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Revisiting the influence of offloading memory on free recall

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Abstract

Relying on external memory aids is a common memory strategy that has long allowed us to "remember" vast amounts of information more reliably than with our internal memory alone. However, recent work has provided evidence consistent with the idea that offloading memory demands encourages a reduced engagement in intentional or top-down memory strategies/efforts, leading to lower memory performance in general. Evidence for this view comes from results demonstrating a reduced primacy effect but intact recency and isolation effects when individuals could offload memory demands (but had to unexpectedly rely on their internal memory at test). In the present investigation, we attempt a replication of these critical results, given some inconsistencies in the findings between studies. In addition, we extend the examination of offloading's impact on memory via examining individual differences in reliance on the external store (when available) and different strategies for the use of that store. Results of the replication are generally consistent with previous research. An individual differences analysis yielded results consistent with the notion that increased reliance on an external store can compromise internal/biological memory in the absence of that store. Finally, a verbal model of offloading memory demands within a framework of effort and study time allocation is presented. Together, the results both reinforce extant research and extend it in new directions.

Keywords Memory · Recall · Offloading

Introduction

Storing to-be-remembered information such as phone numbers and appointments into a smartphone is one of the many ways that we offload cognitive demands to external devices (a form of *cognitive offloading*; Risko & Gilbert, 2016). This distributed approach to memory has long allowed us to reliably store large amounts of information. While one can imagine that adopting such a distributed approach to memory bodes well for accomplishing increasingly complex tasks, it is important to consider the potential memorial consequences of using such a strategy. One question that arises from this behaviour is how it affects the internal representation of the information offloaded. That is, when we are able to rely on an external store to aid our storage and retrieval of to-be-remembered information, how is that information stored in our internal memory?

Recent findings suggest that unaided memory is worse when individuals can expect, at the time of encoding/storage, to have access to an external memory store (i.e., when they expect that they can *offload*), relative to when they expect to rely solely on their internal memory (i.e., when they *cannot* offload; Eskritt & Ma, 2014; Kelly & Risko, 2019a, 2019b; Lu et al., 2020; Sparrow et al., 2011). The reasons for and boundaries of this effect remain unclear. As a result, researchers have begun focusing on better understanding the influence of offloading as a strategy on the internal memory for the offloaded information (Kelly & Risko, 2019a, 2019b; Lu et al., 2020; Risko et al., 2019).

To investigate the potential mechanisms engaged (or not) when individuals can offload memory demands by relying on an external memory store, Kelly and Risko (2019a) examined the influence of offloading memory on the serial position curves of freely recalled items. In their procedure, all participants stored all items of a list of to-be-remembered words into an external store on each of four trials. In the first three trials, all participants had access to their external stores at recall, and therefore all items of the originally encoded list, to develop trust in the external store. Critically, at the beginning of the fourth (and final) trial, one group was made aware that they would be tested with no access to their external store, thus they knew at encoding not to rely on the availability of their external store come retrieval (i.e., the *no-offloading* condition). The other group, at study/encoding, was

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given the impression that they *would continue to be able to* refer to their external store come retrieval, as in the previous three trials but, critically, they *were not* given access during the recall test (i.e., the *offloading* condition; hence a between participants manipulation was used). By comparing the recall performance of these two conditions, Kelly and Risko (2019a) were able to examine the effect of offloading (i.e., the effect of relying on the external memory store) on the serial position curves of freely recalled items.

Kelly and Risko (2019a) were particularly interested in how reliance on an external memory store affected the *primacy* effect, which is typically attributed to top-down memory mechanisms (e.g., rehearsal, imagery; Fischler et al., 1970; Tan & Ward, 2008). Kelly and Risko (2019a) found a robust reduction in the primacy effect for those in the offloading condition. In contrast, the recency effect (indexed as memory performance for final items relative to that of the middle items) was not reduced in the offloading condition, compared with the no-offloading condition. Kelly and Risko (2019a) also directly compared the effect of offloading on the recall of initial and final items and found that the effect of offloading was larger on the former than the latter items. Kelly and Risko (2019a) argued that these findings were consistent with the notion that the lower memory performance observed during offloading is driven by a reduced engagement in top-down memory strategies/effort.

If offloading primarily involves a reduction in top-down memory strategies/effort, then phenomena which are not solely dependent upon such strategies should be observable even when individuals can offload memory demands to an external store. To test this prediction, Kelly and Risko (2019b) examined offloading's influence on the *isolation effect*—the enhanced recall of distinct items among a set of nondistinct items (often called the *von Restorff effect*; Köhler & von Restorff, 1995; von Restorff, 1933). While recall of an isolated item may be enhanced by top-downstrategies/effort(e.g., rehearsal; Dunlosky et al., 2000; Rundus, 1971), it does not appear to be solely reliant on such top-downstrategies/effort(Dunlosky et al., 2000; Fabiani & Donchin, 1995). Kelly and Risko (2019b) used a within-participants design adapted from Kelly and Risko (2019a) wherein participants completed five trials, with the first three trials identical to those of Kelly and Risko (2019a). The latter two trials were both critical in that no participants had access to their external stores during these trials. On each of these two critical trials, half of the participants were given notice that their external store would be inaccessible (i.e., no-offloading) and the other half were not (i.e., offloading; the order of which were counterbalanced). Finally, to manipulate item isolation, the middle item of every list was perceptually isolated by font colour and size from the remaining set of items.

Kelly and Risko (2019b) found robust isolation effects both when individuals expected to rely on internal memory and when they expected to be able to rely on an external memory store. Indeed, there was no appreciable effect of offloading on recalling the isolate. This is consistent with the notion that phenomena not solely reliant on engagement of top-down memory strategies/effort are less affected by offloading. Kelly and Risko (2019b) also aimed to replicate the observation that offloading led to a reduced primacy effect (indexed in the same manner as done by Kelly & Risko, 2019a). However, Kelly and Risko (2019b), in each of two experiments, did not find a robust reduction in the primacy effect in the offloading condition. While the overall pattern of results was similar to that of Kelly and Risko (2019a), it was clearly less robust in Kelly and Risko (2019b). Thus, further work is needed to put the effect of offloading as a function of serial position on stronger footing.

The present investigation

In the present investigation, we returned to the between-participants design used in Kelly and Risko (2019a) and examined both the serial position effects and the isolation effect as a function of offloading. In extending the work of Kelly and Risko (2019a, 2019b), we also wanted to examine the idea that reliance on external memory aids is unlikely to be an all-or-none phenomenon. That is, the use of an external store does not preclude storing information internally as well. Indeed, this fact reveals a potentially important asymmetry present in extant investigations of offloading memory demands. Specifically, when an external store is unavailable, individuals have to rely solely on their internal memory. In contrast, when the external store is available (the typical offloading condition) individuals can rely on both external and internal stores. Understanding individual differences in the reliance on external stores when available, the factors that influence that reliance, and the resultant influence on memory represent a potentially valuable new direction in research on distributed memory. To begin this effort, we included a self-report measure at the end of the experiment wherein individuals were asked two questions about their chosen memory strategies throughout the study. Participants were asked: (i) the extent to which they relied on the external store (versus their internal memory) during the first three trials, wherein they had access to the external store and (ii) the extent to which they had *expected* to rely on the external store (versus their internal memory) in the final trial, wherein they had no access to the external store.

Responses to each of these questions should be differentially related to memory performance. First, provided that relying on an external store represents an effective memory strategy when that store is available (Kelly & Risko, 2019a, 2019b), reliance on the external store should be positively correlated with memory performance. Those who refer to their external store at retrieval give themselves more opportunity to recall the entire set of items, which is challenging to do if relying on an internal-based memory strategy at retrieval. On the critical fourth trial (i.e., when the external store was actually unavailable), on the other hand, those whose strategy involved relying more strongly on the external store should perform more poorly than those reporting an encoding/storing strategy of internal memory reliance. This prediction falls out of previous findings suggesting that the availability of an external store is associated with the disengagement top-down intentional memory strategies/effort at encoding.

In understanding how one allocates memory demands internally and/or externally when external storage is available, we consider different strategies in the use of the external store. One such strategy emerged unexpectedly in Kelly and Risko (2019b). Specifically, during encoding, a number of participants indicated in their external store when an item was distinct. They did so by denoting the isolate specifically (e.g., adding an asterisk, indicating its distinct colour—"*red*"). This behavior could reflect an attempt to remember that the isolate was distinct from the other items. This would be an interesting strategy, given that participants were never instructed to remember which item was the isolate or tested on which item was the isolate. This account of their behaviour makes a straightforward prediction on the critical fourth trial: If participants are denoting the isolate within the external store in an effort to enhance the information available to them upon future use of that store, then doing so should be sensitive to the expectation that one will or will not have such access.

Alternatively, participants may denote the distinctiveness of the isolate in the store as an effort to enhance future recall, as recording the distinctiveness may act as an elaborative encoding technique, adding additional routes to retrieval (Graf & Mandler, 1984). On this account, the expectation of future access to the external store (manipulated on the fourth trial) could arguably have the opposite effect to that outlined above. Namely, individuals might be more likely to record the distinctiveness (i.e., engage in more elaborative retrieval) when they know they have to rely on their internal memory (on the critical trial; i.e., those in the no-offloading condition). To test these hypotheses, we compared whether participants recorded the distinctiveness of an item into their external store as a function of offloading condition. We also investigated whether the recording of distinctiveness in one's external store influences recall of the isolated and nonisolated items (separately analyzed for each offloading condition).

Method

This investigation was preregistered at osf.io/59g3y and we report any deviations from this preregistration.

Participants

Data from 192 participants taking part for course credit were collected and analyzed. This was based on power using proportion tests in R (power.prop.test() function; R Core Team, 2018) and G*Power (the Z proportions test: difference between two independent proportions; Erdfelder et al., 1996) to detect an isolation effect based on that of earlier work for the no-offloading condition specifically (Kelly & Risko, 2019b).

Stimuli

The five 19-item word list set (available at osf.io/e5wrh/) used by Kelly and Risko (2019b) was used here. Items were presented randomly within each list, with the 10th item as the isolate (i.e., randomly determined, thus varied across trials and participants) for half of the participants. Control items were the 10th items for the other half of the participants. Isolates were perceptually distinct (red, size 28 font) from all other items (white, size 18 font). Isolates appeared during each trial for participants in the isolate condition. Lists were counterbalanced across trial position (i.e., first through fourth) such that each list appeared in each trial position equally often. Words were randomized across item positions in each list, including the 10th (isolate) position such that the word serving as the isolate varied.

Procedure

Participants were seated at their own stations, occluded from one another. Stations were equipped with pens, computer with corresponding monitor and keyboard, and a file folder. Participants sat approximately 50 cm in front of their computer monitors and were directed to follow instructions given by the monitor and researcher during the session. Each of the four trials comprised three phases: an encoding phase, a 15-s period without access to their external store, and then a recall phase. A researcher in the room monitored participants to ensure that experimental protocols were properly followed (e.g., that no participants used the external store on the final trial, wherein doing so was not permitted)

Encoding phase

At the start of each trial, participants were presented visually with the list of to-be-remembered words on the monitor. Words were presented one at a time for 3 s with an interstimulus interval of 2.5 s. In the encoding phase, participants were instructed to write down each item as they saw them onto a provided sheet of paper. After the final item, participants placed the written lists into the file folders to remove the external store from their view. Fifteen seconds were given to participants to enclose their written lists in the file folder and to read the instructions for the upcoming recall phase.

Recall phase

In the recall phase, participants were instructed to type the items that they were originally presented in the encoding phase into a text field on the computer with their list as a resource. Participants had access to their list during the recall phases of the first three trials but not during the fourth trial. Half of the participants were told of this after they completed Trial 3 (no-offloading condition); the other half of participants were not given notice (offloading condition).

Post-task questionnaire

The final task of the study was a short questionnaire consisting of two questions asking participants about their memory strategy during the study. Upon completing the questionnaire, participants were told that "*When we refer to 'your memory' below, we are referring to information (i.e., words) stored in your own mind (i.e., not the written list).*" They then proceeded to answer each question. Question 1 asked: "Please select the option that best describes your recall strategy during the FIRST THREE trials of this study (when you were ABLE to refer to your written lists)." Participants responded by selecting one option from the following scale: (1)*I relied EXCLUSIVELY on my written lists*, (2) I relied MOSTLY on my written lists, (3)*I relied ABOUT EQUALLY on both my written lists and my internal memory*, (4)*I relied MOSTLY on my internal memory*, (5)*I relied EXCLUSIVELY on my internal memory*, (6)*None of the above*. Question 2 asked, "Please select the option that best describes your recall strategy during the FINAL TRIAL of this study (when you were NOT able to refer to your written list):". Participants responded in the same manner as for Question 1, but with the answers framed in the context of planned memory strategy. For example, Option (1) above was "I *planned to rely* EXCLUSIVELY on my written list."

Results

Data from three participants were excluded and replaced because they demonstrated that they did not follow instructions (e.g., did not write down the words onto their list at study), which led to incomplete data. Data from 19 participants were not included in the analyses because they participated after the preregistered stopping rule (i.e., 192) had been reached. These data were collected partially as a result of having multiple individuals participate at once (although the task was performed individually) in combination with a desire to retain equal counterbalancing (offsetting data loss in the event that a participant needed to be excluded upon viewing their responses). There were 234 instances (across all trials and conditions) wherein participants recalled an item not on their list. Thirty-eight percent of these instances involved participants recalling items from other lists within the study. All confidence intervals reported (included in figures) are bias-corrected accelerated 95% bootstrap confidence intervals (CI_{95}) using 10,000 replications. Effect sizes are reported in terms of generalized η^2($\eta_G{}^2$; *ez* package in R; Lawrence, 2016) and Cohen's *d*(*lsr* package in R; Navarro, 2015). Data and analysis code are available at OSF (osf.io/e5wrh/).

The preregistration specified the use of both ANOVA (*ez* package in R; Lawrence, 2016) and logistic regression; however, we deviate from the preregistration by foregrounding regression analyses. The results of the two types of analyses (i.e., ANOVA and logistic regression) are qualitatively the same unless specified otherwise. The preregistration also specified the use of mixed-effects modelling for analyses of serial position effects. In doing so (with the *lme4* package in R; Bates et al., 2015), we account for random effects where applicable (i.e., by-participant intercepts and by-item intercepts in the presence of multiple observations, by-participant slopes for within-participant manipulations, and by-item slopes for within-item manipulations; Brown, 2021). To establish the random effects structure, we take a model fitting approach (not preregistered) by comparing the various random effects structures and selecting and reporting the best fitting model maximal model (Barr et al., 2013; Singmann & Kellen, 2019). In the rare instance that inclusion of any random effects led to convergence issues, plain logistic regression is reported (again, noting this deviation). For the fixed effects, we included the highest-level interaction terms where appropriate, removing these terms if not statistically significant (noting these cases).

The mean proportion of control items and isolates recalled from critical position 10 during the first three trials (wherein participants could rely on their external memory store) were from .97 to 1.00, and .99 to 1.00, respectively. When all items were considered, the mean proportion of items recalled during these initial trials ranged from .94 to .89.

The effect of offloading

A logistic regression (not preregistered) with offloading condition as a predictor for recall performance on the final trial (Trial 4) found that those in the offloading condition were significantly less likely to accurately recall items (offloading: .30; no-offloading: .54), $b = -0.99$, $SE = 0.07$, $z = -14.26$, $p < .001$. An analogous one-way analysis of variance (ANOVA) revealed qualitatively the same result, $F(1, 190) = 98.22$, $\eta_G{}^2 = .34$, $p < .001$.

Isolation effects

We conducted a logistic regression with offloading condition (offloading vs. no-offloading) and item type (isolate vs. control) as predictors on recall performance on the final trial (Trial

4). Offloading and isolation did not interact, $b = 0.58$, $SE = 0.64$, $z = 0.91$, $p = .363$, so the interaction was removed from the model. Participants in the offloading condition were significantly less likely to recall items than were participants in the no-offloading condition (offloading: .49; no-offloading: .63), $b = -0.64$, $SE = 0.32$, $z = -2.02$, $p = .044$. The isolate was significantly more likely to be recalled than the control item (isolate: .74; control: .38), $b = 1.59$, $SE = 0.32$, $z = 4.98$, $p < .001$. While the interaction between offloading condition and item type was not significant, we continue with the preregistered plan of simple effects analyses. The isolation effect was significant in both the offloading, $b = 1.88$, $SE = 0.45$, $z = 4.13$, $p < .001$, and no-offloading, $b = 1.30$, $SE = 0.45$, $z = 2.89$, $p = .004$, conditions. The mean proportion of recall for isolates and control items by offloading condition are presented in Fig. 1. An analogous ANOVA revealed qualitatively the same results, such that the main effect of offloading condition was significant, $F(1, 188) = 4.15$, $p = .043$, $\eta_G^2 = .02$, the main effect of item type was significant, $F(1, 188) = 30.10$, $p < .001$, $\eta_G^2 = .14$, but not the interaction between item type and offloading condition, $F(1, 188) = 1.20$, $p = .274$, $\eta_G^2 = .01$.

Recording distinctiveness into the store

Forty-eight participants spontaneously indicated that the isolate was distinct when encoding the items into their external stores. Between offloading conditions, participants were equally likely to indicate the distinctiveness of the isolate in their external store (offloading: .38; no-offloading: .38), $b < 0.01$, $SE = 0.42$, $z = 0$, $p > .999$. There was no effect of indicating the distinctiveness on the likelihood of recalling the isolate in the offloading condition (indication: .72; no indication: .70), $b = 0.11$, $SE = 0.66$, $z = 0.16$, $p = .870$, nor in the no-offloading condition (indication: .78; no indication: .77), $b = 0.06$, $SE = 0.71$, $z = 0.09$, $p = .929$. The same was true for words that were not the isolate in the offloading condition (indication: .27; no indication: .26), $b < 0.01$, $SE = 0.06$, $z = 0.075$, $p = .940$, and no-offloading condition (indication: .50; no indication: 0.53), $b = -0.03$, $SE = 0.05$, $z = -0.52$, $p = .605$.

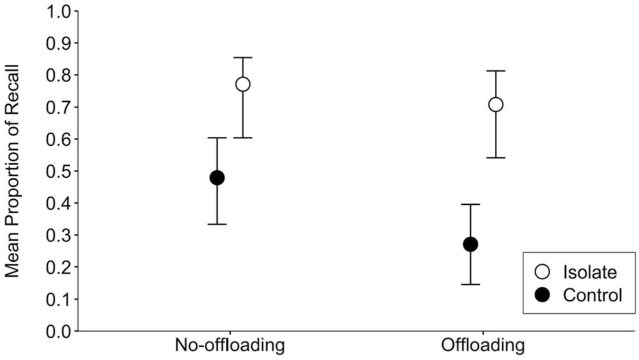

Fig. 1 Mean proportions of items recalled by offloading condition and item type. Error bars are bias-corrected accelerated bootstrap 95% confidence intervals using 10,000 replications

Serial position effects

The following analyses focus on data from participants in the control (nonisolate) condition. Specifically, we examined the recall of the initial two (1 and 2), middle two (10 and 11), and final two (18 and 19) item positions across offloading and no-offloading conditions for only the final trial—Trial 4 (i.e., the critical trial). Note that the preregistration incorrectly specified that serial position analyses would be conducted only on data from the no-offloading–control condition combination. This was in error as we are specifically interested in investigating the effect of offloading on primacy and recency effects. Figure 2 presents the mean proportion of recall as a function of offloading condition and serial position for participants in the control condition.

Primacy To investigate primacy, we included offloading condition (offloading vs. no-offloading) and position (initial vs. middle) as fixed effects on recall performance. The interaction between offloading condition and position was significant, $b = -1.08$, $SE = 0.54$, $z = -1.98$, $p = .048$, such that the effect of offloading was larger on initial items than middle items (initial: .34; middle: .22; in the same direction as in previous investigations; Kelly & Risko, 2019a, 2019b). There were significant primacy effects in both the offloading and no-offloading conditions, $b = 1.33$, $SE = 0.35$, $z = 3.77$, $p < .001$; $b = 2.31$, $SE = 0.45$, $z = 5.15$, $p < .001$. An analogous mixed ANOVA, with offloading as the between-participants factor, found no significant interaction between offloading and position, $F(1, 94) = 1.89$, $p = .172$, $\eta_G^2 = .01$, but main effects of offloading condition, $F(1, 94) = 26.09$, $p < .001$, $\eta_G^2 = .14$, and position, $F(1, 94) = 50.55$, $p < .001$, $\eta_G^2 = .18$. Paired-samples *t* tests found significant primacy effects for both offloading and no-offloading conditions, $t(47) = 4.01$, $p < .001$, $d = 0.58$; $t(47) = 6.06$, $p < .001$, $d = 0.87$.

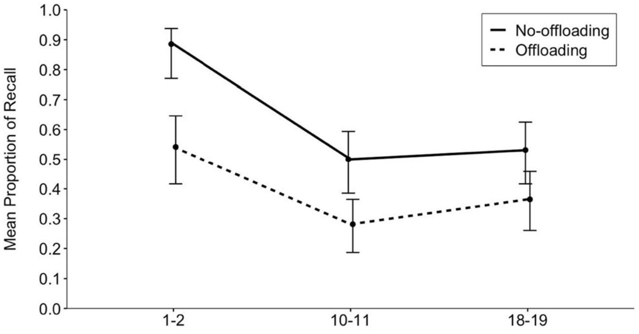

Fig. 2 Mean proportions of items recalled by offloading condition and item position. Error bars are bias-corrected accelerated bootstrap 95% confidence intervals using 10,000 replications

Recency To investigate recency, we used offloading condition (offloading vs. no-offloading) and position (middle vs. final) as fixed effects on recall performance (and with by-participant and by-item intercepts). Offloading condition and position did not interact, $b = 0.26$, $SE = 0.43$, $z = 0.60$, $p = .549$, so the interaction term was removed from the model. Participants in the offloading condition were significantly less likely to recall items than those in the no-offloading condition, $b = -0.81$, $SE = 0.22$, $z = -3.71$, $p < .001$. There was no significant difference in recall performance of middle-list items and final-list items, $b = 0.25$, $SE = 0.21$, $z = 1.16$, $p = .244$. We continue with the preregistered plan of examining the effect of recency in each offloading condition. For the offloading condition, any inclusion of random effects led to convergence issues, as such we report logistic regression. There was no significant recency effect in either the offloading or no-offloading conditions, $b = 0.38$, $SE = 0.31$, $z = 1.23$, $p = .218$; $b = 0.15$, $SE = 0.32$, $z = 0.451$, $p = .652$. An analogous mixed ANOVA, with offloading as the between-participants factor, found qualitatively the same results such that there was no interaction between offloading condition and position, $F(1, 94) = 0.24$, $p = .628$, $\eta_G^2 < .01$, a main effect of offloading condition, $F(1, 94) = 14.46$, $p < .001$, $\eta_G^2 = .07$, and no main effect of position, $F(1, 94) = 1.14$, $p = .287$, $\eta_G^2 = .01$. Paired-samples*t* tests found no significant recency effects for either offloading or no-offloading conditions, $t(47) = 1.11$, $p = .272$, $d = 0.16$; $t(47) = 0.41$, $p = .685$, $d = 0.06$.

All participants Provided that the analyses above are restricted to only those in the control condition, we also ran the analogous analyses when including all participants (not preregistered) such that the middle items are items in the 9th and 11th positions of a list (rather than those in the 9th and 10th positions as the isolate is placed in the 10th position for those in the isolate condition; cf. the main analyses). Note that as these analyses were not preregistered, we will interpret the results using an adjusted alpha level based on the number of tests conducted and reported per section below. In each section below, there are a maximum of three tests conducted and reported in total, thus, we use the adjusted alpha level of .017 (from an unadjusted alpha level of .05; Abdi, 2007).

Primacy When including all participants, a mixed effects logistic regression with offloading condition (offloading vs. no-offloading) and item position (initial vs. middle) as fixed effects on recall performance revealed a significant interaction, $b = -0.87$, $SE = 0.35$, $z = -2.48$, $p = .013$. Specifically, the effect of offloading was significantly larger for initial items than for middle items, which is consistent with the previous investigations (Kelly & Risko, 2019a, 2019b). The effect of offloading on recall performance was significant for both initial items, $b = -2.35$, $SE = 0.44$, $z = -5.33$, $p < .001$, and middle items, $b = -1.07$, $SE = 0.25$, $z = -4.23$, $p < .001$ (the latter analysis for middle items contained random intercepts for participants only to prevent singular fitting).

Recency When including all participants in examining recall performance using mixed-effects logistic regression, with fixed effects of offloading condition (offloading vs. no-offloading) and item position (middle vs. final), there was no significant interaction between condition and position, $b = 0.46$, $SE = 0.31$, $z = 1.47$, $p = .141$, so this was removed from the model. There was a significant main effect of offloading condition, $b = -0.81$, $SE = 0.17$, $z = -4.86$, $p < .001$, but no main effect of position, $b = 0.19$, $SE = 0.16$, $z = 1.24$, $p = .215$,

Initial versus final Like in previous work (Kelly & Risko, 2019a, 2019b), we compared recall for initial versus final list items and this analysis was not preregistered. A mixed-effects logistic regression with item position and offloading condition as fixed effects revealed a significant interaction between offloading condition and item position was significant such that the effect of offloading was larger for initial items than for final items, $b = 1.83$, $SE = 0.51$, $z = 3.61$, $p < .001$. There was an effect of offloading on initial, $b = -2.35$, $SE = 0.44$, $z = -5.33$, $p < .001$ (as reported above), and final items, $b = -0.65$, $SE = 0.25$, $z = -2.62$, $p = .009$.

Self-reported memory strategy

Trials 1–3 versus Trial 4 strategy Table 1 presents the proportion of individuals by offloading condition for each of the levels of self-reported memory strategy associated in Trials 1–3 and Trial 4 (see the Method section for exact wording). One participant in the offloading condition was excluded from the analyses of this section (and Table 1) for not providing a reported strategy for Trial 4 (analyses of this section are not preregistered). We investigated the effect of offloading on the expected recall strategy of Trial 4 and found that those in the offloading condition were significantly more likely to report an external-based strategy (no-offloading: 4.39; offloading: 2.02), $t(182.90) = 15.04$, $p < .001$, $d = 2.18$. During Trials 1–3, where there was no-offloading manipulation, there was no effect of offloading condition on reported strategy (no-offloading: 1.80; offloading: 1.69), $t(188.39) = 0.93$, $p = .352$, $d = 0.14$, as expected.

Trial strategy predicting memory performance We tested the relation between offloading condition (offloading vs. no-offloading) and self-reported expected memory strategy on Trial 4 (1: exclusively external, to 5: exclusively internal) on the recall performance on Trial 4, using linear regression. Offloading condition and memory strategy interacted, such that the participants in the offloading condition had a stronger relation between reported strategy and recall performance than those in the no-offloading condition, $b = 0.04$, $SE = 0.02$, $t =$

Table 1 Proportion of individuals self-reporting each level of memory strategy used in Trials 1–3 (Question 1) and expected to use in Trial 4 (Question 2)

	Trials 1–3					Trial 4				
	1	2	3	4	5	1	2	3	4	5
Offloading	.48	.38	.09	.03	0	.41	.36	.09	.07	.06
No-offloading	.39	.46	.13	.04	0	.02	.08	.05	.22	.64

Note. The scale is: 1: exclusively external, 2: mostly external, 3: equally external and internal, 4: mostly internal, 5: exclusively internal. For Trials 1–3, participants in the offloading condition would not be expected to differ in their responses from those in the no-offloading condition, as no manipulation of offloading had occurred. Proportions may not add to 1.00 due to rounding

2.16, $p = .032$. Specifically, for participants in the offloading condition, those reporting a greater reliance on the external store were less likely to recall items, $b = 0.07$, $SE = 0.01$, $t = 5.42$, $p < .001$. This relation was not as robust for participants in the no-offloading condition, $b = 0.03$, $SE = 0.02$, $t = 1.69$, $p = .094$.

We also examined the relation between self-reported memory strategy in the first three trials (1: exclusively external, to 5: exclusively internal) and recall performance in the first three trials. Note that the first three recall trials are those wherein participants had access to their external stores at recall. The relation between self-reported memory strategy and performance was significant, such that those reporting less reliance on the external memory store had significantly lower recall performance on the first three trials, $r_s = -.27$, $p < .001$.

Comparing findings across investigations

Given the similarity in methods across the current investigation and that of Kelly and Risko (2019b) in examining the effect of offloading on isolate recall, Fig. 3 presents the mean recall proportion as a function of item type and offloading condition for each experiment of Kelly and Risko (2019b; available at osf.io/e5wrh/), the current investigation, and collapsing across these two investigations. The presented data are only those of the critical trials, wherein participants did not have access to their lists upon recall. Isolates presented in Fig. 3 were always of the 10th word position within each list. In Experiment 1 of Kelly and Risko (2019b), control items were those in Positions 8, 9, 11, and 12. In Experiment 2 of Kelly and Risko (2019b) and the current work, both control and isolate items were those presented in

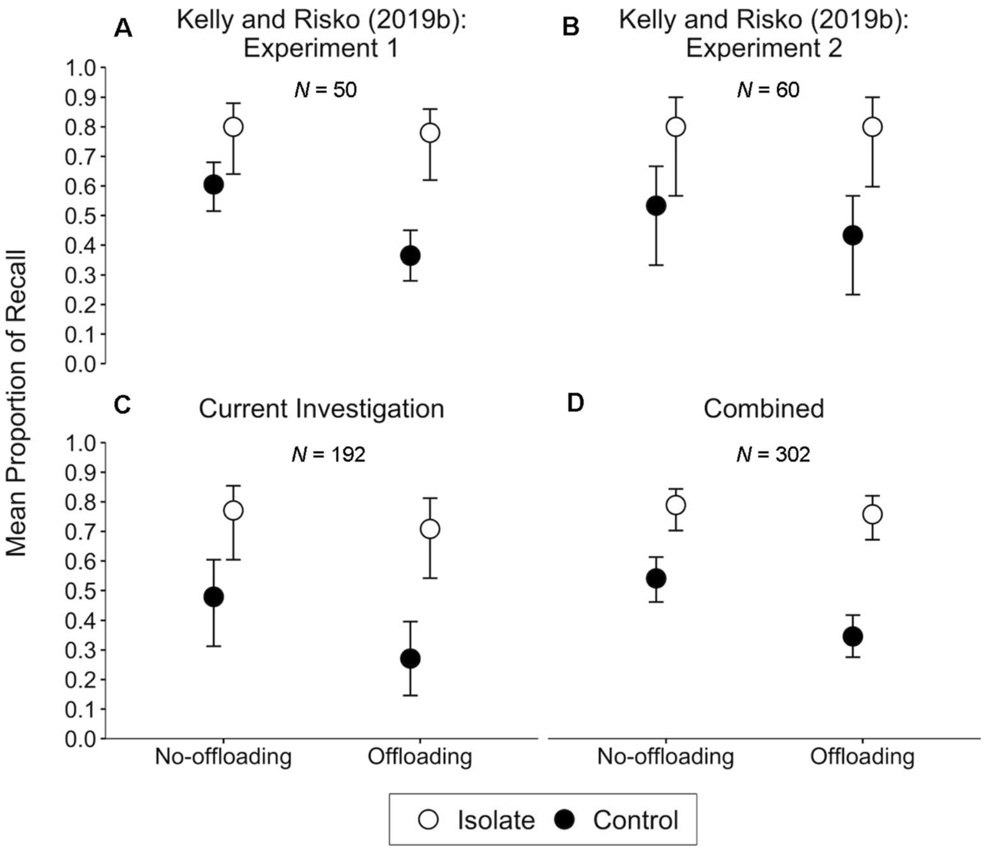

Fig. 3 Mean proportions of items recalled by offloading condition and item type, by investigation (**a–c**) and collapsed across investigation (**d**). Error bars are bias-corrected accelerated bootstrap 95% confidence intervals using 10,000 replications

word Position 10. The results are qualitatively consistent across the different investigations (see Fig. 3). That is, there is a clear isolation effect in both the no-offloading and offloading conditions with the effect appearing slightly smaller in the no-offloading condition.

Figure 4 presents the mean recall proportion as a function of item position and offloading condition across Kelly and Risko (2019a), Kelly and Risko (2019b), the current investigation, and collapsing across these three investigations. Additionally, Fig. 4 presents the difference in the mean recall proportion between the offloading and no-offloading conditions as a function of item position for each investigation. Overall, the patterns across experiments are relatively consistent. In the no-offloading condition, there is a pronounced primacy effect and no recency effect. In the offloading condition, overall memory performance is clearly lower, and the

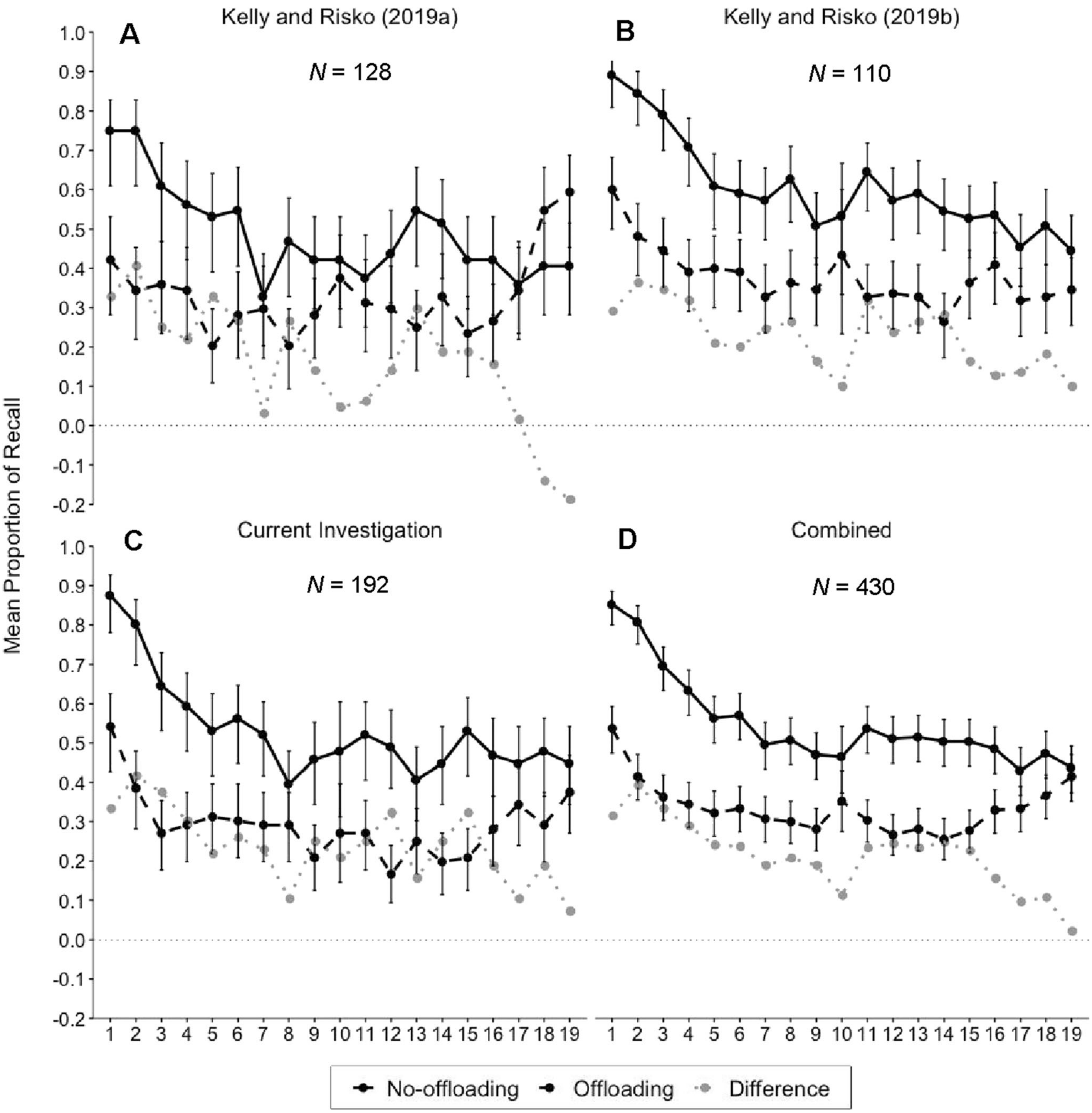

Fig. 4 Mean proportions of items recalled by offloading condition and item position and the offloading effect by item position by investigation (**a**–**c**) and collapsed across investigation (**d**). For uniformity, item position 20 is excluded (only applicable to Kelly & Risko, 2019a). Isolate recall was also excluded, thereby reducing the number of observations for Item Position 10 by 80 in **b**, 96 in **c**, thus by 176 for **d**. Error bars are bias-corrected accelerated bootstrap 95% confidence intervals using 10,000 replications

effect is more pronounced in earlier serial positions. The serial position curve in the offloading condition appears to have a less pronounced primacy effect and unlike the no-offloading condition, possibly a small recency effect overall. The latter was particularly pronounced in Kelly and Risko (2019a). These trends are made even clearer by the mean difference between offloading and no-offloading, which generally decreases as item position increases. This is a consistent pattern across the investigations but was much more pronounced in the original Kelly and Risko (2019a).

General discussion

When we anticipate access to an external memory support, we demonstrate poorer unaided internal memory for that information compared with when there is no such anticipation of external store access (Eskritt & Ma, 2014; Kelly & Risko, 2019a, 2019b; Lu et al., 2020; Sparrow et al., 2011). In the current work, we sought to deepen our understanding of this poorer memory performance by replicating and extending the research of two recent investigations (Kelly & Risko, 2019a, 2019b). To this end, we examined the influence of offloading on memory for distinct information (via the *isolation effect*; e.g., Dunlosky et al., 2000) and on serial position effects. We also examined the frequency of participants spontaneously denoting the distinctiveness of the isolate within their store at encoding and its potential relation with offloading condition and recall. Finally, we investigated whether offloading affected the reported memory strategy used at recall, in addition to whether the reported recall strategy affected memory performance. We discuss these findings in turn.

Offloading and the Isolation effect

The isolation effect on recall performance was robust in both the offloading and the no-offloading conditions, as reported by Kelly and Risko (2019b). Thus, the same general pattern has been reported across a completely within-participants(i.e., Experiment 1; Kelly & Risko, 2019b), mixed (i.e., Experiment 2; Kelly & Risko, 2019b), and completely between-participants design (the current investigation; see Fig. 3). These results are consistent with the notion that the mechanisms underlying the enhanced recall of distinct information are relatively immune to the effects of offloading. Indeed, there was an isolation effect under offloading conditions that was at least as large in magnitude as when relying on internal memory.

We also examined why individuals denoted the distinctiveness of the isolate within their external stores. Of the participants in the isolate condition ($n = 96$), 50% recorded the distinctiveness of the isolate within their store at encoding and the rates of doing so were equal between offloading and no-offloading conditions. Our results are inconsistent with both hypotheses articulated in the introduction: If participants denoted the isolate in the external store for future reference, this behaviour should be more prevalent in the offloading condition. However, if they did so as a kind of elaborative encoding strategy, it should be more prevalent in the no-offloading condition. Neither was the case. Another alternative, consistent with the present results, is that participants interpreted the task as requiring that they denote the isolate in their external store. From this perspective, denoting the isolate would not be expected to be related to whether the participant was expecting future access to their external store (i.e., be sensitive to the offloading manipulation). More insight for why participants denoted the isolate in their store could be obtained by asking them in a posttask question.

Offloading and serial position effects

We tested the effect of offloading on the primacy effect by investigating the interaction between offloading condition (offloading vs. no-offloading) and item position (initial two vs. middle two items). We found some evidence of a reduced primacy effect in the offloading condition compared with the no-offloading condition, thus this effect is clearly not as robust as originally found by Kelly and Risko (2019a). There was an interaction when using mixed effects logistic regression, but none with the analogous mixed ANOVA. Although, when including all participant data, the effect of offloading reducing primacy was more apparent (this analysis was not preregistered). Taken together, if the effect of a reduction to primacy (when primacy is defined as the initial few items versus the middle items) from offloading exists, it is likely to be small. This more muted reduction to the primacy effect appears to be due to a larger effect of offloading on intermediate items here relative to Kelly and Risko (2019a; see Fig. 4). If we consider the true size of the effect of offloading on memory to be that which is approximated by the majority of investigations, then it seems more plausible that the effect of offloading on the initial versus intermediate items is more similar to that found in the current report, and that reported by Kelly and Risko (2019b; see Fig. 4b–c).

When examining the potential influence of offloading on the recency effect, there was little evidence of a recency effect, even when considering all participants. When comparing this result to that of Kelly and Risko (2019a); see Fig. 4a), our current findings differ. Kelly and Risko (2019a) reported a recency effect across most of their conditions, and even reported a small benefit of offloading on the recency effect when collapsing across Experiments 1a and 1b. Interestingly, virtually no recency effects or trends of offloading benefitting final items were reported by Kelly and Risko (2019b), nor supported statistically in the current report (although, Fig. 4 seem to suggest a recency effect might be present). Given that the time between the final item encoded and the onset of free recall is ~14 seconds, it might be surprising by some standards that Kelly and Risko (2019a) found recency effects at all (e.g., Howard & Kahana, 1999).

Despite the small interaction between offloading and primacy (initial compared with middle list items) and no interaction between offloading and recency (later compared with middle list items), it seems clear that the influence of offloading on initial items in the list is larger compared with on final list items. This is clear in the present data set and all the previous ones (see Fig. 4). If the contribution of intentional, top-down effort is greater for initial list than final list items, as argued above, then this general pattern appears consistent with the notion that the availability of an external memory store leads to a withdrawal of study effort during encoding.

Self-reported strategy

As alluded to in our introduction, participants in our paradigm are able to store the to-be-remembered information both internally and externally when offloading is an available strategy (i.e., in the offloading condition). We found on Trial 4, consistent with the manipulation, that participants in the offloading condition were significantly more likely to expect to use an external-based strategy than were those in the no-offloading condition. In a similar vein, on Trials 1–3, individuals reported relying heavily on the external store in general (i.e., when it was always available).

Critically, for participants in the offloading condition on Trial 4, reporting an encoding strategy consisting of a greater reliance on the external store was associated with lower recall performance. This is consistent with the notion that when offloading is an available strategy, there is a reduction in the ability to recall the offloaded information when unexpectedly without the store, compared with when not expecting to offload (Eskritt & Ma, 2014; Kelly & Risko, 2019a, 2019b; Lu et al., 2020; Sparrow et al., 2011). In addition, participants reporting a more external-based memory strategy on the initial three trials had significantly higher recall performance than those reporting a more internal-based memory strategy. This is consistent with the general idea that relying on an external store is an effective memory strategy when its available when needed (i.e., at retrieval).

In asking participants their recall strategies during Trials 1–3 and Trial 4, we are assuming that individuals have some capacity to access this knowledge about their decisions or plans to offload information (or not), retrospectively. Our results suggest that individuals have at least some ability to do this, given that their responses were related to memory performance in theoretical consistent manner. That said, it is also important to note that, because the self-report questions followed the recall phase, participants' recall performance (e.g., on Trial 4) could have influenced their answers. For example, participants in the offloading condition reported significantly more reliance on the external memory store during Trials 1–3 compared with Trial 4, even though there is little reason for them to change their strategy from that used during the earlier trials. Alternative approaches to indexing individual differences in reliance on an external store include indirect methods (e.g., pupil dilation during encoding, study time), more specific memory questionnaires, or behavioural indices that can more directly assess differing memory strategies between offloading conditions (e.g., index degree of top-down, intentional strategies/effort devoted at study).

Toward a (verbal) model of offloading memory

A useful theoretical framework for grounding the research to date on the cost of offloading is within models of metacognitive monitoring and control, and in particular, models aimed at understanding the allocation of study time or effort (e.g., Ackerman, 2014; Dunlosky & Thiede, 1998; Metcalfe & Kornell, 2005; Undorf & Ackerman, 2017). Central to these models are their proposed mechanisms for how individuals decide to continue or discontinue their study of each item. For example, the discrepancy-reduction model suggests that study is stopped when the difference between the perceived learning state and the *norm of study* (i.e., the goal learning level) becomes zero (Dunlosky & Thiede, 1998). Dunlosky and Thiede (1998) also suggested a variant within this model, such that instead of stopping being based on attaining the norm of study, individuals may stop study because they no longer perceive a change in learning for some set amount of time. Similarly, in the region of proximal learning model, individuals are thought to persevere in studying an item until the *perceived rate of learning* slows substantially or becomes zero (Metcalfe & Kornell, 2005). The latter model, however, also has an initial stage wherein individuals choose whether or not items are to be studied in the first place and assumes that individuals do not study items that they consider as already "known" (Metcalfe & Kornell, 2005). More recently, Ackerman (2014) proposed the diminishing criterion model, which uses a stopping rule like that in the discrepancy-reduction model. That is, individuals continue to study until a target level of learning is reached, but with the added notion that individual's target learning level is not constant and, instead, decreases as time spent processing increases. Common to these models of study allocation is a mechanism (or mechanisms) for initiating and/or stopping study based on how individuals perceive the state of their current knowledge for an item relative to some goal with respect to that state of knowledge. Thus, according to these models, individuals do not (usually) study items when it would be superfluous to do so (e.g., when they perceive that they know the item). This general idea is consistent with the notion that individuals are cognitive misers (e.g., Dunn et al., 2016; Kool et al., 2010; Zipf, 1949).

In the context of the aforementioned models, one way to think about having an external memory store available is that individuals judge their knowledge based on the contents of both their internal/biological memory store and the external memory store. The collective knowledge of this extended memory system (i.e., both internal and external memory stores) is then compared with the knowledge goal to determine whether study is needed. Provided that individuals often have good reason to expect their external store to be reliable, as they do in the present experiments, storing an item externally would likely produce a perceived state of knowing that would exceed most knowledge goals or related thresholds. As a result, study effort would be withheld and in situations where the external store is unexpectedly unavailable, memory for information that was stored externally would be diminished relative to situations wherein there was no expectations of external memory support during study. This is consistent with the present and previous empirical work (Eskritt & Ma, 2014; Kelly & Risko, 2019a, 2019b; Lu et al., 2020). That is, the costs associated with having an external store available at study but unexpectedly absent at retrieval appear to influence intentional efforts at encoding.

Despite the consistently observed cost to internal/biological memory for to-be-remembered material when one expects the support of an external memory store, when couched in the aforementioned kinds of models, it becomes clearer the situations wherein such costs might be absent or reduced. If individuals treat the external store independent from their internal/biological memory, the costs should be mitigated. This might include cases wherein the external store is employed as a kind of redundant “back-up” store (e.g., “I will write this down, in case I forget”), or one’s internal/biological memory is employed as a kind of “back-up” store (e.g., “I will try to remember this, in case I don’t have my store”). In both cases, the external store is arguably being used more to *augment* one’s internal/biological memory than as a means of offloading memory demands. In such cases, in the framework described above, one would expect more study effort to be expended than in cases where individuals are offloading demands and, as a result, a smaller (or no) cost of storing information externally. The current self-report results provide some initial support for this idea: In the offloading condition, 52% of participants reported that they expected to use both internal and external memory support on the final trial, and individuals who reported a more internal memory strategy had higher memory performance. Future research aimed at testing these ideas further would provide a more nuanced perspective on the various ways in which memory demands can be distributed over internal and external spaces.

Conclusion

In the present investigation, we found that the influence of offloading on memory performance seemed to be more pronounced for earlier items in a list than those later in a list. This is consistent with the explanation that offloading leads to a reduction in top-down intentional efforts to remember while seemingly unaffecting phenomena not solely dependent on such top-down mechanisms.

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