Contextual familiarity rescues the cost of switching

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Abstract

Changes in context influence the way we form and structure memories. Yet, little is known about how qualitatively different types of context change shape memory organization. The current experiments characterize how different features of context change influence the structure and organization of free recall. Participants completed a context switching paradigm in which we manipulated the frequency of switches and prior experience with the contexts participants were switching between (familiar vs. novel). We then measured immediate and delayed free recall performance and determined the extent to which participants organized items by the order in which they were encoded or the type of context with which they were originally presented. Across two experiments, we found and replicated that rapidly switching to novel, but not familiar contexts, impaired memory recall performance and biased memory towards a greater reliance on temporal information. Critically, we observed that these differences in performance may be due to distinctions in how participants organize their recalls when rapidly switching contexts. Results indicated that participants made more recall transitions to items in a subsequent context when the contexts are repeating, as compared to when the contexts are novel. Overall, our findings support a model in which contextual familiarity rescues the costs associated with rapidly switching to new tasks or contexts.

Keywords*: context switching; free recall; frequency; novelty; episodic memory*

Introduction

Our environment is ever-changing, filled with switches in context that vary in how often switches occur as well as prior exposure to the contexts (i.e., relative novelty). These types of changes profoundly influence how we form and structure memories. However, less is known about how the nature of these context changes influences memory. For instance, consider a typical Sunday. You may spend the day at home, trying to keep an eye on the big game in the living room while preparing dinner in the kitchen. If asked to recall what happened in the game, your later memory of a specific play within the game may become associated with memories of preparing your delicious dinner, supporting the recall of those memories. Instead, you could spend the day running errands in a new shopping mall that just opened up in town. You may have a hard time recalling all of the items purchased since you were overloaded with rapidly switching from one new store to another. Questions remain about how the qualitative features of context change (e.g., frequency and type) influence memory structure and organization.

Utilizing free recall paradigms offers a window into natural memory search, as it provides an assay of how items are bound to their surrounding contexts. Typically, when an item is presented during study, it is stamped into a continuously drifting context representation. The detection of a sufficiently novel representation, however, can cause a sudden shift in context (Polyn et al., 2009a). Prominent models of free recall posit that when an item is later recalled, it retrieves the context representation it was bound to at study, which in turn cues the recall of items encoded in a similar context state (Howard & Kahana, 2002; Kahana, 1996; Polyn et al., 2009a). Within this framework, transitions to a similar context state can be driven by a number of different qualia of context, including perceptual attributes (Heusser et al., 2018), task set/instructions (Polyn et al., 2009b), and stimulus class (DuBrow & Davachi, 2013, 2016). It is less clear how manipulating the dynamics of context changes, rather than the quality, influences free recall memory accessibility and organization.

There are two particular features of contextual change known to influence memory but have yet to be studied in the context of free recall: the frequency of context changes, as well as the relative novelty of the context to which one is switching. In many situations, we are moving back and forth between two familiar environments, such as repeatedly alternating between your kitchen and living room on a Sunday afternoon. Prominent models of free recall posit that our internal context typically lingers, such that at transitions, part of the prior context can drift into the new context. (Chan et al., 2017; Polyn et al., 2009a). When slowly alternating between two different contexts, the internal context that tags individual items is highly differentiated, which has been shown to provide structure for participants' free recall (Heusser et al., 2018; Polyn et al., 2009b). However, given this lingering, rapidly switching between two familiar contexts can cause the features of each to linger and overlap, creating a "blended" contextual representation. Little is known about whether a "blended" internal context representation would be beneficial or detrimental for free recall memory.

One possibility is that recall accuracy would benefit from rapid contextual switching as items will be more easily recalled if they are tagged with more varied contexts, providing more contextual retrieval cues (Lohnas et al., 2011; Siegel & Kahana, 2014). However, memory recall could also be impaired due to the interference of overlapping memories that share a similar internal context representation. When memories share features, retrieving those memories may be more difficult as compared to memories that do not share features due to heightened competition during retrieval (Anderson, 2003). The current set of experiments was designed to arbitrate between these two hypotheses.

The factors that contribute to a blended context may not solely rely on the frequency of switching, but could also be modulated by the learner's familiarity with the contexts between which they are switching. There are many situations in which we experience completely novel environments, such as moving between stores in a brand-new shopping mall. Conflicting findings have demonstrated that novelty can be both beneficial or detrimental to memory (Frank & Kafkas, 2021). Accumulating evidence suggests that salient events, like encountering a novel scene, can separate the overlap amongst two contexts (Zacks & Swallow, 2007). For instance, when novel items are more rare, such as at the event boundary (Heusser et al., 2018) or as oddballs in a list (Ranganath & Rainer, 2003; Von Restoroff, 1933), there is a boost in memory performance for items. However, increasing the amount or frequency of novelty leads to worse memory performance (Radvansky et al., 2011; Reggev et al., 2018; Shepherdson, 2021) and provides less access to subsequent information immediately following (Dux & Marois, 2009). Prior research has shown that increasing the number of novel switches in your environment can be disruptive. In particular, participants demonstrated worse memory for something they were carrying if they walk through multiple novel rooms as compared to one novel or back to a familiar room (Radvansky et al., 2011). These findings lend us to expect that free recall memory would be impaired specifically when individuals are rapidly switching to novel versus familiar events, due to less access to retrieval cues.

This present study uses a context switching paradigm in which we independently manipulate switching frequency and the relative novelty of the contexts. Following encoding, we measure free recall performance and organization. We sought to characterize how these qualitatively different features of context change influence how well these items are remembered and organized. We predict that memory will be differentially affected by switch rate with exposure to novel contexts, such that rapidly switching to a novel context will be more harmful for memory compared to switching at a slower rate. We also predict that returning back to the same context may independently benefit memory. We then determine the extent to which items are organized by the order in which they are encoded or the type of context with which they were originally presented.

Experiment 1

Method

Participants. One hundred and ten participants from the University of Oregon completed this experiment online for course credit. One participant was excluded for chance-level performance on the encoding task, 19 participants were excluded for failing to provide audio usable for verbal recall, and six participants were excluded for writing down words as indicated on a post-experiment questionnaire. The final sample size for analysis was 84 participants (65 female, mean age 19.46 +/- 3.17 SD). Participants were randomly assigned to one of two context switching groups (switch-back = 41; switch-novel = 43). Consent was obtained in a manner approved by University of Oregon's Institutional Review Board.

Stimuli. In brief, encoding consisted of alternating presentations of word and scene stimuli. Scene stimuli consisted of 46 unique scene images, where half depicted an indoor scene and half depicted an outdoor scene (Chang et al., 2019). We randomized the presentation of stimuli appearing in each condition across participants. Cue words were 240 two-syllable nouns presented in capitalized letters (e.g., "GIRAFFE"). Nouns were based on object image labels from the Bank of Standardized Stimuli (Brodeur et al., 2014). Words were randomly assigned to scenes and conditions uniquely for each participant. Stimuli were presented using Inquisit 6 [computer software]. (2020). Retrieved from https://www.millisecond.com.

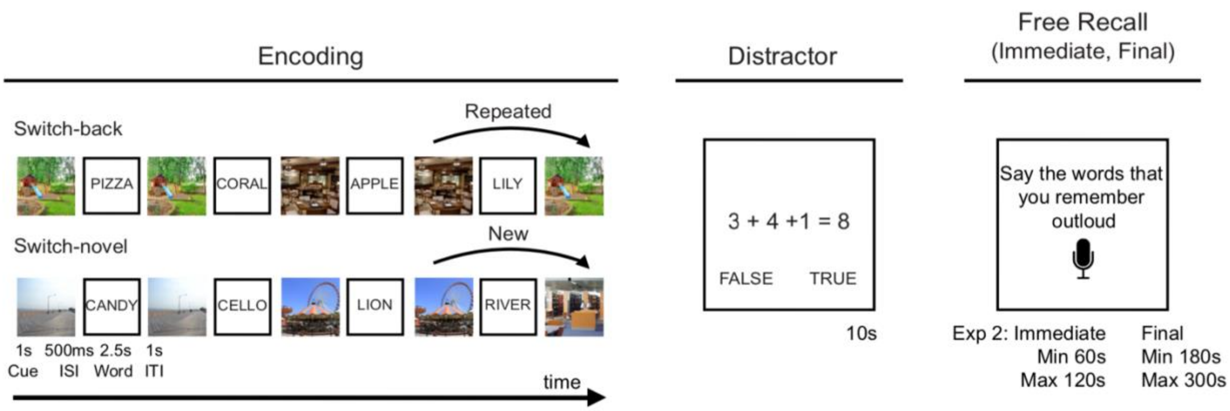

Figure 1. Trial structure for Experiments 1 & 2. Each trial began with the encoding phase. The encoding phase consisted of alternating presentations of word and scene stimuli. Participants were instructed to respond as to whether the item depicted by the word would fit in the scene. After a 10s distractor task, participants verbally recalled as many items as possible from the list that they could. After all eight blocks were completed, participants completed a final recall. The main conditions of interest were the switch-back and switch-novel groups (between-subjects), as well as the no switch, low switch, and high switch conditions (within-subjects). The high switch condition is represented in the diagram.

Procedure. After a brief practice, the experiment consisted of eight blocks, with each block consisting of three sequential phases: encoding, distractor, and recall (Fig. 1). On each trial, participants viewed a scene image for 1,000ms. The image disappeared for 500ms and was then followed by a word presented in the center of the screen for 2,500ms. During the word presentation, participants were instructed to respond as to whether the item depicted by the word would fit in the scene (yes/no). The word remained on the screen for 2,500ms regardless of button press to equate encoding time. Trials were separated by a 1,000ms intertrial interval (ITI) which consisted of a blank screen. Each block in the encoding phase included a total of 24 words.

Within subjects, we manipulated the switch rate between scenes to generate three switch rates: no switch, low switch, and high switch. In the no switch condition, all of the items were studied with the same scene, serving as a baseline condition. In the low switch condition, scene images changed after every four items. Lastly, in the high switch condition, the scene image switched after every two trials, thus switching more rapidly. In this experiment, we induced competition within a block between words to be recalled. If we only have a limited time to recall, the most memorable items will "win", and there is more of a direct comparison as to which condition had the strongest memories (Lohnas & Kahana, 2014; Talmi et al., 2019). To induce this competition, during each block in the encoding phase, participants switched between scenes at *two* different switch rates. To enhance the differences between conditions presented in the same block, the high and low switch rates were not paired together in the same block. Block order was counterbalanced and presentation of scenes appearing in each condition was randomized. Therefore, there were four block types: low switch followed by no switch, high switch followed by no switch, no switch followed by low switch, or no switch followed by high switch.

Participants were randomly assigned to one of two context switching groups in a between-subjects manipulation. In the switch-back group, within a given block, participants switched back and forth between the same two scene images. In other words, when there was a change in the scene context, it would be a repeat of a scene that had already been seen in the block previously. In the switch-novel condition, each time there was a switch in scene context, participants would see a novel scene that had not been seen before in the experiment. In both groups, every block contained new scenes.

Immediately following each encoding phase, participants completed a math distractor task to reduce rehearsal. Participants were presented with math equations in the form of A + B + C = D, where the values of A, B, and C were set to single digit integers (Howard & Kahana, 1999). Participants were instructed to indicate whether the statement was true or false with a key press. The distractor phase lasted 10s in total, but the number of equations completed was variable depending on speed of completion.

After the distraction period, participants were given up to three minutes to verbally recall as many items as possible from the list that they could, without any explicit instructions about the order of the of recall. A written cue indicated the start of the recall period, and participants' microphones were turned on for recording. Participants could move onto the next block whenever they felt that they recalled as many words as they could remember. After all eight blocks were completed, participants moved onto the final recall portion of the experiment. Participants were instructed to verbally recall as many words as they could from the entire experiment for up to three minutes.

Data Analysis. Statistical analyses were conducted in R 3.6.3 (R Core Team (2020); https://www.R-project.org/). Using the *lme4* package in R, Generalized Linear Mixed-Effects Models were used to determine whether switch rate and context switching group predicted the percent of words that participants recalled, with subject and word identity as random effects. Specifically, within each group, we assessed the relationship between percent of words recalled and condition (no switch (low) vs. low switch vs. high switch vs. no switch (high)). Additionally, a separate model was run with condition, group (switch-back vs. switch-novel) and the interaction between condition and group. These analyses were run for both immediate and final recall data. All models additionally controlled for block number and list half (whether the word appeared in the first 12 or last 12 items in the list) as fixed effects.

To determine the extent to which participants tend to successively recall nearby items, we calculated a temporal clustering score for each participant (Polyn et al., 2009). For each recall transition, we determined the temporal distance (in absolute lag) between the serial position of the just-recalled word and the set of not-yet-recalled words. The temporal clustering score is calculated as the proportion of possible lags greater than the observed lag. A score of 1 indicates high temporal clustering, meaning that participants made the shortest transitions possible. A score of 0.5 indicates chance-level temporal clustering, meaning that transitions were just as likely to be to a neighboring or remote item. For this analysis, each participant received two temporal clustering scores: one for high switch blocks and one for low switch blocks. These scores included the no switch condition for each switch type, as they were present for both conditions and removing them would influence the types of transitions made. Temporal clustering scores were computed using publicly available MATLAB (The MathWorks, Natick, MA) scripts from the Behavioral Toolbox (Version 1.01) from the Computational Memory Lab (http://memory.psych.upenn.edu/Behavioral_toolbox).

Verbal recall responses were digitally recorded and annotated offline using Penn Total Recall (http://memory.psych.upenn. edu/TotalRecall). Four undergraduate research assistants, who were blind to which words were randomly assigned to which condition and group, annotated the verbal responses. A recall was classified as valid if the item recalled came from the current list. Items from previous lists, words not in the wordpool, or other vocalizations (e.g, “umm”) were not included in analysis.

Results

Encoding Performance

Given that responses to the encoding task were somewhat subjective, accuracy was calculated based on normative responses. We determined whether each response matched the modal response for when each word was presented with each scene. Overall accuracy was 87.71%. Accuracy and RT did not differ between the switch-back and switch-novel conditions (Accuracy: switch-back- $M = 87.72\%$, $SE = 0.96$, switch-novel- $M = 87.71\%$, $SE = 0.9$), $t(81.42) = 0.008$, $p = .99$; RT: $F(1, 82) = 1.42$, $p = .24$.

Context switching and recall performance

Immediate Recall. Overall, participants recalled 22.37% of the total words during the immediate recall. Free recall accuracy was greater in the switch-back (24.45%) versus switch-novel (20.39%) conditions, $t(82) = 2.18$, $p = .032$, suggesting that participants' memory was better for words when switching back to repeated scenes.

Our first main analysis focused on characterizing interactions between switch rate and relative novelty on immediate recall performance. We ran Generalized Linear Mixed-Effects Models to determine whether switch rate, context switching group, and the switch rate x context switching group interaction predicted the percent of words that participants recalled. Results showed that rapidly switching to novel contexts reduced immediate recall performance over not switching, $z = 3.2$, $p = .001$. This memory deficit was specific to the high switch condition, as there was no detriment to memory in the low switch condition, as compared to no switch, within the switch-novel group. Interestingly, there was a boost in memory recall performance in the high switch condition over not switching at all when switching back to repeated items, z = 2.83, *p* = .005. This resulted in a reliable switch rate x context switching group interaction, specifically when rapidly switching, *z* = 4.21, *p* < .001 (Fig. 2a). This means that switching back to an expected context at a rapid rate may rescue the cost associated with rapidly switching to novel contexts.

We next investigated whether the differences in recall performance above were based on item position in the list, comparing boundary and non-boundary items. Across all groups and conditions, there were no differences in performance based on the position of items (i.e., boundary versus non-boundary; see supplemental materials).

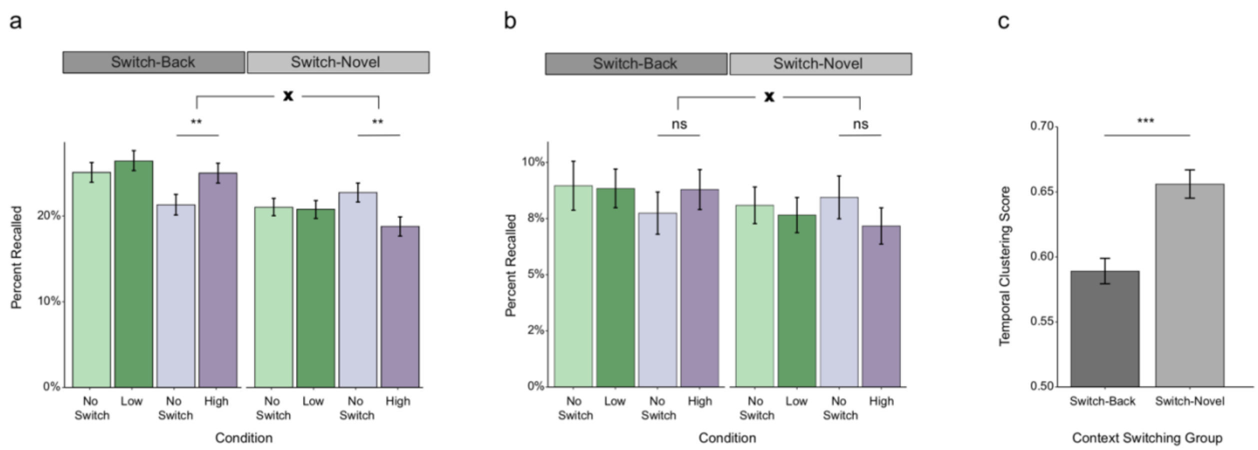

Figure 2. a) Immediate Recall Performance. b) Final Recall Performance. c) Temporal Clustering. Error bars reflect within subject standard error. ns *p* > .05, ** *p* < .01, *** *p* <.001.

Final Recall. Overall, participants recalled 8.08% of the total words during final recall, and there were no differences in the percent of words recalled between the switch-back (8.51%) and switch-novel (7.67%) conditions, *t*(77.12) = 0.77, *p* = .44.

Similar to the immediate memory test, memory recall observed in the switch-novel group was slightly reduced compared to when participants switched back to the same scene context only at a high frequency, *z* = 1.87, *p* = .062 (Fig. 2b). Further, there were no differences in performance based on the position of items (i.e., boundary versus non-boundary; see supplemental materials).

Context switching and recall organization

Temporal Clustering. We next investigated how switch rate and type of context switch (familiar vs. novel) influence recall organization. Results showed that both conditions across both context switching groups showed significant binding of items to their temporal context, as measured by greater than chance-level temporal clustering (*ps* < .001). However, when individuals were switching to novel versus familiar contexts, there was a greater reliance on temporal information (i.e., higher temporal clustering) when switching to completely novel contexts compared to repeated contexts, $t(157.6) = 4.99$, $p < .001$ (Fig. 2c).

Experiment 2

The results of Experiment 1 suggest that costs to memory are limited to situations where individuals are exposed to novel contexts. Specifically, recall memory performance is worse *only* when rapidly switching to novel contexts compared to not switching at all. This suggests not only a benefit for switching back to a familiar context, but that impairments of switching to novel environments only emerged in the context of rapid versus slower switches. Additionally, we found that when participants are switching to novel contexts, they recalled the items in temporal order more often, indicating a reliance on temporal information. This starts to get at why there is a difference between the two context switching groups. However, overall recall performance at both immediate and especially final recall was low.

In Experiment 2, we aimed to replicate the above findings with increased sample size and recall performance. Thus, the goals of Experiment 2 were to 1) replicate the recall performance related findings that the negative effect of switching on memory recall was rescued when switching back to a familiar context and 2) replicate and expand on the recall organization results from Experiment 1 to further investigate how participants in each of these groups structure their recalls and why there may be group differences. To expand on our understanding of how participants structure their recalls, we investigated recall organization by scene in Experiment 2.

Method

Participants. One hundred ninety-two native English speakers were recruited from Prolific. Participants were compensated an initial $6.50 and could receive an additional bonus payment of up to $6.00 for good performance on the encoding and recall portions of the experiment. Nine participants were excluded for chance-level performance on the encoding task, six participants were excluded for failing to provide audio usable for verbal recall, and ten participants were excluded for writing down words as indicated on a post-experiment questionnaire. The final sample size for analysis was 167 participants (90 female, mean age 35.74 +/- 12.98 SD). Participants were randomly assigned to one of two context switching groups (switch-back = 83; switch-novel = 84). Consent was obtained in a manner approved by University of Oregon's Institutional Review Board.

Stimuli. The stimuli used for Experiment 2 were the same as those used in Experiment 1. However, in Experiment 2, we only used 30 of the scene images as the list length was shortened (see below).

Procedure. The procedure for Experiment 2 was identical to that of Experiment 1, except for the following changes aimed at improving participants' verbal recall performance. First, we shortened the list length to only contain 16 items per list. Second, given that the lists were shorter, each switch rate (no switch, low switch, and high switch) was presented in its own block to optimize the number of switch items per condition. Participants saw two blocks of each switch rate for a total of six blocks. Lastly, a minimum time was added to immediate and final recall. For immediate recall, participants had up to two minutes to recall, but would not be allowed to continue until after one minute. For final recall, participants had up to five minutes to recall, but would not be allowed to continue until after three minutes. We changed the instructions to encourage participants to continue to search their memory until the time was finished. One additional change was made in the instructions to improve the clarity of the encoding task and create a more even distribution of yes/no responses. Participants were completing the same encoding task as Experiment 1, but were now instructed to make a yes/no judgment as to whether you could find the item in the scene.

Data Analysis. Data analysis was identical to Experiment 1 with the following addition. We sought to determine the extent to which participants successively recalled items shown with the same scene, or source context. This analysis combined both contextual and temporal factors. We were interested in the question: When a participant makes a local transition, how often is it to the same or a neighboring context? A local transition corresponds to the recall of an item from the same context, or the context immediately preceding (backwards) or immediately following (forwards) the context of the just-recalled item. Only local transitions will be analyzed as this is a fair comparison between the switch-back and switch-novel groups, as transitions are equally different between the two groups. Inclusion of remote transitions would allow participants in the switch-back group to transition between items paired with the same scene throughout in the list, which is not possible in the switch-novel group. For this analysis, we calculated the conditional response probabilities by local transition type, similar to (Polyn et al., 2009a). For each participant, we tallied the number of recall transitions that were between items studied with the same image, the previous image (backwards transition), and the following image (forwards transition), and divided each by their total number of recall transitions. This gives a proportion of local transitions for each participant that was then averaged across all participants in each group. Recalls of items from the first context (2 items from the high switch condition and 4 items from the low switch condition) were removed from analysis as participants are unable to make a backwards transition from these items. Here, we are interested in how organization by source context differs between contextual novelty and familiarity only, within each switch rate condition. The high switch and low switch conditions have a different number of items between each transition (2 vs. 4 items), so therefore it would not make sense to compare these two conditions. Additionally, this analysis was unable to be run in Experiment 1 because within a given block, recalls included items from both a no switch and a switching (low switch or high switch) condition. Therefore, transitions between items are not matched.

Results

Encoding Performance

In Experiment 2, overall accuracy was 85.3%. Accuracy and RT did not differ between the switch-back and switch-novel conditions (Accuracy: switch-back- M = 84.61%, SE = 0.94, switch-novel- M = 85.99%, SE = 0.64), $t(158.27) = 1.13$, $p = .26$; RT: $F(1, 165) = 1.47$, $p = .23$.

Context switching and recall performance

Immediate Recall. Overall, participants recalled 50.47% of the total words during immediate recall. However in this study, there were no differences in the percent of words recalled between the switch-back (51.15%) and switch-novel (49.79%) conditions, $t(164.97) = .51$, $p = .61$. This demonstrates that the design changes made in Experiment 2 were successful in raising recall performance and equating overall accuracy across conditions.

We next tested for interactive effects of switch rates and the novelty of contexts. Replicating Experiment 1, rapidly switching to novel, $z = -2.64$, $p = .008$, but not repeated, contexts reduced immediate memory recall performance, and resulted in a reliable interaction, $z = 2.19$, $p = .03$ (Fig. 3a). Interestingly, this relationship was only observed in the high switch condition, as there was no difference in recall performance in the low switch condition between the two groups, $z = .07$, $p = .94$. Recall performance in the no switch conditions were similar between the switch-novel and switch-back groups, $z = -.003$, $p = .997$. Thus, we directly replicated this effect that memory recall is hindered *only* when switching to novel contexts at a high rate. As in Experiment 1, these effects within the high switch condition were not due to differences in recall performance by item position (see supplemental materials).

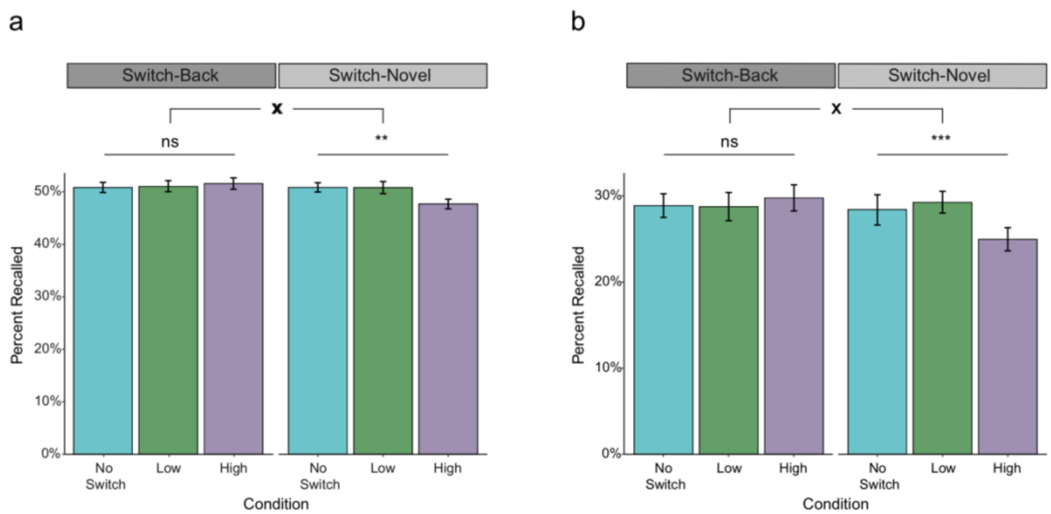

Figure 3. a) Immediate Recall Performance. b) Final Recall Performance. Error bars reflect across subject standard error. ns $p > .05$, ** $p < .01$, *** $p < .001$.

Final Recall. Overall, participants recalled 28.34% of the total words during final recall. There was no difference in the percent of words recalled between the switch-back (29.14%) and switch-novel (27.55%) conditions, $t(161.48) = .73$, $p = .47$.

The results from the final recall portion of the experiment were largely similar to that of immediate recall. Rapidly switching to novel, $z = -3.52$, $p = .0004$, but not repeated contexts reduced immediate memory recall performance, and resulted in a reliable interaction, $z = 2.81$, $p = .005$ (Fig. 3b). This pattern of results reflects those shown in Experiment 1 but are more robust. As in immediate recall, these effects within the high switch condition were not due to differences in recall performance by item position (see supplemental materials).

Context switching and recall organization

Temporal Clustering. Results showed that all conditions across both context switching groups exhibited greater than chance-level temporal clustering (*ps* < .001). However, as expected, there were group differences in the degree of temporal clustering. Replicating the results found in Experiment 1, there was a greater reliance on temporal information (i.e., higher temporal clustering) when switching to completely novel contexts compared to repeated contexts, $t(330.14) = -3.07$, $p = .002$ (Fig. 4a).

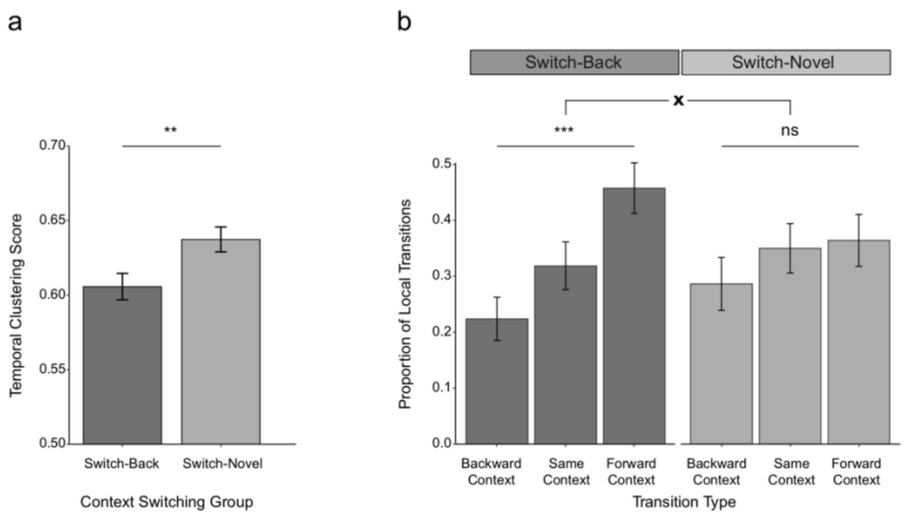

Figure 4. a) Temporal Clustering. b) Recall Transitions by Context. Transition analysis image depicts high switch condition only. Error bars reflect across subject standard error. ns $p > .05$, ** $p < .01$, *** $p < .001$.

Recall Transitions by Context. In our recall performance analyses, we demonstrated that there is something very unique about switching at a high frequency. In particular, there is a memory impairment for items studied during rapid switches to novel contexts, but we did not find this impairment during rapid switches to familiar contexts. We next wanted to unpack why there might be a difference in recall performance during rapid context switching. One possibility is that there is a difference in how participants are organizing their recalls. In the next analysis, we took into account both the temporal as well as the contextual factors of participants' recalls and analyzed the proportion of recall transitions made to the same or neighboring contexts (forwards or backwards). In the high switch condition within the switch-back group, participants made more forward transitions than same, $t(213) = -2.84$, $p = .005$, or backward transitions,

$t(213) = -4.78$, $p < .00$. In fact, there was a significant interaction, where more forward transitions were made, as compared to backwards, only in the switch-back group, $t(444) = -2.15$, $p = .032$ (Fig. 4b). There were no significant differences between any of the transition types in the switch-novel group (Forwards & Backwards: $t(231) = -1.46$, $p = .144$; Forwards & Same: $t(231) = -0.27$, $p = .79$). This demonstrates that there is something qualitatively different about how participants in the two groups organize their recalls when switching at a high frequency.

In the low switch condition, participants transitioned significantly more to items in the same context as compared to forwards or backwards in both the switch-back, (Forwards: $t(246) = -6.56$, $p < .001$, Backwards: $t(246) = -7.1$, $p < .001$), and switch-novel groups, (Forwards: $t(249) = -9.87$, $p < .001$, Backwards: $t(249) = -9.98$, $p < .001$). Unlike in the high switch condition, there is no forward asymmetry and there were no significant differences between the switch-back and switch-novel groups. Of note, results between the low and high switch conditions are unable to be compared as these conditions have a different number of items between each transition (2 vs. 4 items), as the number of potential switch transitions differs across conditions. Taken together, the results from the low switch condition replicate previous findings that participants tend to cluster their responses by context. However, we expand to suggest that during the high switch condition, participants tended to recall items from the following context only during repeated switching, despite being paired with a different external context.

Discussion

Across two studies, we investigated free recall performance and organization after manipulating the frequency and novelty of context participants were switching between. Consistent with our hypothesis, we found that memory was differentially affected by switch rate with exposure to novel contexts. Specifically, we found and replicated that when participants were switching to novel scene contexts, there was a recall memory detriment only when switching at a rapid rate. However, this detriment was not observed when participants switched rapidly back to repeated contexts. Taken together, this suggests that rapidly switching back to familiar contexts may rescue the cost associated with rapidly switching to novel contexts. We also found that participants in each group organized their recalls differently, where there was a greater reliance on temporal information for participants who were continuously exposed to novel contexts. On the other hand, rapidly switching back to the same context led to more local forward transitions to different contexts, suggestive of a lingering context representation.

The results of these two experiments add to a growing body of literature characterizing the effects of switching contexts on free recall performance and organization. Previous studies found that a single change in task set (Polyn et al., 2009a, 2009b) or slowly changing perceptual features (Heusser et al., 2018) during learning are sufficient to impose different structure on free recall. Specifically, they found that more free recall transitions were made between items studied using the same task as compared to items studied using two different tasks. Our findings from the low switch condition are consistent with this result and we extend it to suggest that clustering by source context may be switch rate dependent. Specifically, we found that more recall transitions were made to items from the subsequent context when participants were switching contexts more rapidly. Our results also replicate previous findings that participants tend to recall information in a similar temporal order in which it was originally learned. We extend these findings by showing that temporal clustering is heightened in situations of switching to novel contexts. In certain situations, clustering items by their temporal context may not be as adaptive, where participants may have more success grouping items by a contextual, semantic, or motivational relationship between items (Horwath et al., 2022; Howard & Kahana, 2002; Polyn et al., 2009a). However, in situations when such relational information may be unavailable or changing too quickly, participants may rely more on remembering the items in the order in which they were studied.

Importantly, and adding to prior work on novelty and memory, we demonstrate that the cost of switching to novel events is specific to switching at a high frequency. Specifically, in both experiments, the detriment to free recall performance was eliminated when participants were switching to novel contexts at a slower rate. This is consistent with previous work where increasing the amount or frequency of novelty lead to worse memory performance (Radvansky et al., 2011; Reggev et al., 2018; Shepherdson, 2021). This suggests that with too much novelty, participants' memory performance is hindered. Participants may become overloaded with new information too quickly which influences their ability to remember specific items. For instance, research suggests that novelty-related context disruption may reduce accessibility for items studied prior to the novel events (Polyn et al., 2009a). However, we do not see the same detriment when participants change to new information more slowly. These findings highlight the importance of the frequency at which individuals switch to novel environments. An open question for future work is to understand why switching to novel contexts more slowly does not hinder free recall.

Our findings also support a clear memory distinction between switching back to a repeated context and switching to novel contexts. Specifically, across both experiments we found a cost for switching to novel contexts at a high frequency that was not present when switching to repeated contexts. In fact, memory performance after rapidly switching back to repeated contexts was just as good as when participants were not switching contexts at all. This suggests that rapidly switching back to repeated contexts may rescue the costs of rapidly switching to novel contexts. A similar result was found in previous work, where participants demonstrated worse memory for an item they were carrying if they walked through multiple novel rooms ("double switch") as compared to returning back to a room they were just in (Radvansky et al., 2011). Here, we provide novel evidence for this memory effect after multiple switches using a free recall paradigm.

Lastly, the current findings provide support for the framework that rapidly switching back to repeated contexts creates a "blended" context representation. In particular, we found that participants in the switch-back group made more local forward transitions to items in a different context. This finding is consistent with the idea that free recall is bias in the forward direction (Howard & Kahana, 2002; Kahana, 1996). This provides evidence for a "blended" context representation as, according to CMR, individuals are more likely to recall items encoded with a similar context representation (Polyn et al., 2009a). This would thus imply that despite the items being paired with two different external contexts, they are encoded with a similar internal context representation. As expected, this type of context representation only occurs in the switch-back group. In this group, there is less of a cost for thinking about the first context into the second context as you are continuously switching back between those two contexts. Therefore, the first and second contexts are both active and can be used to access memories for the unique items. On the other hand, in the switch-novel group, if many contexts were continuously active, this could lead to interference. Additionally, previous research using a similar analysis to the present study found that in lists with a single task switch, participants were more likely to recall their next item from the same task (Polyn et al., 2009a), suggesting that this framework is specific for context switching at a higher frequency. The present results begin to suggest that this creation of a “blended” context representation may serve as a better retrieval cue in familiar contexts compared to contexts with high amounts of novelty. Future working using neuroimaging techniques can better understand the internal context representations during rapid context switching and how that influences memory structure and performance.

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Supplementary Materials

A Generalized Linear Mixed-Effect model was run to determine whether item position in the event predicted the percent of words that participants recalled, with subject, word identity, and response time as random effects and block number as a fixed effect. Items were labeled as boundary items if the previous item was from a different context. For the low switch condition, preboundary items are items immediately preceding boundary items, and postboundary items are items immediately following boundary items. The third item in the list was not included in analysis. For the high switch condition, since there are only two items, the items will be labeled as a boundary and non-boundary items. Primacy and recency items (first four and last four for low switch, first two and last two for high switch) were removed from this analysis.

Experiment 1

During immediate recall in the high switch condition, there was no difference in percentage of words recalled between boundary and non-boundary items in the switch-back, $z = 0.31$, $p = .76$ or switch-novel, $z = 0.23$, $p = .82$, groups. Similarly, in the low switch condition, there was no recall benefit for boundary items over preboundary, $z = 0.08$, $p = .94$ or postboundary items, $z = -1.32$, $p = .19$ in the switch-back condition. Likewise, there was no recall benefit for boundary items over preboundary, $z = -0.26$, $p = .80$, or postboundary items, $z = -0.36$, $p = .72$ in the switch-novel group. This would suggest that item position did not contribute to the differences in condition and group discussed previously.

We found a similar result during final recall. In the high switch condition, there was no difference between boundary and non-boundary items in the switch-back, $z = 0.60$, $p = .55$ or switch-novel, $z = 1.34$, $p = .18$, groups. Additionally, In the low switch condition, there was no recall benefit for boundary items over preboundary, z = 1.12, p = .26 or postboundary items, z = 1.36, p = .17 in the switch-back condition. Similarly, there was no recall benefit for boundary items over preboundary, z = 0.23, p = .82, or postboundary items, z = 0.07, p = .95 in the switch-novel condition. Taken together, these results show that there is no difference based on position of items, and participants are similarly likely to recall items from boundary and non-boundary positions across all conditions.

Experiment 2

During immediate recall in the high switch condition, there was no difference between boundary and non-boundary items in either the switch-back, z = 0.29, p = .77 or switch-novel, z = 1.04, p = .30 groups. However, in the low switch condition, more boundary item words were recalled in the switch-back group as compared to preboundary items, z = 2.25, p = .02. Surprisingly, there was no recall benefit for boundary items in the switch-novel group over preboundary, z = -.34, p = .73 or postboundary items, z = -.22, p = .83.

We replicate this pattern during final recall. In the high switch condition, participants recalled more boundary than non-boundary items in the switch-back group, z = 2.74, p = .006. However, there was no difference between boundary and non-boundary items in the switch-novel, z = 0.77, p = .44 group. However, in the low switch condition, more boundary item words were recalled in the switch-back group as compared to postboundary items, z = 2.9, p = .004. As with immediate recall, there was no recall benefit for boundary items in the switch-novel group over preboundary, z = .66, p = .51 or postboundary items, z = .49, p = .63.

Together, we found and replicated that in the high switch condition, there was no memory difference in boundary or non-boundary items. This is consistent with previous work that also did not observe a boost in free recall of boundary items, perhaps because boundaries may selectively increase associative binding between an item and its context (Heusser et al., 2018). However, we did find that when the context was switching more slowly, participants recalled more boundary items than neighboring items only in the switch-back group. It is possible that we see enhanced recall at event boundaries in the low switch condition and not the high switch condition because the boundary creates an event in a stable context, like an oddball. However, if the context becomes blended as in the high switch condition, there is a lack of a clear boundary.