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Abstract

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Introduction

Short-term memory (STM) lies at the heart of cognition. It has limited capacity and therefore exerts a profound influence on people's ability to remember, decide, plan, retrieve, and act. The operations and capacity of STM have been studied extensively with various behavioral tasks and neural measurements. Behavioral tasks include recognition, recall, cued recall, serial recall, free recall, and continuous monitoring for short-term repeats of earlier items. Reviewing the voluminous literature on STM goes well beyond the scope of this article. Rather, the present focus is on one method for assessing STM: short-term probe recognition. In this paradigm, a short list of items is presented sequentially. The lists typically vary in length from one to eight items. The items can be letters, numbers, words, pictures, colors, among other choices. Following the list a test item (the probe) is presented. Test probes selected from the just seen list are termed old items or targets; test items not from that list are termed new items or foils. Observers are instructed to indicate whether the test probe was old or new as rapidly as possible without making errors. The results demonstrate one form of limited capacity because accuracy drops and response time (RT) gets longer as the list-length increases

The earliest studies of this sort were carried out in such a way (e.g. slow presentations) that rehearsal could have been (and likely was) used during presentation of the list (Sternberg, 1966). More recent studies have minimized rehearsal opportunities. Typical results (Monsell, 1978; McElree Dosher, 1989; Nosofsky et al., 2011) show that performance decreases as a test probe's lag on the study list increases (where lag is defined as the number of items intervening between the item's presentation on the study list and its test). A simple account has item strength dropping as time after presentation increases. In addition the lag functions lie more or less lie atop one another for different list lengths, so average performance for longer lists decreases due to the inclusion of items with greater lags. We will see later that these results depend on the use of a 'varied mapping' procedure (VM): Across trials the same items are continually reused, sometimes as targets and sometimes as foils.

A class of models that does well to explain these data are based on the concept of 'familiarity': Due to having been seen recently on the study list, targets are more familiar (have more 'strength') than foils. Nosofsky et al. (2011, 2014a) implemented a version of such a familiarity model to explain both accuracy and RT as functions of list length and lag. It is based on a variant of the Exemplar Based Random Walk (EBRW) model proposed originally by Nosofsky and Palmeri (1997) for categorization: Evidence is accumulated as a random walk until a target or foil boundary is reached. The value of familiarity determines the probability of taking a step toward either the target or foil decision boundary.

In recent research, Nosofsky, Shiffrin and Cao (Nosofsky et al., 2014b, in press; Cao, Shiffrin, Nosofsky, 201X) have explored in detail the contributions to performance of traces of items from prior lists and of learning that takes place as list presentations continue. The paradigms compare VM to 'consistent mapping' (CM), critically important manipulations first explored in detail by Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977). In CM, items are consistently mapped across trials: Targets remain targets and foils remain foils. As found by Shiffrin and Schneider for joint memory and visual search, Nosofsky et al.'s (2014a,b, in press) studies show that CM memory-search performance is dramatically better than VM performance. Furthermore, any list-length effects tend to disappear for CM. In addition, the CM improvements in pure memory-search paradigms occur very rapidly, early in a single session of training.

The dominant theoretical interpretation of the enhanced CM performance is that it arises due to various forms of long-term learning. Within the context of pure memory-search tasks, Nosofsky et al. (2014b) and Cao et al. (201X) have argued that observers learn long-term item-response mappings between items and their assigned responses: Because one set of items always serve as targets, and a separate set always serves as foils, observers can learn to attach old and new responses to the items in each set in order to perform the task, thereby bypassing the need to engage in a capacity-limited STM search of the present study list. Indeed, the process of of long-term item-response learning has been posited to be among the major routes to achieving automaticity in wide varieties of cognitive tasks (e.g., Logan, 1988). We emphasize here that the process of "item-response learning" is conceptually distinct from that of "familiarity": the latter is influenced solely by the frequency and recency with which an individual item is experienced, whereas the former depends on the extent to which items are consistently mapped to particular responses.

Although Nosofsky et al. (2014b) and Cao et al. (201X) attributed the CM advantage to item-response learning, a careful analysis reveals that it can also be broadly explained in terms of simple familiarity-based processes and by the fact that participants can adopt different familiarity-based decision criteria across VM and CM tasks. In general there are two sources of familiarity in these paradigms: Short-term familiarity caused by an item's appearance on the list just studied, and long-term familiarity caused by an item's appearance on prior lists in the experiment. The short-term familiarity can be used to perform the task, since it differs for targets and foils. In VM, long-term familiarity is high and equal for targets and foils, because both have been experienced numerous times in lists presented on previous trials of the experiment. Thus to the extent that long-term familiarity adds to short-term familiarity, it acts to add noise and degrade VM performance. By contrast, in CM, long-term familiarity is high for targets, but tends to be low for foils: It is high for targets because they occur with high frequency on study lists presented throughout the experiment; it is low for foils because these items are never presented on the previous study lists. Thus in CM long-term familiarity can help performance, adding extra evidence to short-term familiarity that will aid in discriminating targets from foils. Additional evidence bearing on the role of familiarity-based processing is provided by short-term probe recognition tasks that use "all-new" (AN) items (Nosofsky et al., 2014a,b; in press): These items appear on study lists at most once throughout the experiment. As opposed to CM and VM, AN items are unfamiliar on the basis of prior trials. Short-term probe recognition performance for AN is typically intermediate between CM and VM, a result consistent with predictions from familiarity-based models: AN should perform better than VM, because there is no substantial noise contributed by long-term familiarity; but worse than CM because the extra discrimination from long-term familiarity that helps CM is missing in AN.

To gain evidence bearing on whether changed familiarity-based criterion settings may underlie the dramatic performance differences observed across pure-list VM, CM, and AN conditions – at least during the early stages of learning – Nosofsky et al. (in press) tested a 'mixed-lists' condition. In this condition, the individual study lists contained equal mixtures of VM, CM and AN items, so that responding would be based on a common set of processes and criteria. For purposes of comparison, they also tested pure-list VM, CM and AN conditions. The main results are shown in Figure 1. As can be seen in the left panels, the pure CM and VM conditions show the dramatic differences in performance that were expected. By contrast, the mixed conditions (right panels) showed a complicated pattern but the key result was that there was virtually no difference in performance for the old-CM versus the old-VM targets. Because the old-CM and old-VM items were roughly equally familiar and the mixed-list design forced the use of a common set of decision criteria, the broad pattern of results seems explainable in terms of a familiarity-based decision model. The mixed-condition results challenged the view that an automatic form of item-response learning took place for the old-CM items: otherwise, because the old-CM items received consistent item-response mappings, whereas the old-VM items did not, performance on old-CM targets should have been dramatically better than for the VM targets.

Experiment 1

There were 9 blocks of 25 trials each. The first block was considered as a training block that was not included in the final analysis. Set size of memory-list was either 2, 4, or 8, randomly vary on each trial. The participants were trained on CM and/or VM items in the prob-recognition memory-search task. A single item has a unique item type, thus it could never be both CM or VM items. There were one (within-trail) mixed condition, which mixed CM/VM within study list of each trial; one pure CM condition, which only involve CM items, in the study list; and one pure VM condition that only involve VM items in study list (memory-list in the following). Each participant only experience one condition, and the sequence for participants to be assigned to conditions was counterbalanced.

Methods

Participants. Participants were undergraduate students of Indiana University who receive course credits as requirements in an introductory psychology course. There were 90 participants in total, including xx participants in mixed condition, xx participants in pure CM condition and xx participants in pure VM condition.

Stimuli and Apparatus . The stimuli were composed of 2,400 daily life pictures from the website of Talia Konkle (Brady, Konkle, Alvarez, and Olivia, 2008). Each image subtended a visual angle of approximately 7 degrees and was displayed on the center of a grey background. The experiment was conducted with MATLAB Psychophysics Toolbox (Brainard, 1997) on PCs. All participants were tested in private, sound-attenuated booths.

Procedures. For all conditions: The memory-list in each trial is composed of different pictures drawn differently according to test condition (that will be introduced below). On each trial, the memory-list were determined to appear either on the left or the right of the screen with 0.5 probability. Each image was moved horizontally to left or right with a visual angle of approximately X. For each trial, all pictures in memory-list always appeared on one location (left or tight) after the side was determined, and the test-probe appeared on the center of the screen regardless of the side chosen. Pictures in the memory-list were displayed in random order, followed by the test-probe. On each trial, a test-probe was randomly chosen with a 0.5 probability to be target or foil – the target was randomly drawn from pictures in the memory-list of that trial; and the foil was drawn differently according to different test condition (that will be introduced below).

Mixed condition. For each participant: The experiment lasted about 45 minutes. The mixed condition contains CM and VM items mixed within each trial. At the beginning of the experiment, a grand-CM-set and a grand-VM-set, that each was composed of 12 different pictures, were randomly determined. The grand-CM-set was separated randomly into a CM-left-set composed of 6 pictures and a CM-right-set composed of 6 pictures.

For each trial: First, a random set size (2,4, or 8) and the side(left, right) were determined with random chance. Second, the memory-list would be determined. The memory-list was composed of a half CM items and a half VM items. The manner of CM items to be drawn depend on the side. Using SIDE to represent the side chosen in a given trial, the CM items in the memory-list were drawn randomly from the CM-SIDE-set (e.g. If it was left side, CM items in memory-list were drawn from CM-left-set). In other hand, the VM items were simply drawn randomly from the grand-VM-set. Third, the test-probe was determined to be either target or foil. A target probe was a picture drawn randomly from the current memory-list. A foil probe was randomly selected to be CM-foil or VM-foil. The CM-foil was also depend on the side. Using nSIDE to represent the opposite of the chosen side, the CM-foil was randomly drawn from the CM-nSIDE-set (e.g. If it was left side, CM-foil was randomly drawn from the CM-right-set). In other hand, the VM-foil was simply drawn randomly from the remaining pictures in the grand-VM-set.

An example for how CM items were manipulated were provided below: An CM item (C-left) in the CM-left-set, was possible to be drawn as a part of the memory-list when the side was left. Furthermore, C-left was also possible to be drawn as a foil test-probe when the side was right. This means that a given CM item was always served as a target on one side, and foil on the other side. Therefore, an implicite association can be found here: the CM-SIDE-target was always drawn from CM-SIDE-set, and CM-SIDE-foil was always drawn from the CM-nSIDE-set. However, a given VM item could be served as both target or foil on either side, so there wasn't an association to indicate if a VM item is always a target (foil) on one side.

The instruction: When the experiment started, the participants were instructed, by texts on the screen, to memorize pictures in the memory-set and indicate if the test probe was a part of the memory-list on each trial. There were two candidate keys - 'F' (the key on the left) and 'J' (the key on the right) to press.

Since the pictures appear on different locations across trials, participants were instructed to press the side of the key consistent to the side pictures appeared if they have seen the pictures in memory-list, and the opposite side of key if not. For example, if the memory-list appeared on the left side, participants would press 'F' to indicate if they have seen the picture, and 'J' to indicate if they haven't.

Participants were also instructed to put index fingers on these two keys all the time, and respond as fast and as accurate as possible. Therefore, participants were only instructed to notice if they have seen the probe picture or not without being informed of the CM-VM manipulation.

On each trial, a fixation point (*) appeared on the center of the screen for 0.5 seconds, and the inter-stimulus-interval between each pictures in the memory-list was 0.1 second. Following, a new fixation point ("+") appeared on the center screen for 0.5 second, followed by a test probe appear on the center of the screen. The test probe stayed on the screen until the key response was registered, and only 'F' or 'J' keys were possible to be registered. After this, a blank screen lasted for 0.5 second was displayed, and followed by a feedback ("correct" or "incorrect") lasted for 1 second.

Pure Conditions. The procedure for the pure conditions was the same as for the mixed condition, except for the manner of construction of the memory sets. For the CM-pure condition, the grand-CM-set was composed of 18 items randomly selected from the 2400-image set for each participant. Then, the grand-CM-set was separated randomly into a CM-left-set composed of 8 items, and a CM-right-set composed of 8 items. For the VM-pure condition, the grand-VM-set was composed of 18 items randomly drawn from the 2400-image set for each participant. For both conditions, the target and foil test-probe were selected in the same manner as the corresponding item type described in the mixed condition.

The sampling procedures ensure that the frequencies for CM and VM items to appear are equate across mixed and pure conditions. (table for frequency to appear?)

Results.

Experiment 2

Experiment 2 was conducted in different semester compare to experiment 1. There were 9 blocks of 24 trials each, and the first block was also not included in the final analysis. The number of trials were adjusted to an even number because of the alternated-between-trial mixed condition that will be explained below. Set size of memory-list was either 2, 4, or 8, randomly vary on each trial. Comparing to experiment 1, the current experiment include three types of items, including CM, VM, and AN, to be presented potentially. A single item has a unique item type. The CM and VM items was served as the same manner as experiment 1, and the AN items were the ones that if appear in either memory-list (thus possible to be chosen as targets) or as foils, then were always randomly drawn from the remaining pictures in the 2400-image set that haven't appeared before.

The experiment contains six conditions, including two within-trail mixed conditions, one alternated-between-trial mixed condition, and three pure conditions. (need a general introduction for differences in each condition here or not? The motivations were currently introduced seperately in each condition)

(motivation for AN to appear, is it right?)The AN items in this experiment and served as pure condition or a part in MIX condition where only mix CM with AN. We introduce the AN items because it may force the participant to use item-response learning in within-trial mixed condition if there were any. When we only mixed CM with AN, the long-term familiarity would be very high for CM items and significantly small (approximate zero) for AN items. With high long-term familiarity only for CM items, we predicted that participants may show more item-response learning. Each participant only experience one condition, and the sequence for participants to be assigned to conditions was counterbalanced [foot note: except for about half participant in MIX-4 condition (that will be explained below). This is because the MIX-4 condition was introduced several days after the other conditions.].

Besides the differences mentioned above, compared to experiment 1, the current experiment presented the test probe on the side determined in each trial rather than in the middle. After experiment 1, we discovered that presenting test probes on the side as the memory list appeared might help participant to be less confused by the experiment procedure. The manner for the test probe to appear and the instruction for participants to respond were not influence by this change.

Participants. Participants were undergraduate students of Indiana University who receive course credits as requirements in an introductory psychology course. There were 202 participants, including 34 in alternate condition, 32 in MIX-8 condition, 34 in MIX-4 condition, 33 in AN pure condition, 34 in CM pure condition, and 35 in VM pure condition.

Stimuli and Apparatus. The stimulus and apparatus were the same as they were in experiment 1.

The procedures. Within-trial Mixed Conditions. The within-trial mixed conditions were similar to the mixed conditions in experiment 1, except the item types to be mixed and the number of CM items in the grand-CM-set. The current experiment mixed CM/AN within memory-list of each trial. The two within-trial mixed conditions were MIX-4 condition, which contains 8 CM in the grand-CM-set with 4-CM items in each side's set, and MIX-8 condition, which contains 16 CM in the grand-CM-set with 8-CM items in each side's set. Comparing to the MIX-8 condition, MIX-4 condition contained less CM items, thus the frequency for each CM item to appear was also higher in MIX-4 condition. (motivation to vary number of CM items?).

While all other procedures are the same as experiment 1, AN items were displayed in the manner as introduced above.

Alternated-between-trial Mixed Condition (Alternated Condition). The alternated condition was mixing two different type of items between each trial, and the trials with one type of item were always followed by the trials with another type item. In another words, the two different trials including two different type of items appeared alternatively. To give each trial kind equal number of times to appear, the trial number in each block was adjusted to an even number. The alternated condition was similar to the pure conditions in experiment 1, except that the item type were CM/AN and they alternate once after each trial. The CM trials follow all procedures as in experiment 1, and the AN trials were also similar except that all items in the memory list and the foil were new images drawn from the overall image set. (Motivation for alternate condition, is it correct?) The motivated condition was designed to check if participants were able to shift strategies across trials, and it might also help to know if participants were still learning when the CM items were mixed with other items between trial but not within trial.

Pure Conditions. The pure conditions included pure CM, pure AN and pure VM conditions, The pure CM and pure VM conditions are exactly the same compare to experiment 1 (except for one less trial in each block). The pure AN conditions were similar to the manner AN appear in within-trial mixed conditions.

(frequency table?)

Results.

The Model

As for the success of exemplar-based random walk model (EBRW, Nosofsky Palmeri, 1997) applied in similar probe-recognition tasks (in press; Cao, Shiffrin, Nosofsky, 201X, Cao et al., 2018, Nosofsky et al., 2014 a,b), we applied an extended version of it to the current experiments. Because our model was a further extension to the version of the EBRW model applied by Cao, Shiffrin, and Nosofsky (201X), a brief will be provide below.

First, in one trial, considering all items in the memory list as exemplars stored in participants' memory, we assume that different exemplars is associated with different memory strength. The memory strength (m) is assumed to be a decreasing function of lag j (lag with the backward order which appear in the memory-list):

$$m_j = j^{-\beta} + \alpha$$

Where α reflects the asymptotic strength at long lags and β reflects the rate of decrease.

Second, the test-probe (i) in each trial is thought to be a trigger to initiate a 'race' between the exemplars in that trial, and the activation ($a_i j$) of an exemplar is considered to be a function of memory list, and/or a free parameter – similarity (s):

$$a_{ij} = m_j, \text{if } t_i = e_j$$

$$a_{ij} = m_j s, \text{if } t_i \neq e_j$$

Third, a base random walk is applied by assuming the upper boundary to be 'old' and lower boundary to be 'new'. Starting in a zero position, the random walk go up or down in one unit each time. The probability (or drift rate) for the walk to go to the old (upper) boundary is given by:

$$p_i = A_i/(A_i + c)$$

Where A_i represent the summation of the activation of that kind of the test-probe:

$$A_{ij} = \sum_j a_{ij}$$

Following, a modified version of the representation for the probability for the random walk to move toward +OLD was applied as:

$$p_{old}[i] = \frac{A_i + LTM_{old}[i]}{(A_i + LTM_{old}[i]) + (c + LTM_{new}[i])}$$

where LTM_{old} denote the long term activation of the test-probe that drives the random walk to go toward the +OLD boundary, and vice versa for LTM_{new}

... Results to fit the above model?

As an extension of the model, we expanded the long-term memory terms to be the addition of long-term familiarity (F) and long-term long-term learning (L) [1]. Thus, the theoretical probability for the random walk to move toward +OLD is:

$$p_{old}[i] = \frac{A_i + F_{old}[i] + L_{old}[i]}{(A_i + F_{old}[i] + L_{old}[i]) + (c + L_{new}[i])}$$

Noting that the long-term familiarity for new item is apparently expected to be zero, therefore, the $F_{new}[i]$ term is not written in the above equation. Further, the familiarity term and the learning term are expected to have different relationship/constrains as shown below:

[1] In the following, learning represents item-response learning