition predictor was anchored on the sequential study condition (i.e., 0 = *sequential*, 1 = *simultaneous*).

+ $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 5

Two-level hierarchical generalized linear model of recall performance predicted by item value, list, study time, number of times studied, and study condition (Model 3) in Experiment 2

Fixed effects	**Model 3**	**Model 3: Provisional recall**
Intercept (β_{00})	-1.62***	0.44*
Predictors of intercept Condition (β_{01})	1.25***	-0.22
Value (β_{10})	0.21***	0.12**
Predictors of value Condition (β_{11})	0.02	0.10*+
List × Value (β_{20})	0.05**	0.02
Predictors of list × value Condition (β_{21})	0.03	0.05+
Number of times studied (NoS) (β_{30})	3.75***	1.74***
Predictors of NoS Condition (β_{31})	-3.40***	-1.50**
List × NoS (β_{40})	-0.01	0.03
Predictors of list × NoS Condition (β_{41})	0.14	0.001
Study time (ST) (β_{50})	0.25***	0.10***
Predictors of ST Condition (β_{51})	-0.08	0.04
List × ST (β_{60})	-0.003	-0.01
Predictors of list × ST Condition (β_{61})	-0.04	-0.01
Random effects	**Variance**	**Variance**
Intercept (person-level) (r_0)	0.33***	0.59***
Value (r_1)	0.04***	0.02**
List × Value (r_2)	0.004***	0.003**
NoS (r_3)	0.12***	0.04***
List × NoS (r_4)	0.005**	0.002+
ST (r_5)	0.02***	0.001**
List × ST (r_6)	0.003**	0.001**

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. Level 1 was of the form $\eta_{ij} = \pi_{0j} + \pi_{1j}$ (Value) + π_{2j} (List × Value) + π_{3j} (NoS) + π_{4j} (List × NoS) + π_{5j} (ST) + π_{6j} (List × ST). Level 2 was of the form $\pi_{0j} = \beta_{00} + \beta_{01}$ (Condition) + r_{0j}, $\pi_{1j} = \beta_{10} + \beta_{11}$ (Condition) + r_{1j}, $\pi_{2j} = \beta_{20} + \beta_{21}$ (Condition) + r_{2j}, $\pi_{3j} = \beta_{30} + \beta_{31}$ (Condition) + r_{3j}, $\pi_{4j} = \beta_{40} + \beta_{41}$ (Condition) + r_{4j}, $\pi_{5j} = \beta_{50} + \beta_{51}$ (Condition) + r_{5j}, $\pi_{6j} = \beta_{60} + \beta_{61}$ (Condition) + r_{6j}. Condition was anchored on the sequential study condition (i.e., 0 = *sequential*, 1 = *simultaneous*).

+ $p < .10$

*+ $p = .05$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 6

Two-level hierarchical generalized linear mediation analysis of recall performance in the sequential condition in Experiment 2

Fixed effects	Model 1	Model 2a: Study time	Model 2b: Studied or Not studied	Model 3
Intercept (β_{00})	-1.51***	1.84***	2.13**	-11.63***
Value (β_{10})	0.32***	0.20***	0.02	0.26**
Order (β_{20})	-0.24***	-0.18***	-0.68***	-0.10***
List × Value (β_{30})	0.05*	0.04*	-0.01	0.04*
List × Order (β_{40})	0.01	0.04***	0.02	0.01
Studied or Not studied (β_{50})	---	---	---	10.90***
Study time (β_{60})	---	---	---	0.26***
Random effects	**Variance**	**Variance**	**Variance**	**Variance**
Intercept (person-level) (r_0)	0.42***	0.13**	11.08***	0.18
Value (r_1)	0.10***	0.03***	0.04	0.08
Order (r_2)	0.03***	0.03***	0.44***	0.01
List × Value (r_3)	0.004***	0.001	0.02	0.003
List × Order (r_4)	0.002***	0.001**	0.19***	0.0003
Studied or Not studied (r_5)	---	---	---	0.92
Study time (r_6)	---	---	---	0.02

Note. Recall performance was coded as 0 (*not recalled*) or 1 (*recalled*); study selections were coded as 0 (*not studied*) or 1 (*studied*). As applicable, logit link function was used to address binary dependent variables. Level 1 models in Model 1, Model 2a, and Model 2b were of the form η_{ij} (binary outcomes) or Y_{ijk} (continuous outcomes) = $\pi_{0j} + \pi_{1j}$ (Value) + π_{2j} (Order) + π_{3j} (List × Value) + π_{4j} (List × Order). Level 1 of Model 3 was of the form $\eta_{ij} = \pi_{0j} + \pi_{1j}$ (Value) + π_{2j} (Order) + π_{3j} (List × Value) + π_{4j} (List × Order) + π_{5j} (Studied or Not studied) + π_{6j} (Study time). Level 2 models were of the form $\pi_{0j} = \beta_{00} + r_{0j}$, $\pi_{1j} = \beta_{10} + r_{1j}$, et cetera.

* $p < .05$

** $p < .01$

*** $p < .001$