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Task context and organization in free recall

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Abstract

Prior work on organization in free recall has focused on the ways in which semantic and temporal information determine the order in which material is retrieved from memory. Tulving's theory of ecphory suggests that these organizational effects arise during the recall process, through the interaction of a retrieval cue with the contents of memory. Using the continual-distraction free-recall paradigm (Bjork & Whitten, 1974) to minimize retrieval during the study period, we show that encoding task context can organize recall, suggesting that task-related information is part of the retrieval cue. We interpret these results in terms of the Context Maintenance and Retrieval model (CMR; Polyn, Norman, and Kahana, submitted), in which an internal contextual representation, containing semantic, temporal, and source-related information, serves as the retrieval cue and organizes the retrieval of information from memory. We discuss these results in terms of the guided activation theory (Miller & Cohen, 2001) of the role of prefrontal cortex in task performance, as well as the rich neuropsychological literature implicating prefrontal cortex in memory search (e.g, Schacter, 1987).

KEYWORDS: episodic memory, organization, memory search, free recall, orienting task.

Task context and organization in free recall

Introduction

Behavioral investigations of the human memory system suggest that representations of events and items are associated with an internal context representation whose state changes slowly over time (Howard & Kahana, 2002a; Kahana, Howard, & Polyn, in press; Sederberg, Howard, & Kahana, in press). By these context-based theories, the composition of this internal context representation (and its associations with studied material) determines the order with which information is pulled from memory. While decades of behavioral work have established a rich set of context-dependent behavioral phenomena, direct neural evidence for such a context representation is scarce. While a number of researchers have begun to characterize the patterns of neural activity observed during memory search (Wheeler, Petersen, & Buckner, 2000; Prince, Daselaar, & Cabeza, 2005; Polyn, Natu, Cohen, & Norman, 2005; Sederberg et al., 2007b), the functional contribution of the identified brain areas to the search process remains an open question.

While direct neural evidence for the context representation is scarce, rich theories have arisen from the neuropsychological literature proposing that prefrontal cortex has a central role in the maintenance and manipulation of internal representations specifying the spatiotemporal context in which a given memory occurred (Schacter, 1987; Shimamura, 1994; Norman & Schacter, 1996; Moscovitch & Winocur, 2002). An emerging framework, described by Polyn and Kahana (2008), attempts to integrate these neuropsychological theories of the role of prefrontal structures in memory with the role of prefrontal cortex in task performance. Specifically, this framework builds upon the ideas of guided activation theory (Miller & Cohen, 2001), in which prefrontal cortex maintains patterns of activation relevant to the current behavioral task, such as features of salient stimuli (Braver et al., 2001) or task representations (Cohen, Dunbar, & McClelland, 1990). This notion that task-relevant information may be maintained during study (guiding the system to respond appropriately to stimuli) as well as during memory search (guiding the system to retrieve associated memories), may be an important step in bridging neural and behavioral theories of human memory.

By the Polyn and Kahana (2008) framework, context representations maintained in prefrontal cortex and representations of studied material in posterior cortical regions both project to hippocampus, where they are associated with one another. During retrieval, the still active context representation can once again project to hippocampus, which then reactivates the associated features of the studied material in posterior regions (see also, Norman, Detre, & Polyn, 2008). If prefrontal cortex is the locus of contextual information in the brain, and if these contextual features are bound to the features of studied items, then one would expect recalled items to cluster according to the type of information that is maintained in the context representation.

Behavioral analysis of clustering during memory search has a long history, and researchers in this area have reported organization of recalled material according to semantic similarity, temporal proximity, and several types of external source characteristics, such as spatial location (Curiel & Radvansky, 1998), modality (auditory or visual, Murdock & Walker, 1969), gender of the speaker, and even typeface of the word (Hintzman, Block, & Inskeep, 1972; Nilsson, 1974). Recently, Polyn, Norman, and Kahana (submitted) provided evidence that internal source characteristics can also strongly influence the organization with which items are retrieved from memory. Participants studied a list of items, and shifted back and forth between two encoding tasks over the course of the list. During recall, the items tended to cluster according to the task identity associated with the word being recalled. Polyn et al. (submitted) presented the Context Maintenance and Retrieval (CMR) model in which memory search is driven by a context representation containing information related to the source characteristics of the studied material. They suggested that these organizational effects arise during the retrieval process, as a consequence of associations between the context representation and the features of the studied material.

Our modern understanding of the retrieval process owes much to the work of Endel Tulving (Tulving, 1962, 1972; Tulving & Donaldson, 1972; Tulving, 1974, 1979). Tulving focused theoretical attention on the importance of understanding the dynamics occurring during retrieval itself, as opposed to the tendency in the literature to focus on the encoding process (Tulving, 1983). Tulving's work highlighted the importance of organization in understanding memory search, and specifically, the role of the retrieval cue in determining the relative probability with which various studied items will be retrieved from memory. Free recall provides us with a paradigm where the ability of a participant to successfully retrieve studied material depends on the moment-to-moment composition of an internally maintained retrieval cue, and the associations between this cue and stored information. Tulving referred to this interaction between the retrieval cue and stored information as ecphory (Tulving, 1983; Semon, 1921), and established its theoretical importance in a series of studies (Tulving & Thompson, 1973; Wiseman & Tulving, 1976; Bartling & Thompson, 1977).

The current experiment is designed to extend our understanding of the role of this ecphoric process in the phenomena of source organization. Specifically, we are interested in determining to what degree organization by source characteristics depends upon processes carried out during the study period, versus processes carried out during search itself. The above mentioned study by Polyn et al. (submitted) showed organization by task context using an immediate free-recall paradigm. As a number of theorists have pointed out, using data from the overt rehearsal variant of the free-recall paradigm, the pattern of item rehearsals engaged in by the participant is an important predictor of later recall organization (Rundus &

Atkinson, 1970; Tan & Ward, 2000; Laming, 2006). As such, it is difficult to determine whether the organizational effects observed by Polyn et al. (submitted) arose due to covert rehearsal during the study period, or due to the retrieval cue during the recall period. In order to isolate the contribution of the composition of the retrieval cue to organizational phenomena, we used a variant of the continual-distraction free-recall paradigm (Bjork & Whitten, 1974), in which participants engage in distracting mental activity before and after each item on the study list. This drastically reduces the ability of participants to engage in covert rehearsal of the study material, and should afford us a more pure estimate of the contribution of the retrieval cue to the organization of studied material.

This study was designed to provide evidence that encoding task representations are maintained in the cognitive system during memory search, and affect the organization with which information is pulled from memory. The guided activation theory, reviewed above, suggests that these encoding task representations reside in prefrontal cortex, and are associated with the representation of the studied item. The CMR model further suggests that these same task representations will be reinstated during memory search, and that the presence of a particular task representation may allow one to predict the course of recall dynamics. We further explore this issue in the discussion.

Methods

24 Undergraduates at Princeton University (17 female) participated in this experiment for course credit and payment. Participants were run in a variant of the continual-distraction free-recall paradigm (Bjork & Whitten, 1974). Each participant performed 12 trials of the paradigm (the first 4 trials were practice and were not included in the present analysis). On each trial, 12 items were presented on a computer screen. Each item was judged using one of two tasks, a pleasantness judgment ("good" or "bad") and a size judgment ("big" or "small",

relative to a shoebox). Each study item was preceded by a task cue (for 1.5 seconds), after which the study item appeared for another 1.5 seconds. Subjects indicated their judgment with a key press. After each stimulus presentation subjects performed a distraction task for 9 seconds (counting backward by sevens from a three-digit number) before the next task cue appeared. A distraction period of the same duration preceded the list. After the final distraction period participants were given 50 seconds to verbally recall as many items from the list as they could in any order. Each trial was drawn from one of two conditions: a control condition where each item was studied with the same task, and a task-shift condition, where the shift took place between the sixth and seventh items.

Verbal responses were digitally recorded and scored for recall order and verbalization onset with software developed by the Kahana lab (`http://memory.psych.upenn.edu`). A recall was classified as valid if the item recalled came from the current list. Items from previous lists, or from extra-experimental sources (intrusions) were not included in the current analyses. A given output transition between items during the recall period was considered valid if it was between two valid recalls.

Word lists were drawn from a subset of the Toronto Noun Pool (Friendly, Franklin, Hoffman, & Rubin, 1982); the subset excluded words inappropriate to the current encoding tasks (such as abstract words like “absence”). Lists were tested to ensure that the mean Kučera-Francis frequency (Kučera & Francis, 1967) value of the list fell within a certain range (20 to 50), and that the frequency variance fell within another range (100 to 6000). These numbers were arrived at by randomly generating a large number of sample lists, and inspecting histograms of mean and variance of frequency across these lists. The threshold values above were chosen to include the modes of the distributions, and exclude the long tails. Word-similarity scores derived with latent semantic analysis (Landauer & Dumais, 1997) were used to ensure that close semantic associates did not appear in the same list. A given list could not include two words with a similarity score exceeding 0.25.

Results

As described above, the Context Maintenance and Retrieval (CMR) model suggests that a representation of the encoding task used to study each item is maintained in an internal context representation and is then used to guide recall. A basic prediction of the theory is that the encoding task context used to process the most recent items will be active during the beginning of the recall period, increasing the likelihood that the post-shift items will be recalled. Our first analysis investigates the likelihood of recalling particular items as a function of list position (and consequently task identity, since participants shifted from one encoding task to the other halfway through the list in the task-shift condition). Since performance on the control lists for each of the two tasks was not significantly different (using a paired t-test on mean percent correct by encoding task; $t(23) = -1.87; p > 0.05$) all analyses of the effects of task-shift were conducted without regard to task identity.

We used an analysis of variance to compare the proportion of items recalled before and after the task shift in the task-shift condition (and from equivalent serial positions in the control condition). This two-by-two analysis of variance (list type: control or task-shift by list half: pre- or post-shift) showed no main effect of list type ($F(1, 23) = 4.00; MSE = 0.21; p > 0.05$), or of list half ($F(1, 23) = 1.65; MSE = 0.17; p > 0.2$). However, it did reveal a significant interaction between list type and list half ($F(1, 23) = 4.81; MSE = 0.21; p < 0.05$). A contrast investigating this interaction revealed that participants recalled significantly more post-shift items in the task-shift condition relative to the control condition ($t(23) = -3.46; p < 0.05$). No difference was observed between the pre-shift items in the two conditions ($t(23) = 0.39; p > 0.1$). In summary, items studied after the task-shift were more memorable than items from equivalent serial positions in the control lists, and there was no cost to the memorability of items studied prior to the task shift. We investigate this phenomenon further by inspecting the probability of recall by serial position (Figure 1, top plot), which shows that this advantage for the post-shift items is most pronounced for the items studied immediately after the task shift. The bottom plot in Figure 1 shows the difference in memorability for each serial position between the two conditions; the error bars are 95% confidence intervals on the subject means.

Insert Figure 1 about here

The CMR model predicts that post-shift items will not only be more memorable, but that the first recall should be a post-shift item, since the retrieval cue is more consistent with the context of these items. The probability of first recall curve shown in Figure 2 (top plot) provides insight regarding the composition of retrieval cue at the start of the recall period (Hogan, 1975; Howard & Kahana, 1999; Laming, 1999). Both conditions show a sizable long-term recency effect, as well as a primacy effect for the first list item in both conditions. Most interestingly, Figure 2 reveals an enhanced probability for the first post-shift item (serial position 7) to be recalled first in the task-shift condition, as compared to the control condition ($t(23)=-2.46$, $p<0.05$). Again, the bottom plot in Figure 2 shows the difference in probability of first recall for each serial position between the two conditions; the error bars are 95% confidence intervals on the subject means.

Insert Figure 2 about here

The CMR model was developed to explain organizational effects in memory search. As mentioned, the core of this model is a context representation that contains information related to the encoding task used during the study period. When this same task representation is used to guide retrieval, we observe organization, or clustering, of items by task context. Task clustering can be measured by calculating the probability that a given recalled item is then followed by a same-task or a between task transition. In order to demonstrate this organizational effect we compare the recall sequences from the task-shift condition to those from the control condition. If items were drawn from the list randomly, one would expect the probability of drawing two items from the same task successively to be distributed about 0.5. However, by the principle of contiguity (Kahana et al., in press), items studied nearby in time tend to be recalled successively, and since by design same-task items are contiguous, this will inflate the probability of a "same-task" transition in the control lists (that is, between items from the same serial positions as same-task items in the task-shift lists). Indeed, Table 1 shows that the probability of making a same-task transition in the control condition is significantly above 0.5 (Wilcoxon signed rank test: $z = -2.6; p < 0.01$), due to the contiguity effect. Nevertheless, the organizational effect of task context leads to a significant increase of the probability of a same-task transition above this baseline (Table 1; Wilcoxon signed rank test: $z = -2.86; p < 0.005$)

Insert Table 1 about here

Besides reorganizing the contents of memory, task context also exhibits itself behaviorally in a longer interresponse time (Murdock & Okada, 1970) when a participant recalls an item from one task context followed by an item from the other task context (as compared to transitions between similar serial positions in the control condition). We assessed this difference by comparing the set of interresponse times for between-task transitions in the task-shift condition, with the set of interresponse times between equivalent serial positions in the control lists. As shown in Table 1, on average the interresponse times from the task-shift condition are longer by about 2 seconds (Wilcoxon rank sum test: $z = -2.55; p < 0.05$). Polyn et al. (submitted) observed a similar increase in interresponse times with task shifts and interpreted it as a "recall shift cost", analogous to the shift cost in response times seen in the task-switching literature (Allport, Styles, & Hsieh, 1994). They suggested that these increased interresponse times arose because items studied with different encoding tasks were associated with distinct retrieval cues, such that transitions between items studied with different tasks are slower because of the inconsistency in task context associated with the two items.

Interresponse times in free recall are sensitive to a number of factors; they increase exponentially with output position (Murdock & Okada, 1970), and they increase as a function of serial position lag between the two recalled items (Howard & Kahana, 2002b). Given the multiple sensitivities of interresponse times in free recall, it is important to determine whether this recall shift cost can be explained simply by a difference in mean output position or mean serial lag between the successively reported items. The mean output position for between-task transitions was 3.4 in the task-shift condition, and 3.2 for transitions between equivalent serial positions in the control condition, a difference which is not significant by a t-test across subject means ($t(22) = 1.08; p > 0.2$). The mean serial lag for between-task transitions was 6.2 in the task-shift condition and 6.1 in the control condition, which was also not significant by a t-test across subject means ($t(22) = 0.14; p > 0.5$).

A final analysis was conducted to ensure that more subtle differences in the distribution of output positions for between-task transitions in the two conditions could not be contributing to this effect. For each subject, we calculated their mean between-task interresponse time separately for each output position for the control and the task-shift condition. If a given subject had no valid interresponse times for a particular output position in one of the conditions, that output position was excluded from the analysis. Then, for each subject and output position, we calculated the difference between the mean interresponse times for the two conditions, removing the effect of output position. We were then able to calculate the mean difference score for each participant, revealing an average increase in interresponse time of 2543 msec for between-task transitions in the task-shift condition. A t-test on these mean difference scores across participants was significant ($t(22) = 3.19; p < 0.005$).

Discussion

Polyn et al. (submitted) introduced the Context Maintenance and Retrieval (CMR) model, which proposes that organizational effects observed during memory search reflect the use of a slowly changing, information-rich context representation to guide recall. By this model, the context representation contains information related to the temporal context, semantic characteristics, and source attributes (such as encoding task) of the studied material. In particular, they showed that by manipulating the task context associated with subsets of the studied items, items associated with a similar task context would cluster during recall. The current experiment extends the results of Polyn et al. (submitted) by demonstrating these organizational effects in a variant of the continual-distraction free-recall paradigm, in which participants perform an unrelated distraction task before and after each item on the study list. First, we review the empirical findings of this investigation, and then we discuss the implications of this work for neuroscientific investigations of human memory.

We found that the shift in task context that occurred midway through the study list altered the participant's recall behavior in a number of ways, consistent with the hypothesis that task-related information in the retrieval cue is used to guide recall. First, items studied after the task shift were more likely to be recalled than similar items in a control condition, and there was no decrease in memorability for pre-shift items (Figure 1). Polyn et al. (submitted) found a similar increase in likelihood of recall for the most recently studied items in a task-shift condition. However, they also found that items from earlier list positions were less likely to be recalled. They proposed that this cost for the memorability of earlier list items in the task-shift condition was due to the disruptive nature of the process of shifting back and forth between tasks. In the current paradigm, participants shift to an unrelated distraction task between every studied item, which in effect equalizes the number of task shifts on the control and shift lists. While this is consistent with the task-shift disruption hypothesis proposed by Polyn et al. (submitted), one important difference between the two paradigms was the total number of task shifts in a given list (6 or 7 in Polyn et al. (submitted), 1 here). As such, it would be useful to conduct a follow-up experiment with the same list structure as Polyn et al. (submitted), but manipulating whether the continual distraction paradigm was used.

The organizational effects of introducing a task shift can be observed immediately in the recall period, with a significantly increased likelihood of the first post-shift item coming first in the recall sequence (Figure 2). In other words, there is a primacy effect for the set of same-task items following the mid-list shift in encoding task. The CMR model, although designed to explain source-related organizational effects, does not predict this effect, mostly because it was not designed to explain the primacy effect in free recall. In a standard free-recall paradigm, one might explain this effect by suggesting that the task shift disrupted some covert rehearsal process, forcing one to restart rehearsal with the first post-shift item. However, it is unlikely that the current effect is due to covert rehearsal, as the distraction task greatly reduces the ability of participants to engage in covert rehearsal during the study period. This may be evidence for a novelty-related enhancement of learning (Von Restorff, 1933), in which the mismatch between the new encoding task representation and the representation of the previous encoding task triggers more focused attention on the first post-shift item.

Task-related organizational effects are seen throughout the recall period, as summarized by the same-task transition probabilities in Table 1. The fact that we observe a large degree of task-related clustering (Table 1) in a paradigm where rehearsal (i.e., study-period reorganization) is minimized suggests that the mechanism underlying this effect is operating primarily during the recall period. This task clustering phenomenon is accompanied by an increase in interresponse times for recall transitions between items in different task contexts. All of these results are consistent with the CMR model; same-task items are likely to be recalled successively since they are associated with similar states of the context cue, while between-task transitions are slow, since the item being transitioned to is not associated with the same task context as the just-recalled item.

As mentioned in the introduction, the CMR model is designed to explain the ecphoric process by which the context-based retrieval cue interacts with the contents of memory to retrieve studied material. As explored by Polyn and Kahana (2008), a context-based model such as this makes a number of predictions for researchers interested in identifying the neural substrate of such a context representation. Three hypotheses central to the model are: 1) task-related information is activated when an item is studied, and is associated with the studied item; 2) when a given item is recalled, it reinstates the same task-related activity that was present when the item was originally studied; and 3) this task-related activity is then used as part of a retrieval cue to determine which item is recalled next.

These hypotheses make a number of clear predictions regarding the dynamics of a task context representation during a memory experiment. For example, it may be possible to use pattern-classification techniques (Polyn et al., 2005; Norman, Polyn, Detre, & Haxby, 2006) to identify the pattern of neural activity associated with each encoding task during the study period. One can then look for evidence of the reinstatement of these task-related patterns during the recall period. The CMR model makes the clear prediction that if one detects a task-related pattern, this will allow one to predict the task identity of the next recalled item, and that the strength of the task-related patterns will be the greatest when the participant is recalling a cluster of same-task items (as opposed to an isolated item from a particular task). Of course, substantial challenges may arise in demonstrating the neural correlates of task-clustering. For example, it is possible that a given task representation will be associated with a different pattern of neural activity during the study period as compared to the recall period, due to numerous differences between the two periods, such as the presence of an item in the environment during study.

While the CMR model does not make predictions about the particular anatomical regions involved in the maintenance of task context, in the introduction we reviewed evidence from the task performance literature suggesting that prefrontal cortex has a critical role in the maintenance and updating of task-related information (Miller & Cohen, 2001). As suggested in Polyn and Kahana (2008) certain subregions of prefrontal cortex may play a dual role: guiding the system to respond appropriately to presented stimuli (during task performance) and guiding the system to retrieve appropriate information from memory (during recall).

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	Prob. of same-task transition	Mean between-task interresponse time (msec)
Control	0.58 (0.03)	4699 (431)
Task-shift	0.70 (0.02)	6637 (666)

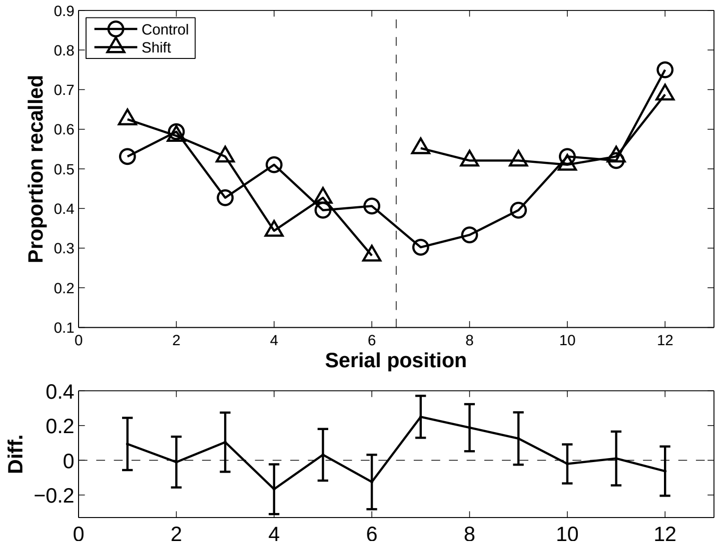
Table 1

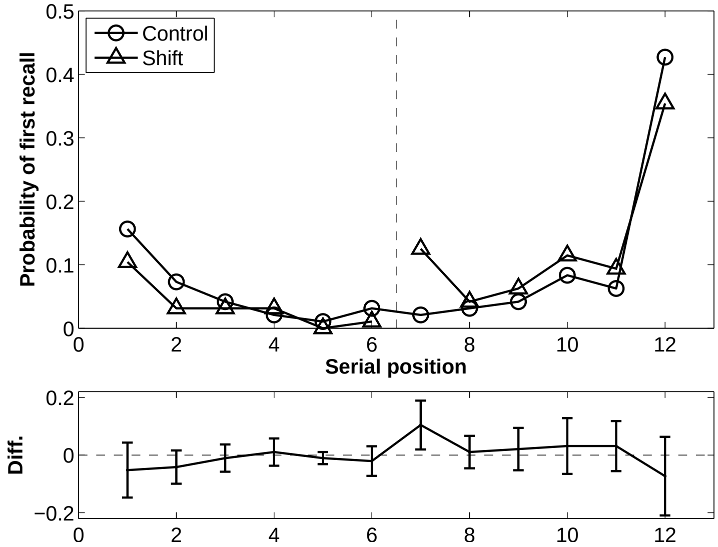
Note. Standard error is across subject means is reported in parentheses. See text for details of the statistics.

Figure Captions

Figure 1. The top plot shows the probability of recall by serial position for the two experimental conditions (control and task-shift). The bottom plot shows the difference in performance between the two conditions at each serial position, revealing an increased tendency to recall items following the task-shift. See text for associated statistics.

Figure 2. The top plot shows the probability of first recall (PFR) by serial position for the two experimental conditions (control and task-shift). The bottom plot shows the difference in performance between the two conditions, and reveals an increased likelihood to first recall the first item studied after the task shift. See text for associated statistics.


Control
Shift
Proportion recalled
Serial position
Diff.
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
4
6
8
10
12
0.4
0.2
0
−0.2


Control
Shift
Probability of first recall
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
Serial position
Diff.
0.2
0
−0.2