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Metacognitive control, serial position effects, and effective transfer to self-paced study

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Abstract
Serial position effects involve the differential recall of information based on its temporal order at encoding. Previous research indicates that learners may be aware of these effects under certain encoding conditions, but it is unclear whether metacognitive control is sensitive to serial position effects. The current study examined whether there are serial position effects in participants' study time and whether they can learn about serial position effects under fixed encoding conditions and then transfer what they have learned to self-paced study conditions. Specifically, participants were given lists of to-be-remembered words and studied each word for a fixed duration on initial lists, but self-paced their study time on later lists. Results revealed that self-paced study times oppositely mirrored serial position effects (i.e., briefer study times in the beginning and end of each list), and serial position effects were reduced in self-paced study conditions, particularly in participants initially studying under fixed conditions before self-pacing their study time. Specifically, participants may have monitored their output and, based on observations of forgetting middle items, transferred their learning of serial position effects from prior lists. Thus, participants may use forgetting and serial position information to guide encoding, indicating that fundamental properties of the memory system can be incorporated into the processes that guide metacognitive control.

Keywords Serial position effects · Metacognition · Control · Transfer of learning

In free recall tests of memory for word lists containing around 10 or more units of information, the likelihood that an item is recalled is often predicted by its location within the list, known as the serial position effect (Glanzer & Cunitz, 1966; Murdock, 1962; Waugh & Norman, 1965). Specifically, the serial position effect involves enhanced recall for the information presented in the beginning (primacy items) and at the end of a list (recency items) relative to information in the middle. Elevated recall for primacy and recency items can occur in many contexts, such as recalling lists of words (e.g., Grenfell-Essam & Ward, 2012; Unsworth & Engle, 2007), when remembering information offloaded to an external memory source (e.g., Kelly & Risko, 2019), and when recalling the presidents of the United States (e.g., Roediger & Crowder, 1976).

While primacy effects generally arise as a result of increased rehearsal, recency effects are largely attributed to the retrieval phase. For example, during a given item's presentation, participants also often rehearse previously presented items resulting in primacy items getting the most rehearsal, leading to better memorability for primacy items (see Fischler et al., 1970; Rundus, 1971; Rundus & Atkinson, 1970). In contrast, the recency effect largely depends on the delay between the presentation of the final to-be-remembered item and the beginning of the recall test. Specifically, if the recall test immediately follows the study phase, participants often dump the most recently rehearsed items from working memory stores resulting in pronounced recency effects (Crowder, 1969). However, a delay between the encoding phase and the recall test generally reduces recency effects (Glanzer & Cunitz, 1966; Howard & Kahana, 1999; Waugh & Norman, 1965). Thus, serial position effects typically arise as a result of both encoding and retrieval processes.

To evaluate people's awareness of their memory processes (i.e., metacognition; Nelson & Narens, 1990; see also Dunlosky et al., 2016; Nelson, 1996), researchers often solicit judgments of learning (JOLs): metacognitive self-assessments of the likelihood of later remembering information (see

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Rhodes, 2016, for a review). When JOLs are made immediately after an item is studied, these judgments are often informed by the cues available during learning. Koriat (1997) proposed a useful theoretical framework for evaluating the cues that inform JOLs whereby three types of cues inform metacognitive judgments: *intrinsic*, *extrinsic*, and *mnemonic* cues. Intrinsic cues include processing fluency, word-pair relatedness, or other characteristics that influence or are believed to influence memory. Extrinsic cues involve the learner's encoding operations as well as factors such as study time, the type of memory test, or the presence of a distractor task. Lastly, mnemonic cues involve learners' experience with the to-be-learned material such as how easily an item comes to mind in response to a cue. Although judgments are sometimes based on cues that do not influence memory performance, such as font size or word volume (e.g., Rhodes & Castel, 2008, 2009), within this framework, JOLs are generally accurate if judgments and performance are based on the same factors (Dunlosky & Matvey, 2001; Tiede & Leboe, 2009; see also Bröder & Undorf, 2019; Koriat, 2015).

To determine whether people are metacognitively aware of serial position effects, Dunlosky and Matvey (2001) presented participants with lists of either related or unrelated word pairs and asked them to predict the likelihood of remembering each pair. Results revealed that these predictions were generally less sensitive to serial position (i.e., an extrinsic cue in this instance) compared with intrinsic cues like the relatedness of the word pairs. Thus, in some encoding conditions, people are metacognitively unaware of serial position effects and instead base predictions of future remembering on the intrinsic qualities of the information.

To reduce the extent to which participants rely on intrinsic cues and to increase the influence of extrinsic cues on participants' metacognitive judgments, Castel (2008) presented participants with word lists and asked them to make a *pre-JOL* (a JOL before studying each word; see also Mueller & Dunlosky, 2017). On initial study–test trials, participants did not properly incorporate serial position information but were able to learn about primacy and recency effects after gaining task experience (i.e., after several lists). As a result, on later lists, pre-JOLs generally mirrored actual recall performance whereby judgments and recall were greatest for primacy and recency items. Thus, when making judgments before encoding each item, no intrinsic cues are available at the time of the judgment leaving only extrinsic and mnemonic cues to inform JOLs and experience-based learning can lead to better informed and more accurate metacognition.

If participants use intrinsic cues like item relatedness or processing fluency to monitor their learning (e.g., Rhodes & Castel, 2008, 2009), this can lead to an inefficient allocation of study time and potentially poorer memory outcomes (e.g., Metcalfe & Finn, 2008). In contrast to measures of metacognitive monitoring (i.e., JOLs), metacognitive control processes are based on information gained from monitoring and are often captured by the self-regulation of study time (Dunlosky et al., 2016; Egner, 2017; Nelson, 1996; Nelson & Narens, 1990; Son & Metcalfe, 2000; Thiede & Dunlosky, 1999). Prior research has illustrated that metacognition plays a vital role not only in monitoring one's memory but also in controlling learning by selecting what information to study for longer periods (see Ariel, 2013; Ariel & Dunlosky, 2013; Ariel et al., 2009; Dunlosky & Ariel, 2011a, 2011b, for agenda-based regulation framework). However, research has yet to determine how serial position effects influence metacognitive control processes.

Previous work has indicated that learners' allocation of their rehearsal time for items in each serial position drives serial position effects (Fischler et al., 1970; Rundus, 1971; Rundus & Atkinson, 1970) and under certain encoding conditions, people have some metacognitive awareness of serial position effects (Castel, 2008). However, research has yet to examine how this awareness can influence study behavior and subsequent memory performance (but see Krinsky, 1993). Specifically, we were interested in how participants incorporate extrinsic or mnemonic factors such as serial position effects when making study decisions.

The current study

Much prior work examining serial position effects has manipulated presentation rate and list length (e.g., Brodie & Murdock, 1977; Glanzer & Cunitz, 1966; Murdock, 1962; Roberts, 1972; Tan & Ward, 2000; Waugh, 1967), and there has been continued interest in theories of free recall (Brown et al., 2007; Davelaar et al., 2005; Farrell, 2012; Laming, 2010; Lehman & Malmberg, 2013; Lohnas et al., 2015; Polyn et al., 2009; Sederberg et al., 2008) but little work has investigated how learners self-pace their study time as a function of presentation position. Although there is some evidence of potentially inverted serial position effects in learners' allocation of study time within a list (see Krinsky, 1993; Unsworth, 2016; Zimmerman, 1975; see also Belmont & Butterfield, 1971; Kellas et al., 1973; Kellas & Butterfield, 1971; McFarland & Kellas, 1974), further work is necessary to replicate these effects and determine whether participants can learn about serial position effects and maximize recall on later lists via strategic metacognitive control mechanisms to counteract serial position effects.

In the current study, we investigated whether participants demonstrate serial position effects in their study time for a list of to-be-remembered words and if participants can learn to predict the serial position curve to maximize learning. Specifically, we presented participants with lists of to-be-remembered words, along with the item's serial position within the list, to determine whether participants can learn about serial position effects as a product of task experience and effectively apply their knowledge of serial position effects to optimize memory performance, a process potentially involving the transfer of learning (the influence of prior learning on the learning of new material; McGeoch, 1942; see Barnett & Ceci, 2002, for a review).

After several study–test trials with fixed study time, we allowed participants to self-pace their study time on later lists. Rather than allocating similar amounts of study time to each item, we expected participants self-pacing their study time to demonstrate metacognitive awareness of serial position effects after gaining task experience. Specifically, we expected participants to spend less time studying primacy and recency items and more time studying items in the middle of each list by transferring their learning of serial position effects from prior lists to more effectively engage metacognitive control mechanisms to counteract serial position effects and maximize memory performance.

In addition to understanding whether people can learn from experience and subsequently shift patterns of self-paced study based on their awareness of serial position effects, we were also interested in the efficiency of self-paced study time. For example, there are instances whereby the allocation of more study time for a given item is not accompanied by a corresponding benefit to memory performance (i.e., the labor-in-vain effect; see Nelson & Leonesio, 1988). This surplus of study time in hopes to achieve a desired level of performance illustrates the potential memory inefficiency as a consequence of poor metacognitive control. Applied to serial position effects, if participants spend more time studying primacy and recency items compared with items in the middle of a list, this may lead to an overall recall deficit as a result of the labor-in-vain effect. Conversely, if participants take serial position effects into account and differentially allocate their study time across serial positions, this could lead to a flattening of the serial position curve and better recall efficiency.

Experiment 1

In Experiment 1, participants studied six lists of 15 words, and each word was presented alongside its serial position within the list (e.g., 1. Table, 2. Shirt . . . 15. Lamp) such that participants were aware of the serial position of each word (see Castel, 2008). Participants either studied each item for 2 seconds, self-paced their study time (with a maximum of 8 seconds), or studied each item for 2 seconds on the first three lists and then self-paced their study time (with a maximum of 8 seconds) on the last three lists. This final "transfer" condition allowed for an examination of how participants might learn about serial position effects without any need to control their study time on early lists and use this knowledge to inform subsequent study allocation decisions. Specifically, the absence of any metacognitive control aspects on initial lists may allow learners to get better acclimated to serial position effects, leading to a recall advantage for middle items on later lists and a reduction in serial position effects.

Method

Participants After exclusions, participants were 126 undergraduate students (M_{age} = 19.83, SD_{age} = 1.98) recruited from the University of California Los Angeles (UCLA) Human Subjects Pool. Participants were tested online and received course credit for their participation. Participants were excluded from analysis if they admitted to cheating (e.g., writing down answers) in a posttask questionnaire (participants were told that they would still receive credit if they cheated). This exclusion process resulted in two exclusions. A sensitivity analysis indicated that for a repeated-measures, between-subjects analysis of variance (ANOVA) with three groups (study schedule: fixed, self-paced, transfer) and six measurements (list), with a medium correlation between repeated measures (recall on Lists 1–6, r = .58), assuming alpha = .05, power = .90, the smallest effect (interaction between group and list) the design could reliably detect is η^2 = .01.

Materials and procedure Participants were told that they would be presented with six lists of words, with each list containing 15 words, and that their task was to remember the words for a later test. Words were accompanied by their serial position within the list (e.g., 9. Twig, 10. Donkey, 11. Book) and the words were nouns that contained between four and seven letters and had an everyday occurrence rate of at least 30 times per million (Thorndike & Lorge, 1944). In the study phase, study time was either fixed (2 seconds; n = 42), self-paced (maximum of 8 seconds; n = 43), or fixed (2 seconds) for the first three lists and self-paced (maximum of 8 seconds) for the last three lists (n = 41). After the presentation of all 15 words, participants were given an immediate free recall test (1 minute) in which they recalled as many words as they could from the list, in any order they wished. Immediately following the recall period, participants were informed of the number of correctly recalled words for that list, but were not given feedback about specific items. Following the conclusion of the task, participants reported what encoding strategies (if any) they had used to remember the words. Specifically, participants indicated whether they simply read each word as it appeared, repeated the words as much as possible, developed rhymes for the words, used sentences to link the words together, developed mental images of the words, grouped the words in a meaningful way, or utilized some other strategy (participants could select some, all, or none).

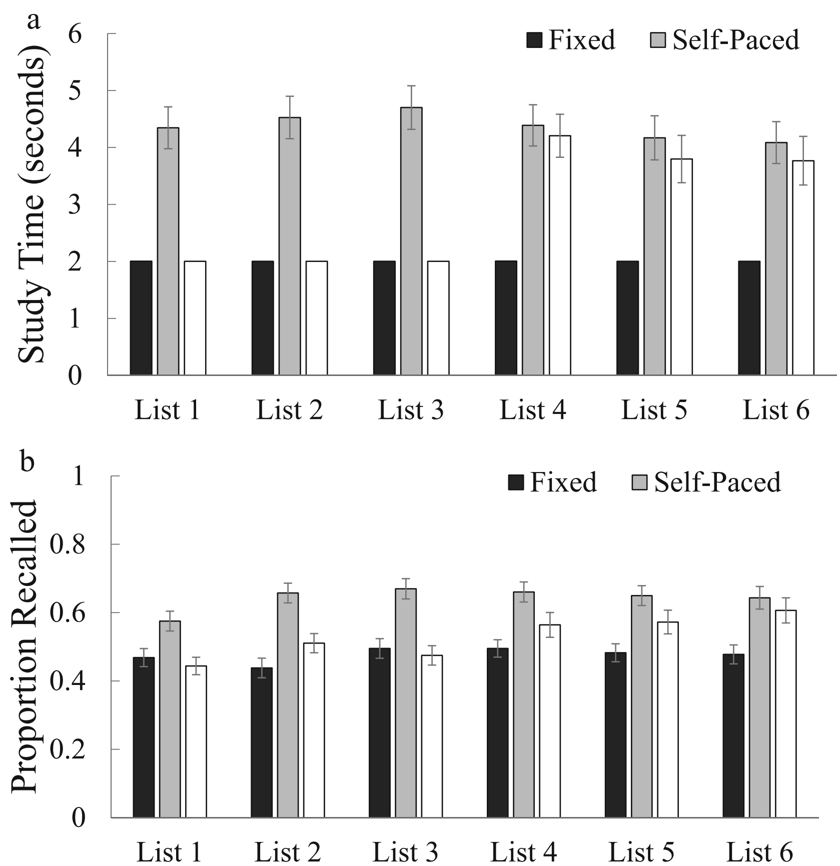

Fig. 1 Study time (**a**) and recall (**b**) as a function of study schedule and list in Experiment 1. Error bars reflect the standard error of the mean

Results

Effects of experience Study time as a function of study schedule and list is shown in Fig. 1a. To compare study time on self-paced lists, we conducted a 2 (study schedule: transfer, self-paced[1]) × 3 (list: 4–6) repeated-measures, between-subjects ANOVA. However, Mauchly's test of sphericity indicated violations for list (Mauchly's W = .88, p = .005). Huynh–Feldt-corrected results revealed a main effect of list, $F(1.82, 149.38) = 4.38$, $p = .017$, $\eta^2 = .05$, such that study time decreased on later lists, but pairwise comparisons did not reveal any significant differences between study time on List 4 (M = 4.30, SD = 2.38), List 5 (M = 3.99, SD = 2.59), and List 6 (M = 3.93, SD = 2.56; all $p_{\mathrm{bonf}} > .058$). Furthermore, results did not reveal a main effect of study schedule, $F(1, 82) = .30$, $p = .583$, $\eta^2 < .01$, such that participants in the self-paced study condition (M = 4.21, SD = 2.31) spent a similar amount of time studying each word as participants in the transfer condition (M = 3.92, SD = 2.53). Moreover, list did not interact with study schedule, $F(1.82, 149.38) = .26$, $p = .748$, $\eta^2 < .01$.

To examine differences in overall recall performance (see Fig. 1b), a 3 (study schedule: fixed, self-paced, transfer) × 6 (list) repeated-measures, between-subjects ANOVA revealed a main effect of list (Mauchly's W = .70, p < .001: Huynh–Feldt-corrected results), $F(4.60, 565.14) = 6.89$, $p < .001$, η^2 = .05, such that the proportion of words recalled improved with task experience. Additionally, results revealed a main effect of study schedule, $F(2, 123) = 13.53$, $p < .001$, $\eta^2 = .05$, such that participants self-pacing their study time recalled a greater proportion of words (M = .64, SD = .15) than participants with fixed study time (M = .48, SD = .14; $p_{\mathrm{bonf}} < .001$, d = .45) and participants in the transfer condition (M = .53, SD = .17; p_{bonf} = .002, d = .31); however, participants with fixed study time recalled a similar proportion of words as participants in the transfer condition (p_{bonf} = .346, d = .14). Moreover, list interacted with study schedule, $F(9.19, 565.14) = 3.31$, p < .001, η^2 = .05, such that participants in the transfer condition increased their recall performance once able to self-pace their study time.

Serial position effects To examine study time as a function of serial position and study schedule (see Fig. 2a), we computed a series of quadratic regressions. As shown in Table 1 (top panel), there were reverse serial position effects in

[1] We did not include the fixed study time group in this analysis, because study time was constant (2 seconds).

Table 1 Quadratic regression with study time (top) and recall (bottom) predicted by serial position in Experiment 1

Study Schedule	R^2	*b1*	*b2*	*F*	*p*
Self-Paced (Lists 1-3)	.028	.307	-.203	27.45	< .001
Self-Paced (Lists 4-6)	.044	.251	-.203	44.53	< .001
Transfer (Lists 4-6)	.028	.094	-.013	26.43	< .001

Study Schedule	R^2	*b1*	*b2*	*F*	*p*
Fixed (Lists 1-3)	.074	-.135	.008	75.45	< .001
Fixed (Lists 4-6)	.085	-.133	.009	88.16	< .001
Self-Paced (Lists 1-3)	.047	-.093	.005	47.16	< .001
Self-Paced (Lists 4-6)	.042	-.095	.006	42.72	< .001
Transfer (Lists 1-3)	.070	-.130	.008	69.23	< .001
Transfer (Lists 4-6)	.053	-.097	.007	51.52	< .001

participants' study time such that they spent more time studying items in the middle of the list compared with primacy and recency items, and this effect was strongest[2] in participants self-pacing their study time, particularly on Lists 4–6. Similarly, to examine recall as a function of serial position and study schedule (see Fig. 2b), a series of quadratic regressions (see Table 1, bottom panel) revealed that there were serial position effects in participants' recall such that primacy and recency items were recalled better than items in the middle of the list, but when participants were allowed to self-pace their study time, serial position effects were reduced. Particularly, participants in the transfer condition showed a greater reduction in serial position effects on later lists than participants self-pacing their study time on all six lists.

Output order To investigate whether serial position predicted the output position of retrieved items, we conducted a multilevel model (MLM) where we treated the data as hierarchical or clustered (i.e., multilevel), with items nested within individual participants. Across lists and conditions, results revealed that serial position significantly negatively predicted output position, $t(6149) = -8.47$, $p < .001$, such that the later the presentation position, the earlier in the retrieval phase words tended to be recalled. Thus, on an immediate recall test, recency items can still be well recalled despite shorter study times if they are outputted first.

Efficiency Next, we computed a recall "efficiency" index for each participant by dividing the proportion of words recalled on a given list by the average study time per word for that list. A 3 (study schedule: fixed, self-paced, transfer) × 6 (list) repeated-measures, between-subjects ANOVA revealed a main effect of list (Mauchly's $W = .10$, $p < .001$: Huynh–Feldt-corrected results), $F(2.37, 291.53) = 3.86$, $p = .016$, $\eta^2 = .03$, such that efficiency increased with task experience. However, there was not a main effect of study schedule, $F(2, 123) = 1.33$, $p = .270$, $\eta^2 = .02$, such that participants with fixed study time ($M = .24$, $SD = .07$), participants self-pacing their study time ($M = .21$, $SD = .12$), and participants in the transfer condition ($M = .24$, $SD = .10$) were similarly efficient. Finally, list interacted with study schedule, $F(4.74, 291.53) = 2.78$, $p = .020$, $\eta^2 = .04$, such that participants in the transfer condition became more efficient once able to self-pace their study time, potentially resulting from greater encoding effort or strategies on middle items.

Strategy use Participants generally reported using multiple encoding strategies ($M = 3.26$, $SD = 1.25$), but this did not reliably differ between each group, $F(2, 123) = 2.60$, $p = .079$, $\eta^2 = .04$. In terms of each specific strategy, 74% reported reading the words as they appeared, 77% reported engaging in rote rehearsal, 11% reported developing rhymes for the words, 60% reported using sentences to link the words together, 52% reported grouping the words in a meaningful way, and 53% reported using mental imagery.

Discussion

In Experiment 1, allowing participants to self-pace their study time reduced serial position effects compared with fixed study conditions. Specifically, serial position effects may have been reduced as a result of participants spending more time studying items in the middle of each list, indicating some metacognitive awareness of primacy and recency effects. Additionally, participants appear to learn about serial position effects as a result of task experience (i.e., after several lists) and use this knowledge to inform future study decisions

[2] Since each model is based on different data (i.e., Lists 1–3 versus Lists 4–6), we are unable to compute a formal comparison between models. Rather, we examine the serial position curves in terms of their relative effect sizes (i.e., R^2). Specifically, we frame our discussion in terms of how much of the variance the relative quadratic models accounted for, with models accounting for more variance (revealing a greater quadratic trend) indicating more pronounced serial position effects and models accounting for less variance (revealing a weaker quadratic trend) indicating flatter serial position curves.

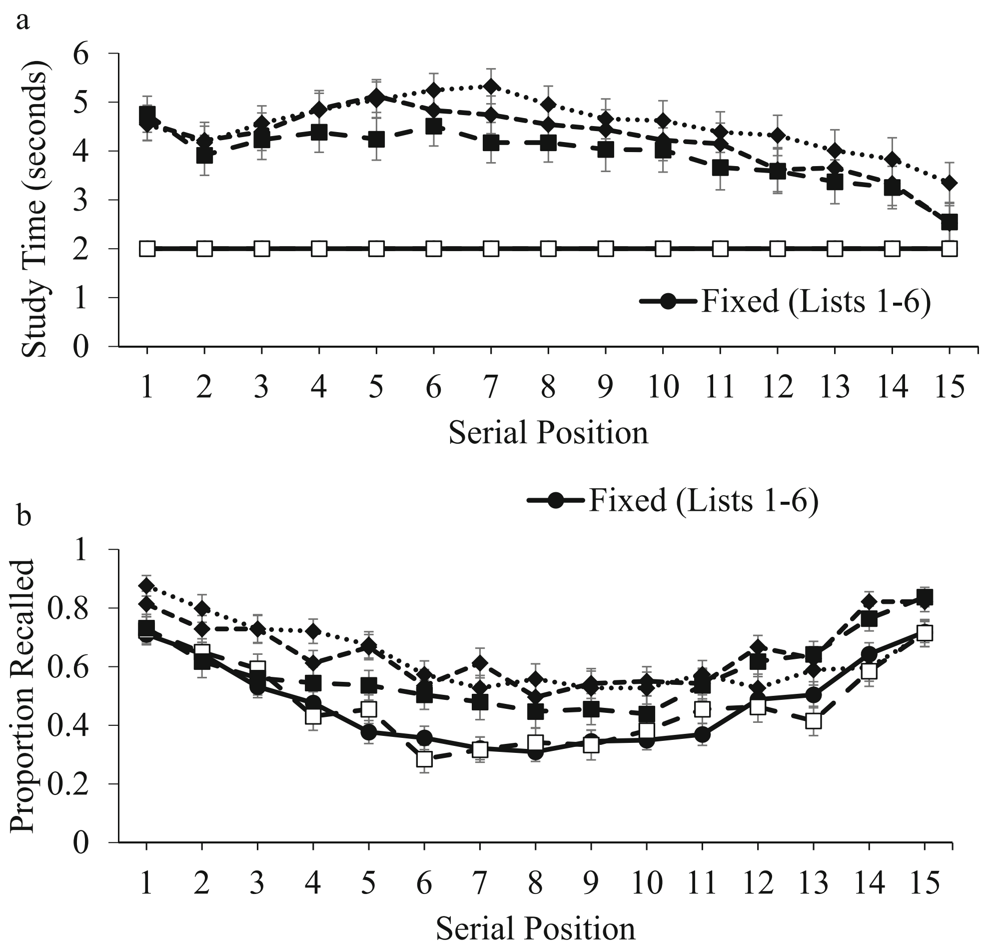

Fig. 2 Study time (**a**) and free recall probability (**b**) as a function of serial position in Experiment 1. Error bars reflect the standard error of the mean

whether study time on initial lists was fixed or self-paced. Thus, although not asked to estimate the likelihood of remembering each item, participants may be monitoring their output and engaging in strategic metacognitive control mechanisms to maximize memory output.

Experiment 2

In Experiment 1, both groups of participants that were given the opportunity to self-pace their study time showed a reduction in serial position effects compared with participants under fixed encoding conditions. However, learners in the transfer condition may have anchored their study time on later lists based on the relatively short study time given on the first three lists. These participants may have shown a greater reduction in serial position effects and transfer of learning if given more time to study the items on initial lists. In Experiment 2, we investigated how participants self-pace their learning on later lists when study time is longer on the first three lists as well as the subsequent effects on their serial position effects and recall efficiency. We used similar methods as in Experiment 1, but participants either studied the first three lists for 2 seconds or 5.5 seconds before self-pacing their study time for the last three lists.

Method

Participants After exclusions, participants were 88 undergraduate students (M_{age} = 19.93, SD_{age} = 2.16) recruited from the UCLA Human Subjects Pool. Participants were tested online and received course credit for their participation. Participants were excluded from analysis if they admitted to cheating (e.g., writing down answers) in a posttask questionnaire (participants were told that they would still receive credit if they cheated). This exclusion process resulted in two exclusions. A sensitivity analysis indicated that for a repeated-measures, between-subjects ANOVA with two groups (study schedule: 2 seconds initial study, 5.5 seconds initial study) and six measurements (list), with a medium correlation between repeated measures (recall on Lists 1–6, r = .57), assuming alpha = .05, power = .90, the smallest effect (interaction between group and list) the design could reliably detect is η^2 = .01.

Materials and procedure The materials and procedure in Experiment 2 were similar to Experiment 1, except that participants either studied the first three lists for 2 seconds (n = 44) or 5.5 seconds (n = 44) before self-pacing study time (maximum of 8 seconds) for the last three lists.

Results

Effects of experience Study time as a function of study schedule and list is shown in Fig. 3a. To examine group differences in study time on the self-paced lists, a 2 (study schedule: 2 seconds initial study, 5.5 seconds initial study) × 3 (Lists 4–6) repeated-measures, between-subjects ANOVA revealed a main effect of list (Mauchly's W = .84, p < .001; Huynh–Feldt-corrected results), $F(1.76, 151.51) = 8.67$, $p < .001$, η^2 = .09, such that study time on List 4 (M = 4.24, SD = 2.41) was greater than study time on List 5 (M = 3.76, SD = 2.50; p_{bonf} = .006, d = .34) and List 6 (M = 3.71, SD = 2.51; p_{bonf} = .003, d = .36); however, study time on Lists 5 and 6 was similar (p_{bonf} > .999, d = .05). Additionally, results revealed a main effect of study schedule, $F(1, 86) = 9.33$, $p = .003$, η^2 = .10, such that participants studying each word for 2 seconds on initial lists spent less time studying each word on later lists (M = 3.17, SD = 2.19) than participants studying each word for 5.5 seconds on initial lists (M = 4.64, SD = 2.54). However, list did not interact with study schedule, $F(1.76, 151.51) = .83$, $p = .424$, η^2 = .01. Thus, there were anchoring effects such that a greater fixed study time on initial lists led to increased self-paced study time on later lists.

To examine recall as a function of task experience (see Fig. 3b), we conducted a 2 (study schedule: 2 seconds initial study, 5.5 seconds initial study) × 6 (list) repeated-measures, between-subjects ANOVA. Results revealed a main effect of list (Mauchly's W = .61, p < .001; Huynh–Feldt-corrected results), $F(4.33, 372.07) = 3.22$, $p = .011$, η^2 = .03, such that recall improved with task experience. Additionally, results revealed a main effect of study schedule, $F(1, 86) = 7.51$, p = .007, η^2 = .08, such that participants initially studying each word for 5.5 seconds (M = .64, SD = .17) recalled more words than participants initially studying each word for 2 seconds (M = .54, SD = .16). Moreover, list interacted with study schedule, $F(4.33, 372.07) = 6.84$, $p < .001$, η^2 = .07, such that, once able to self-pace their study time, recall increased in participants initially studying each word for 2 seconds.

Serial position effects To examine recall as a function of serial position when study time was fixed (Lists 1–3; see Fig. 4a), we computed a series of quadratic regressions. As shown in

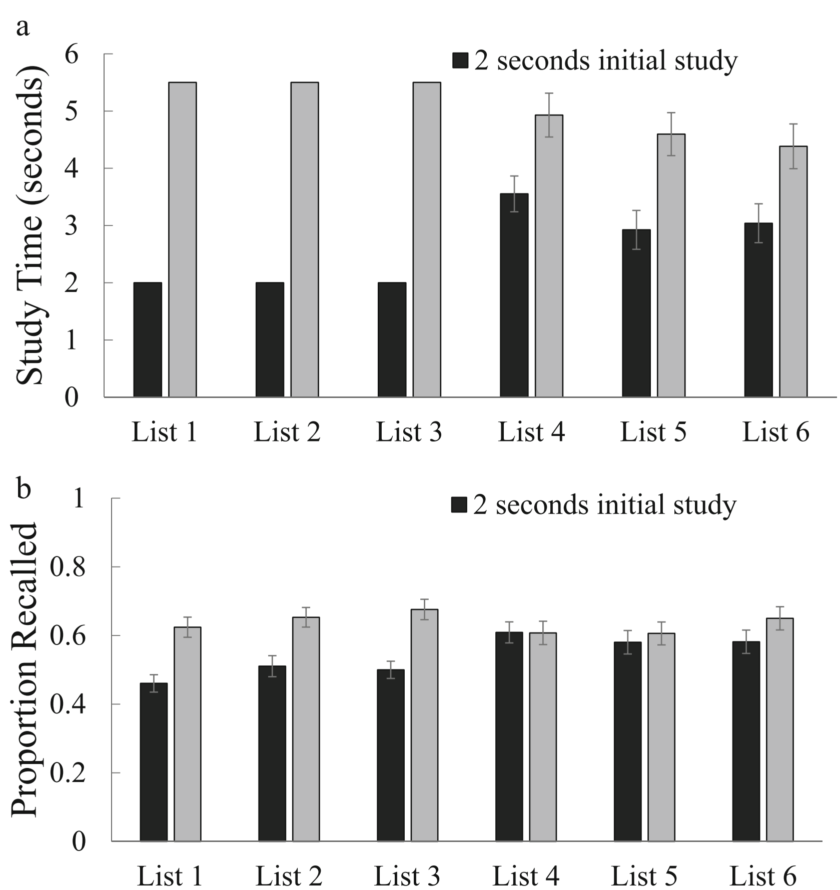

Fig. 3 Study time (**a**) and recall (**b**) as a function of study schedule and list in Experiment 2. Error bars reflect the standard error of the mean

Table 2 (bottom panel), both groups showed serial position effects, but serial position effects were more pronounced in participants studying each item for 2 seconds. Next, quadratic regressions of study time predicted by serial position on Lists 4–6 (see Fig. 4b) revealed that there were serial position effects in participants' study time, and this effect was strongest in participants initially studying each item for 2 seconds (see Table 2, top panel). Furthermore, to examine recall as a function of serial position when study time was self-paced (Lists 4–6; see Fig. 4c), quadratic regressions revealed that participants again showed serial position effects and this effect was still more pronounced in participants initially studying each item for 2 seconds (see Table 2, bottom panel).

Output order To investigate output position as a function of serial position, we conducted a MLM with items nested within individual participants. Results revealed that serial position significantly negatively predicted output position, $t(4593) = -7.63$, $p < .001$, such that the greater the serial position, the sooner in the retrieval phase words tended to be recalled, similar to Experiment 1.

Efficiency To illustrate group differences in recall efficiency (proportion of words recalled divided by study time per word), a 2 (study schedule: 2 seconds initial study, 5.5 seconds initial study) × 6 (list) repeated-measures, between-subjects ANOVA revealed a main effect of list (Mauchly's $W = .05$, $p < .001$: Huynh–Feldt-corrected results), $F(2.04, 175.33) = 8.67$, $p < .001$, $\eta^2 = .09$, such that participants became more efficient once able to self-pace their study time. Additionally, results revealed main effect of study schedule, $F(1, 86) = 43.67$, $p < .001$, $\eta^2 = .34$, such that participants initially studying each item for 2 seconds were more efficient ($M = .26$, $SD = .09$) than participants initially studying each item for 5.5 seconds ($M = .15$, $SD = .06$). However, list did not interact with study schedule, $F(2.04, 175.33) = 1.56$, $p = .213$, $\eta^2 = .02$.

Strategy use Participants generally reported using multiple encoding strategies ($M = 2.98$, $SD = 1.26$), but this reliably differed between each group, $t(86) = 2.62$, $p = .010$, $d = .56$, such that participants initially studying each item for 5.5 seconds reported using more encoding strategies ($M = 3.32$, $SD = 1.16$) than participants initially studying each item for 2 seconds ($M = 2.64$, $SD = 1.28$), perhaps due to having more time to study each word. In terms of each specific strategy, 77% reported reading the words as they appeared, 78% reported engaging in rote rehearsal, 8% reported developing rhymes for the words, 57% reported using sentences to link the words together, 39% reported grouping the words in a meaningful way, and 39% reported using mental imagery.

Discussion

Similar to Experiment 1, when self-pacing their study time, participants spent more time studying items in the middle of the list indicating a metacognitive awareness of serial position effects in long-term memory. Therefore, metacognitive control may be tuned to serial position effects such that participants differentiate their study time in response to the perceived effectiveness of learning, correctly noting that recall is poorer for items in the middle of the lists and reacting by spending more time studying these items. However, the flattening of the serial position curve in the group initially studying each word for 5.5 seconds occurred without the reverse serial position effects in study time (which was fixed), indicating that differentially allocating study time may not be necessary for the flattening of the serial position curves. Specifically, before the self-paced study lists, the group studying each item for 2 seconds likely did not have time for strategic rehearsal while the group studying each item for 5.5 seconds likely had sufficient time to increase effort and attention to the mid-list items. Thus, the experience of output failure may influence subsequent studying or rehearsal under both fixed and self-paced encoding conditions.

In Experiment 2, although both groups became more efficient once able to self-pace their study time, when the initial fixed study time was 5.5 seconds compared with 2 seconds, participants spent more time studying each word on later lists without a recall advantage. Consequently, participants initially studying each item for 2 seconds were more efficient than

Table 2 Quadratic regression with study time (top) and recall (bottom) predicted by serial position in Experiment 2

Study Schedule	R^2	*b1*	*b2*	*F*	*p*
2 seconds initial study (Lists 4-6)	.055	.196	-.020	57.36	< .001
5.5 seconds initial study (Lists 4-6)	.030	.171	-.017	31.09	< .001

Study Schedule	R^2	*b1*	*b2*	*F*	*p*
2 seconds initial study (Lists 1-3)	.084	-.142	.009	90.95	< .001
5.5 seconds initial study (Lists 1-3)	.053	-.103	.006	54.94	< .001
2 seconds initial study (Lists 4-6)	.058	-.111	.007	61.28	< .001
5.5 seconds initial study (Lists 4-6)	.031	-.080	.005	31.22	< .001

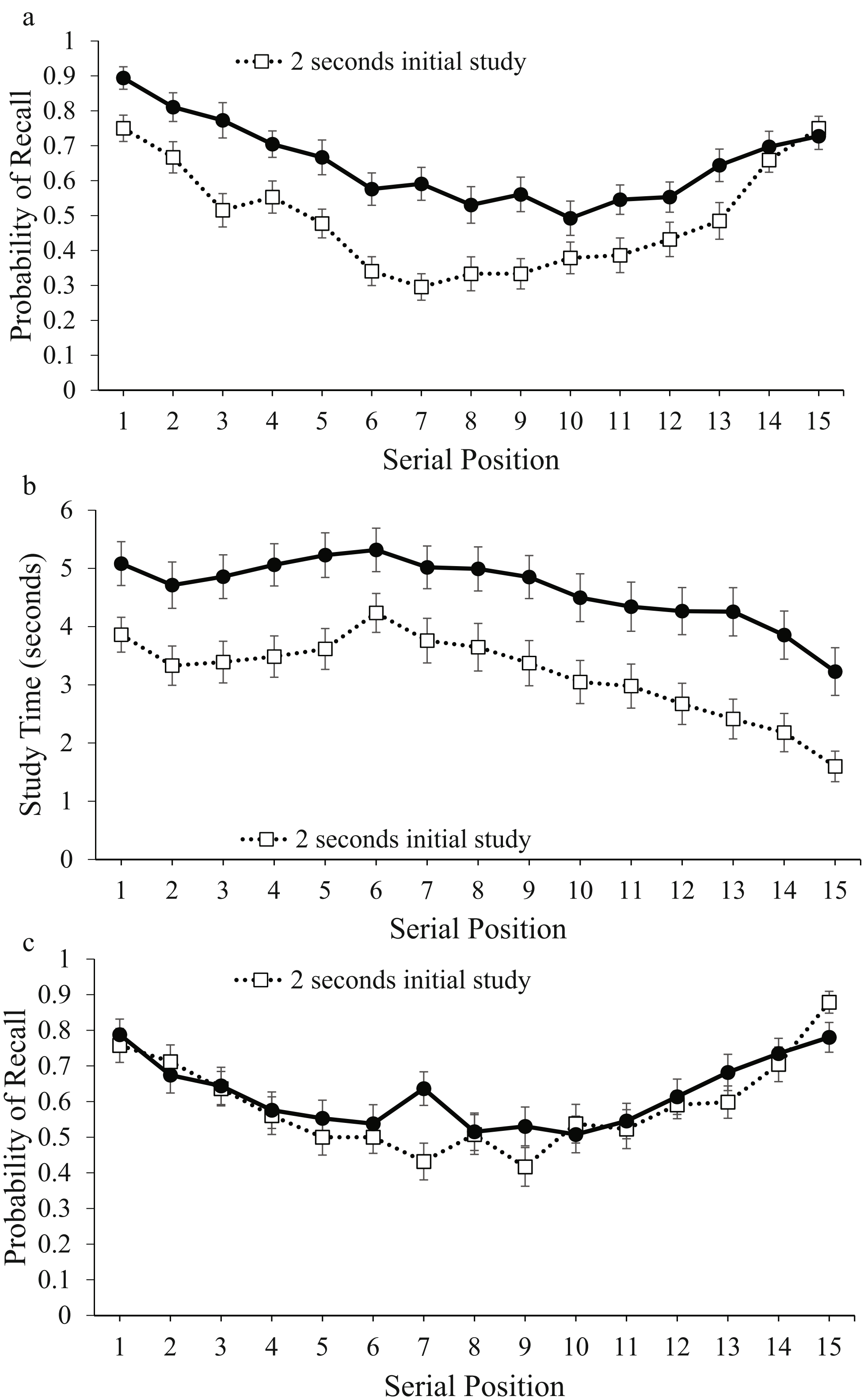

Fig 4 Free recall probability on Lists 1–3 (**a**), study time on Lists 4–6 (**b**), and free recall probability on Lists 4–6 (*c*) as a function of serial position in Experiment 2. Error bars reflect the standard error of the mean

participants initially studying for 5.5 seconds. This more efficient learning in participants with more limited initial study time may be due to a transfer of learning in metamemory. Specifically, when initial study time is briefer, and participants feel rushed (resulting in more pronounced serial position effects), the need to engage more efficient metacognitive mechanisms may become more prevalent, and participants may transfer this learning to later lists by using more efficient strategies to encode each item. Thus, after observing instances of forgetting items from the middle of the list, participants can become more efficient in their memory for these items.

Experiment 3

In Experiments 1 and 2, we demonstrated reverse serial position effects in participants' study time, potentially the result of participants' metacognitive awareness of serial position effects and a transfer of learning to achieve more efficient memory. In Experiment 3, we investigated participants' metacognitive awareness of serial position effects and potential transfer of learning when a delay precedes the recall test. Specifically, participants completed a similar task as in Experiment 1, but with a 30-second distraction task before completing the recall test. Prior work has shown that a recall delay reduces recency effects (Glanzer & Cunitz, 1966; Howard & Kahana, 1999; Waugh & Norman, 1965) and we wanted to determine whether participants adjust study time in light of reduced recency effects resulting from delayed recall.

Method

Participants After exclusions, participants were 132 undergraduate students (M_{age} = 19.81, SD_{age} = 1.76) recruited from the UCLA Human Subjects Pool. Participants were tested online and received course credit for their participation. Participants were excluded from analysis if they admitted to cheating (e.g., writing down answers) in a posttask questionnaire (participants were told that they would still receive credit if they cheated). This exclusion process resulted in four exclusions. A sensitivity analysis indicated that for a repeated-measures, between-subjects ANOVA with three groups (study schedule: fixed, self-paced, transfer) and six measurements (list), with a medium correlation between repeated measures (recall on Lists 1–6, r = .55), assuming alpha = .05, power = .90, the smallest effect (interaction between group and list) the design could reliably detect is η^2 = .01.

Materials and procedure The task in Experiment 3 was similar to the task in Experiment 1, except that instead of completing each free recall test immediately after the study phase, participants first completed a 30-second distraction task requiring them to rearrange the digits of several three-digit numbers in descending order (e.g., 123 would be rearranged to 321; adapted from Rohrer & Wixted, 1994; Unsworth, 2007). Participants were given 3 seconds to view each of the 10 three-digit numbers and subsequently rearrange the digits. Similar to Experiment 1, study time was either fixed (2 seconds; n = 44), self-paced (maximum of 8 seconds; n = 44), or fixed (2 seconds) for the first three lists and self-paced (maximum of 8 seconds) for the last three lists (n = 44).

Results

Effects of experience Study time as a function of study schedule and list is shown in Fig. 5a. To compare study time on self-paced lists, we conducted a 2 (study schedule: transfer, self-paced[3]) × 3 (list: 4–6) repeated-measures, between-subjects ANOVA. Results did not reveal a main effect of list (Mauchly's W = .83, p < .001; Huynh–Feldt-corrected results), $F(1.74, 149.93)$ = .11, p = .871, η^2 < .01, such that study time on List 4 (M = 3.68, SD = 2.09), List 5 (M = 3.63, SD = 2.08), and List 6 (M = 3.59, SD = 2.32) was similar. Additionally, results did not reveal a main effect of study schedule, $F(1, 86)$ = .17, p = .682, η^2 < .01, such that participants in the self-paced study condition (M = 3.55, SD = 2.06) spent a similar amount of time studying each word as participants in the transfer condition (M = 3.72, SD = 1.84). Furthermore, list did not interact with study schedule, $F(1.74, 149.93)$ = .81, p = .433, η^2 = .01.

To examine differences in overall recall performance (see Fig. 5b), a 3 (study schedule: fixed, self-paced, transfer) × 6 (list) repeated-measures, between-subjects ANOVA revealed a main effect of list (Mauchly's W = .73, p < .001; Huynh–Feldt-corrected results), $F(4.60, 593.44)$ = 10.80, p < .001, η^2 = .07, such that the proportion of words recalled improved with task experience. However, results did not reveal a main effect of study schedule, $F(2, 129)$ = .29, p = .751, η^2 < .01, such that participants self-pacing their study time (M = .52, SD = .19), participants with fixed study time (M = .49, SD = .16), and participants in the transfer condition (M = .51, SD = .19) recalled a similar proportion of words. Moreover, list interacted with study schedule, $F(9.20, 593.44)$ = 3.18, p < .001, η^2 = .04, such that participants in the transfer condition increased their recall performance once able to self-pace their study time.

Serial position effects To examine study time as a function of serial position and study schedule (see Fig. 6a), we computed a series of quadratic regressions. As shown in Table 3 (top panel), there were reverse serial position effects in participants' study time such that participants spent more time studying items in the middle of each list compared with primacy and recency items, but this effect was similar across study schedules. Furthermore, to examine recall as a function of serial position and study schedule (see Fig. 6b), a series of quadratic regressions (see Table 3, bottom panel) revealed that there were serial position effects in participants' recall such

[3] Similar to Experiment 1, we did not include the fixed study time group in this analysis, because study time was constant (2 seconds).

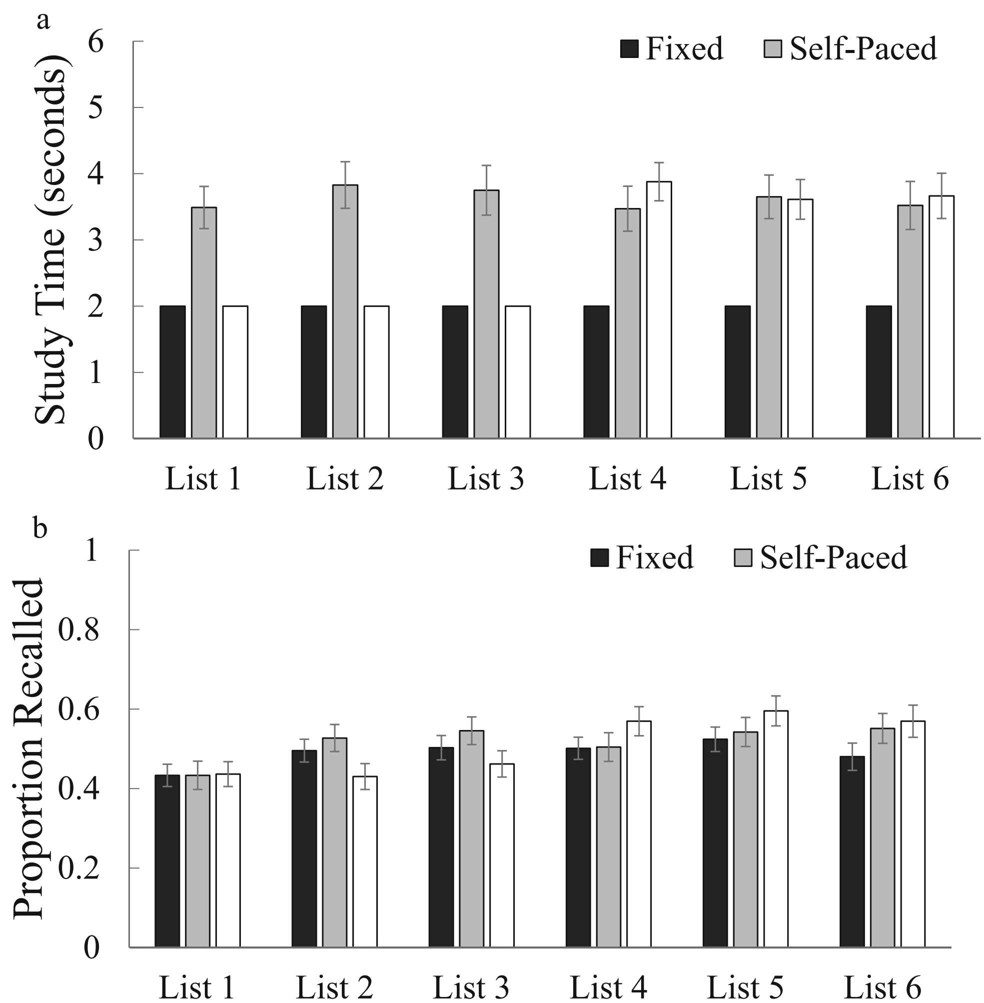

Fig. 5 Study time (**a**) and recall (**b**) as a function of study schedule and list in Experiment 3. Error bars reflect the standard error of the mean

that primacy items were recalled better than items in the middle and end of the list. However, contrary to Experiment 1, when participants were allowed to self-pace their study time, serial position effects were not reduced.

Output order To investigate whether serial position predicted the output position of retrieved items, we conducted a MLM with items nested within individual participants. Results revealed that serial position significantly positively predicted

Table 3 Quadratic regression with study time (top) and recall (bottom) predicted by serial position in Experiment 3

Study Schedule	R^2	*b1*	*b2*	*F*	*p*
Self-Paced (Lists 1-3)	.023	.233	-.019	22.82	< .001
Self-Paced (Lists 4-6)	.023	.196	-.017	22.77	< .001
Transfer (Lists 4-6)	.021	.122	-.012	21.10	< .001

Study Schedule	R^2	*b1*	*b2*	*F*	*p*
Fixed (Lists 1-3)	.061	-.103	.005	64.65	< .001
Fixed (Lists 4-6)	.044	-.099	.005	45.64	< .001
Self-Paced (Lists 1-3)	.058	-.071	.003	61.08	< .001
Self-Paced (Lists 4-6)	.052	-.090	.004	53.97	< .001
Transfer (Lists 1-3)	.039	-.071	.003	40.40	< .001
Transfer (Lists 4-6)	.038	-.073	.003	39.46	< .001

output position, $t(5932) = 22.60$, $p < .001$, such that the earlier the presentation position, the sooner in the retrieval phase words tended to be recalled. Thus, participants spent less time studying recency items and the recall of these items may have also suffered as a consequence of participants recalling primacy items before recency items in the delayed recall test.

Efficiency To examine group differences in recall efficiency (proportion of words recalled divided by average study time per word), a 3 (study schedule: fixed, self-paced, transfer) × 6 (list) repeated-measures, between-subjects ANOVA did not reveal a main effect of list (Mauchly's $W = .30$, $p < .001$: Huynh–Feldt-corrected results), $F(3.10, 399.44) = 2.55$, $p = .053$, $\eta^2 = .02$, such that participants were similarly efficient throughout the task. However, there was a main effect of study schedule, $F(2, 129) = 3.89$, $p = .023$, $\eta^2 = .06$, such that participants encoding under fixed study conditions ($M = .24$, $SD = .08$) were more efficient than participants self-pacing their study time ($M = .20$, $SD = .10$; $p_{\text{bonf}} = .025$, $d = .23$), but not participants in the transfer condition ($M = .21$, $SD = .07$; $p_{\text{bonf}} = .139$, $d = .18$); additionally, participants in the transfer condition were similarly efficient as participants self-pacing their study time ($p_{\text{bonf}} > .999$, $d = .06$). Moreover, list interacted with study schedule, $F(6.19, 399.44) = 2.44$, $p = .024$, $\eta^2 = .04$), such that participants in the self-paced condition became more efficient with task experience, but participants in the transfer condition became less efficient once able to self-pace their study time.

Strategy use Participants generally reported using multiple encoding strategies ($M = 3.23$, $SD = 1.31$) and this did not reliably differ between each group, $F(2, 129) = 2.05$, $p = .133$, $\eta^2 = .03$. In terms of each specific strategy, 78% reported reading the words as they appeared, 77% reported engaging in rote rehearsal, 11% reported developing rhymes for the words, 61% reported using sentences to link the words together, 45% reported grouping the words in a meaningful way, and 49% reported using mental imagery.

Discussion

In Experiment 3, participants studied items in the middle of the list more than recency items, similar to Experiments 1 and 2. However, this did not result in reduced serial position

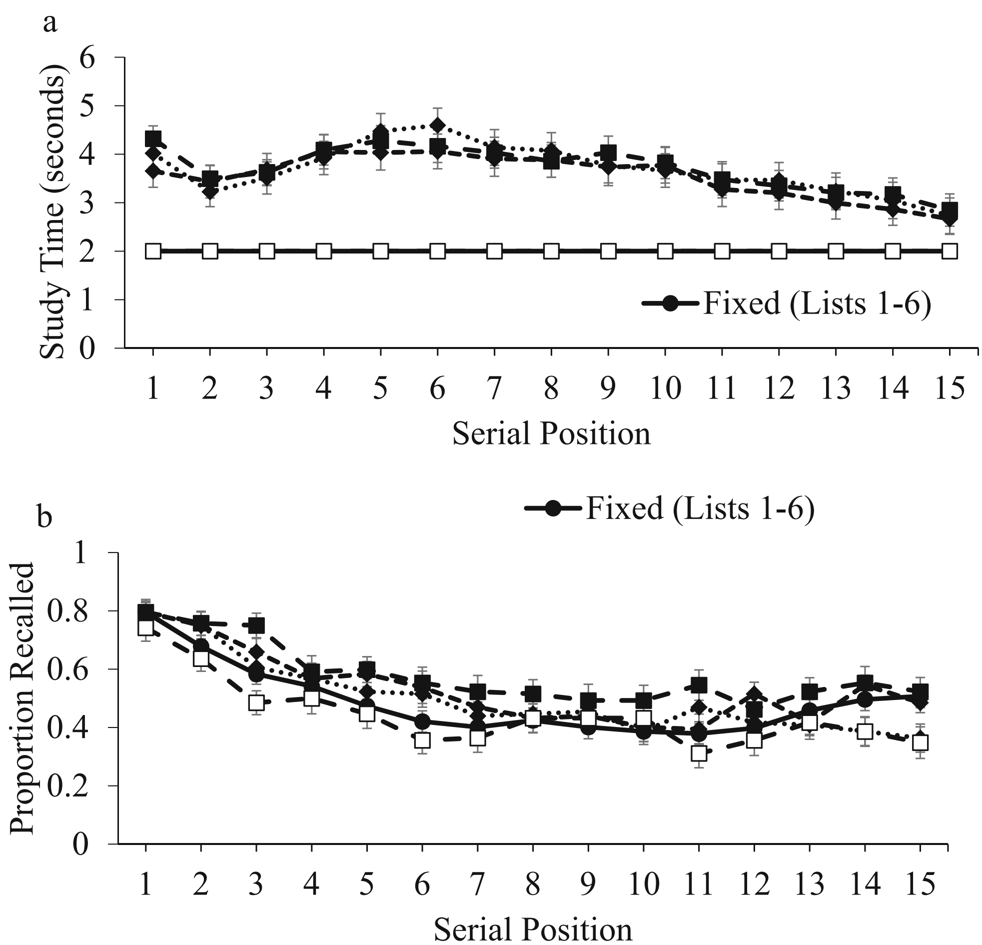

Fig. 6 Study time (**a**) and free recall probability (**b**) as a function of serial position in Experiment 3. Error bars reflect the standard error of the mean

effects as participants in each condition still demonstrated a primacy effect but mitigated recency effects, consistent with previous work using delayed free recall paradigms (e.g., Glanzer & Cunitz, 1966; Howard & Kahana, 1999). Thus, the transfer of learning observed in Experiments 1 and 2 was diminished in the presence of a delay, an extrinsic cue (cf. Koriat, 1997; Koriat et al., 2004) that may not be considered or incorporated when participants make metacognitive control decisions. Specifically, participants may use short-term memory models rather than a more accurate understanding of how a delay will affect long-term memory.

Furthermore, participants self-pacing their study time studied each word for a longer duration, but in contrast to Experiment 1, there were no group differences in recall performance. As a result, participants self-pacing their study time demonstrated poorer efficiency compared with participants under fixed encoding conditions. Thus, participants self-pacing their study time exemplified the labor-in-vain effect (Nelson & Leonesio, 1988), whereby increases in study time led to only small benefits to performance and subsequently to less efficient memory than participants under fixed encoding conditions.

General discussion

When studying large amounts of information, serial position effects refer to enhanced memory for items learned at the beginning (primacy) and the end (recency) of a learning period (Glanzer & Cunitz, 1966; Murdock, 1962; Waugh & Norman, 1965). Failing to consider the effect of an item's temporal order at encoding could result in unexpected forgetting of important information, particularly if that information appeared in the middle of a study period. However, previous work has illustrated that people have some metacognitive awareness of serial position effects (Castel, 2008), indicating that participants may be able to engage metacognitive control processes to more efficiently study information, decrease serial position effects, and reduce the forgetting of information presented in the middle of a list.

In the present study, we investigated whether participants could reduce serial position effects when allowed to self-pace their study time and if they could transfer learning of serial position effects from prior, fixed study conditions to subsequent self-paced study conditions. Since there is evidence that participants have some metacognitive awareness of serial position effects (Castel, 2008), we expected participants to attempt to maximize memory utility by allocating the most study time towards information in the middle of a list compared with primacy and recency items. In line with our hypotheses, results revealed that serial position effects were reduced when participants were allowed to self-pace their study time and serial position effects were incorporated into self-paced study decisions such that participants spent more time studying items in the middle of each list compared with the primacy and recency positions.

Participants' patterns of study time indicate that metacognitive control may be informed by item memorability such that participants employ a study time allocation model whereby more difficult items are allocated more study time (see the discrepancy-reduction model; Thiede & Dunlosky, 1999). However, although participants exert strategic control when choosing what to study, processes responsible for choosing how long to study each item are less attributable to metacognitive control (Koriat et al., 2006). Additionally, previous work has demonstrated that metacognitive control can be influenced by habitual processes, such as reading from left to right, and participants are not fully capable of modifying resulting biases in recall performance (e.g., Ariel et al., 2011; Dunlosky & Ariel, 2011b). Thus, the study trends observed in the present experiments suggest that participants either employ metacognitive control strategies even without experiencing serial position effects under fixed-study conditions or that this pattern arises as a consequence of habitual or motivational processes whereby participants speed up at the beginning and the end of a studied list.

Rather than strategic or habitual behavior, the inverted serial position effects observed in participants' study times could also indicate that the heightened study of middle items reflects increased rehearsal of primacy items. Specifically, mid-list study time may be shared between both primacy and middle items (i.e., cumulative rehearsal). For example, the study time for Serial Position 8 may not be solely a measure of the time spent studying the item in Position 8, but may also include the time used to rehearse previously presented items (see Fischler et al., 1970; Rundus, 1971; Rundus & Atkinson, 1970). However, due to the excessive amount of information, participants may subsequently abandon this cumulative rehearsal strategy, leading to quicker study times for items at the end of the list. Thus, similar study patterns using immediate and delayed recall procedures could reflect cumulative rehearsal rather than strategic control mechanisms.

Future work may benefit by using overt rehearsal procedures (see Tan & Ward, 2000; Ward et al., 2003) whereby participants rehearse words out loud to determine how items are differentially rehearsed as a function of their serial position within a list. However, although the extended time participants spend studying mid-list items likely includes rehearsal of primacy items, participants tend to use a myriad of encoding strategies. For example, many participants reported using many strategies like creating sentences to link the words together and grouping the words in a meaningful way, encoding strategies that may simultaneously benefit recall for both primacy and mid-list words. Thus, the flattening of the serial position curve observed in the current study indicates that participants were able to more effectively encode words in the middle of the list via the allocation of additional study time, regardless of whether some of the additional study time was used to rehearse previously presented items.

Across experiments, participants studied recency items the least, indicating that participants may have expected to maximize memory performance by "dumping" recency items from working memory stores (Crowder, 1969) rather than spending more time studying these items. However, in the presence of a delay, the ability to retrieve items from working memory stores is often impaired (e.g., Glanzer & Cunitz, 1966; Howard & Kahana, 1999) leading to poorer recall efficiency. At a theoretical level, in the present work (and especially in Experiments 1 and 2), participants may use serial position information to guide metacognitive control processes, but do not incorporate the effects of a delay between study and test (an extrinsic cue; see Koriat et al., 2004). However, the transfer of the knowledge of serial position effects likely also relies on the use of experiential or mnemonic cues (i.e., experiences of having poorer recall for mid-list content). Thus, experience may give rise to extrinsic cues, specifically that mid-list items tend to be more poorly recalled and can benefit from additional study time compared with primacy and recency items.

While differentially allocating study time may contribute to reduced serial position effects, the additional study time spent on the information in the middle of each list generally improved participants' efficiency. To calculate each participants' recall efficiency, we divided the proportion of words recalled by the average amount of time participants spent studying each word. Results indicated that recall efficiency showed the greatest improvement when initially under more constrained study conditions (only 2 seconds to encode each word) before self-pacing study time, and this increase in efficiency may be due to the interaction between metacognitive monitoring and control (see Dunlosky et al., 2016; Nelson, 1996; Nelson & Narens, 1990; Son & Metcalfe, 2000; Thiede & Dunlosky, 1999). Specifically, participants likely monitor their output, and their awareness of list length plus the enhanced recall of primacy and recency items likely influences and informs later study choices such that participants spend more time studying items from serial positions with poor retrieval performance on previous lists.

Despite improved efficiency when brief, fixed encoding conditions transitioned to self-paced study, participants' efficiency was greatly reduced when the initial fixed study time was longer (5.5 seconds). For participants given more study time on initial lists, metacognitive monitoring may have been governed more by intrinsic cues (i.e., word salience) than extrinsic or mnemonic cues like serial position (see Koriat, 1997; Koriat et al., 2004), leading to unexpected forgetting of items in the middle of the list and poorer efficiency. Specifically, the transfer of knowledge regarding serial position effects likely relies on the use of experiential or mnemonic cues (i.e., experiences of having poorer recall for mid-list content) such that experience may give rise to extrinsic theories about serial position effects indicating that there is a complex mixture of cues being used to guide study decisions.

Although serial position within a list is generally considered an extrinsic or mnemonic cue, since each item was presented along with its serial position in the study phase in the current study, serial position may have been more salient and thus also serve as an intrinsic factor. Future work could present each item without its serial position explicitly given to ensure that an item's serial position does not become salient (and thus an intrinsic factor potentially influencing study time). Additionally, future work not including a recall test after each list could further demonstrate that observations of forgetting mid-list items (mnemonic cues) are needed to transfer knowledge about serial position effects to the allocation of study time on later lists.

In a more applied setting, such as classroom-based self-regulated learning, if students have a list of chapters from a textbook or a lineup of lecture content to review for an exam (assuming they are all equally important), although students may prefer to study or restudy information in chronological order (which may provide a feeling of fluency), differentially allocating study time towards primacy or recency information may result in suboptimal memory performance. Rather, the present study suggests that students may experience the greatest benefit by spending more of their time studying information from the middle of their textbook or lectures from the middle of the term. Future research could investigate whether the results observed in the current study would generalize to longer learning sessions typical in classroom learning. Moreover, additional work could examine how the difficulty of information is incorporated into self-regulated study decisions of information based on when it was learned. Furthermore, future work could present participants with lists of information to remember, but utilize a paradigm allowing participants to restudy information to further reveal the extent to which people are metacognitively aware of serial position effects and how they can overcome them.

In sum, the current study revealed that people may learn about serial position effects under certain fixed encoding conditions and then transfer what they have learned to self-paced study conditions. After studying lists of to-be-remembered words for a fixed duration, subsequent lists with self-paced study time resulted in study times that oppositely mirrored serial position effects (i.e., briefer study times in the beginning and end of each list), and participants self-pacing their study time demonstrated reduced serial position effects. Participants may have monitored their output and transferred their learning of serial position effects from prior lists to engage in more efficient metacognitive control mechanisms, and this strategy may be useful for maximizing memory output. Thus, the present work provides insight regarding how intrinsic, extrinsic, and mnemonic cues can be incorporated into the processes that guide metacognitive control.

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Declarations

Conflicts of interest The authors certify that they have no affiliations with or involvement in any organization or entity with any financial or nonfinancial interest in the subject matter or materials discussed in this manuscript.

References

Ariel, R. (2013). Learning what to learn: The effects of task experience on strategy shifts in the allocation of study time. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*(6), 1697–1711. https://doi.org/10.1037/a0033091

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

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

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

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128*(4), 612–637. https://doi.org/10.1037/0033-2909.128.4.612

Belmont, J. M., & Butterfield, E. C. (1971). Learning strategies as determinants of memory deficiencies. *Cognitive Psychology, 2*(4), 411–420. https://doi.org/10.1016/0010-0285(71)90024-7

Bröder, A., & Undorf, M. (2019). Metamemory viewed through the judgment lens. *Acta Psychologica, 197*, 153–165. https://doi.org/10.1016/j.actpsy.2019.04.011

Brodie, D. A., & Murdock, B. B. (1977). Effect of presentation time on nominal and functional serial-position curves of free recall. *Journal of Verbal Learning and Verbal Behavior, 16*(2), 185–200. https://doi.org/10.1016/S0022-5371(77)80046-7

Brown, G. D. A., Neath, I., & Chater, N. (2007). A temporal ratio model of memory. *Psychological Review, 114*(3), 539–576. https://doi.org/10.1037/0033-295X.114.3.539

Castel, A. D. (2008). Metacognition and learning about primacy and recency effects in free recall: The utilization of intrinsic and extrinsic cues when making judgments of learning. *Memory & Cognition, 36*(2), 429–437. https://doi.org/10.3758/MC.36.2.429

Crowder, R. G. (1969). Behavioral strategies in immediate memory. *Journal of Verbal Learning & Verbal Behavior, 8*(4), 524–528. https://doi.org/10.1016/S0022-5371(69)80098-8

Davelaar, E. J., Goshen-Gottstein, Y., Ashkenazi, A., Haarmann, H. J., & Usher, M. (2005). The demise of short-term memory revisited: Empirical and computational investigations of recency effects. *Psychological Review, 112*(1), 3–42. https://doi.org/10.1037/0033-295X.112.1.3

Dunlosky, J., & Ariel, R. (2011a). Self-regulated learning and the allocation of study time. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 54, pp. 103–140). Academic Press.

Dunlosky, J., & Ariel, R. (2011b). The influence of agenda-based and habitual processes on item selection during study. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(4), 899–912. https://doi.org/10.1037/a0023064

Dunlosky, J., & Matvey, G. (2001). Empirical analysis of the intrinsic-extrinsic distinction of judgments of learning (JOLs): Effects of relatedness and serial position on JOLs. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*(5), 1180–1191. https://doi.org/10.1037/0278-7393.27.5.1180

Dunlosky, J., Mueller, M. L., & Thiede, K. W. (2016). Methodology for investigating human metamemory: Problems and pitfalls. In J. Dunlosky & S. K. Tauber (Eds.), *Oxford library of psychology: The Oxford handbook of metamemory* (pp. 23–37). Oxford University Press.

Egner, T. (2017). *The Wiley handbook of cognitive control*. Wiley Blackwell. https://doi.org/10.1002/9781118920497

Farrell, S. (2012). Temporal clustering and sequencing in short-term memory and episodic memory. *Psychological Review, 119*(2), 223–271. https://doi.org/10.1037/a0027371

Fischler, I., Rundus, D., & Atkinson, R. C. (1970). Effects of overt rehearsal procedures on free recall. *Psychonomic Science*, *19*(4), 249–250. https://doi.org/10.3758/BF03328801

Glanzer, M., & Cunitz, A. R. (1966). Two storage mechanisms in free recall. *Journal of Verbal Learning & Verbal Behavior, 5*(4), 351–360. https://doi.org/10.1016/S0022-5371(66)80044-0

Grenfell-Essam, R., & Ward, G. (2012). Examining the relationship between free recall and immediate serial recall: The role of list length, strategy use, and test expectancy. *Journal of Memory and Language, 67*(1), 106–148. https://doi.org/10.1016/j.jml.2012.04.004

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

Kellas, G., & Butterfield, E. C. (1971). Effect of response requirement and type of material on acquisition and retention performance in short-term memory. *Journal of Experimental Psychology, 88*(1), 50–56. https://doi.org/10.1037/h0030663

Kellas, G., Ashcraft, M. H., Johnson, N. S., & Needham, S. (1973). Temporal aspects of storage and retrieval in free recall of categorized lists. *Journal of Verbal Learning and Verbal Behavior, 12*(5), 499-511. https://doi.org/10.1016/S0022-5371(73)80030-1

Kelly, M. O., & Risko, E. F. (2019). Offloading memory: Serial position effects. *Psychonomic Bulletin & Review, 26*, 1347–1353. https://doi.org/10.3758/s13423-019-01615-8

Koriat, A. (1997). Monitoring one's own knowledge during study: A cue-utilization approach to judgments of learning. *Journal of Experimental Psychology: General, 126*(4), 349–370. https://doi.org/10.1037/0096-3445.126.4.349

Koriat, A. (2015). Knowing by doing: When metacognitive monitoring follows metacognitive control. In D. S. Lindsay (Ed.), C. M. Kelley (Trans.), A. P. Yonelinas, & H. L. Roediger, III (Eds.), *Remembering: Attributions, processes, and control in human memory: Essays in honor of Larry Jacoby* (pp. 185–197). Psychology Press.

Koriat, A., Bjork, R. A., Sheffer, L., & Bar, S. K. (2004). Predicting one's own forgetting: The role of experience-based and theory-based processes. *Journal of Experimental Psychology: General, 133*(4), 643–656. https://doi.org/10.1037/0096-3445.133.4.643

Koriat, A., Ma'ayan, H., & Nussinson, R. (2006). The intricate relationships between monitoring and control in metacognition: Lessons for the cause-and-effect relation between subjective experience and

behavior. *Journal of Experimental Psychology: General, 135*(1), 36–69. https://doi.org/10.1037/0096-3445.135.1.36
Krinsky, R. (1993). Serial position and the "labor-in-vain" effect. *Bulletin of the Psychonomic Society*, *31*, 304–306. https://doi.org/10.3758/BF03334936
Laming, D. (2010). Serial position curves in free recall. *Psychological Review, 117*(1), 93–133. https://doi.org/10.1037/a0017839
Lehman, M., & Malmberg, K. J. (2013). A buffer model of memory encoding and temporal correlations in retrieval. *Psychological Review, 120*(1), 155–189. https://doi.org/10.1037/a0030851
Lohnas, L. J., Polyn, S. M., & Kahana, M. J. (2015). Expanding the scope of memory search: Modeling intralist and interlist effects in free recall. *Psychological Review, 122*(2), 337–363. https://doi.org/10.1037/a0039036
McFarland, C. E., & Kellas, G. (1974). Mode of input effects on subject-controlled processes. *Journal of Experimental Psychology, 103*(2), 343–350. https://doi.org/10.1037/h0036819
McGeoch, J. A. (1942). *The psychology of human learning: An introduction.* Longmans, .
Metcalfe, J., & Finn, B. (2008). Evidence that judgments of learning are causally related to study choice. *Psychonomic Bulletin & Review, 15*(1), 174–179. https://doi.org/10.3758/PBR.15.1.174
Mueller, M. L., & Dunlosky, J. (2017). How beliefs can impact judgments of learning: Evaluating analytic processing theory with beliefs about fluency. *Journal of Memory and Language*, *93*, 245–258. https://doi.org/10.1016/j.jml.2016.10.008
Murdock, B. B. (1962). The serial position effect of free recall. *Journal of Verbal Learning and Verbal Behavior, 64*(5), 482–488. https://doi.org/10.1037/h0045106
Nelson, T. O. (1996). Consciousness and metacognition. *American Psychologist, 51*(2), 102–116. https://doi.org/10.1037/0003-066X.51.2.102
Nelson, T. O., & Leonesio, R. J. (1988). Allocation of self-paced study time and the "labor-in-vain effect". *Journal of Experimental Psychology. Learning, Memory, and Cognition, 14*(4), 676–686. https://doi.org/10.1037/0278-7393.14.4.676
Nelson, T. O., & Narens, L. (1990). Metamemory: A theoretical framework and some new findings. In G. H. Bower (Ed.), *The psychology of learning and motivation* (pp. 125–173). Academic Press. https://doi.org/10.1016/S0079-7421(08)60053-5
Polyn, S. M., Norman, K. A., & Kahana, M. J. (2009). A context maintenance and retrieval model of organizational processes in free recall. *Psychological Review, 116*(1), 129–156. https://doi.org/10.1037/a0014420
Rhodes, M. G. (2016). Judgments of learning. In J. Dunlosky & S. K. Tauber (Eds.), *The Oxford handbook of metamemory* (pp. 65–80). Oxford University Press.
Rhodes, M. G., & Castel, A. D. (2008). Memory predictions are influenced by perceptual information: Evidence for metacognitive illusions. *Journal of Experimental Psychology: General, 137*(4), 615–625. https://doi.org/10.1037/a0013684
Rhodes, M. G., & Castel, A. D. (2009). Metacognitive illusions for auditory information: Effects on monitoring and control. *Psychonomic Bulletin & Review, 16*, 550–554. https://doi.org/10.3758/PBR.16.3.550
Roberts, W. A. (1972). Free recall of word lists varying in length and rate of presentation: A test of total-time hypotheses. *Journal of Experimental Psychology, 92*(3), 365–372. https://doi.org/10.1037/h0032278
Roediger, H. L., & Crowder, R. G. (1976). A serial position effect in recall of United States presidents. *Bulletin of the Psychonomic Society*, *8*(4), 275–278. https://doi.org/10.3758/BF03335138
Rohrer, D., & Wixted, J. T. (1994). An analysis of latency and interresponse time in free recall. *Memory & Cognition, 22*(5), 511–524. https://doi.org/10.3758/BF03198390
Rundus, D. (1971). Analysis of rehearsal processes in free recall. *Journal of Experimental Psychology, 89*(1), 63–77. https://doi.org/10.1037/h0031185
Rundus, D., & Atkinson, R. C. (1970). Rehearsal processes in free recall: A procedure for direct observation. *Journal of Verbal Learning and Verbal Behavior, 9*(1), 99–105. https://doi.org/10.1016/S0022-5371(70)80015-9
Sederberg, P. B., Howard, M. W., & Kahana, M. J. (2008). A context-based theory of recency and contiguity in free recall. *Psychological Review, 115*(4), 893–912. https://doi.org/10.1037/a0013396
Son, L. K., & Metcalfe, J. (2000). Metacognitive and control strategies in study-time allocation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*(1), 204-221. https://doi.org/10.1037/0278-7393.26.1.204
Tan, L., & Ward, G. (2000). A recency-based account of the primacy effect in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*(6), 1589–1625. https://doi.org/10.1037/0278-7393.26.6.1589
Thiede, K. W., & Dunlosky, J. (1999). Toward a general model of self-paced study: An analysis of selection of items for study and self-paced study time. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(4), 1024–1037. https://doi.org/10.1037/0278-7393.25.4.1024
Thorndike, E. L., & Lorge, I. (1944). *The teacher's work book of 30000 words.* Bureau of Publications.
Tiede, H. L., & Leboe, J. P. (2009). Metamemory judgments and the benefits of repeated study: Improving recall predictions through the activation of appropriate knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(3), 822–828. https://doi.org/10.1037/a0015122
Unsworth, N. (2007). Individual differences in working memory capacity and episodic retrieval: Examining the dynamics of delayed and continuous distractor free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(6), 1020–1034. https://doi.org/10.1037/0278-7393.33.6.1020
Unsworth, N. (2016). Working memory capacity and recall from long-term memory: Examining the influences of encoding strategies, study time allocation, search efficiency, and monitoring abilities. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 42*(1), 50–61. https://doi.org/10.1037/xlm0000148
Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review, 114*(1), 104–132. https://doi.org/10.1037/0033-295X.114.1.104
Ward, G., Woodward, G., Stevens, A., & Stinson, C. (2003). Using overt rehearsals to explain word frequency effects in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(2), 186–210. https://doi.org/10.1037/0278-7393.29.2.186
Waugh, N. C. (1967). Presentation time and free recall. *Journal of Experimental Psychology, 73*(1), 39–44. https://doi.org/10.1037/h0024125
Waugh, N. C., & Norman, D. A. (1965). Primary memory. *Psychological Review, 72*(2), 89–104. https://doi.org/10.1037/h0021797
Zimmerman, J. (1975). Free recall after self-paced study: A test of the attention explanation of the spacing effect. *The American Journal of Psychology, 88*(2), 277–291. https://doi.org/10.2307/1421597

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