# 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. The set size of the 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 was one (within-trail) mixed condition, which mixed CM/VM within the 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 involved 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 received 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 the 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 the 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, each 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 half CM items and half VM items. The manner of CM items to be drawn depended 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 the left side, CM items in the memory-list were drawn from the CM-left-set). On the 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 the CM-SIDE-set, and the CM-SIDE-foil was always drawn from the CM-nSIDE-set. However, a given VM item could serve as both target or foil on either side, so there wasn’t an association to indicate whether 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 the pictures appeared on if they have seen the pictures in memory-list, and the opposite side of the 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 torespond 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 that appeared 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 which lasted for 0.5 second was displayed, and followed by a feedback ("correct" or "incorrect"), which 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 semesters 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 varying on each trial. Compared 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 appeared 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 separately 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 CM mixed 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 influenced by this change.

**Participants.** Participants were undergraduate students of Indiana University who received 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 other words, the two different trials including two different types of items appeared alternatively. To give each trial kind an 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 was 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 compared to experiment 1 (except for one less trial in each block). The pure AN conditions were similar to the manner AN appears in within-trial mixed conditions.

(frequency table for stimuli?)

# Results.

**The Model**

As for the success of the 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 in 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 are 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):

*mj* = *j−β* + *α*

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 (*aij*) of an exemplar is considered to be a function of memory list, and/or a free parameter – similarity (*s*):

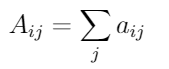
*aij* = *mj,* if *ti* = *ej*

*aij* = *mjs,* if *ti* = *ej*

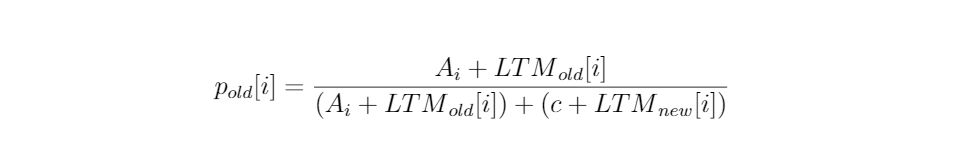
Third, a base random walk is applied by assuming the upper boundary to be ’old’ and lower boundary to be ’new’. Starting in a zero position, the random walk go up or down in one unit each time. The probability (or drift rate) for the walk to go to the old (upper) boundary is given by:

*pi* = *Ai/*(*Ai* + *c*)

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



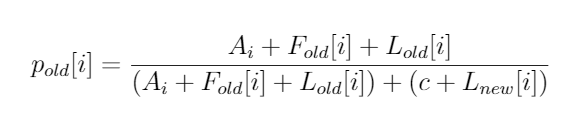
Following, a modified version of the representation for the probability for the random walk to move toward +OLD was applied as:



where *LTMold* denote the long term activation of the test-probe that drives the random walk to go toward the +OLD boundary, and vice versa for *LTMnew*

... Is results to fit the above model required?

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]](#footnote-1). Thus, the theoretical probability for the random walk to move toward +OLD is:



Noting that the long-term familiarity for new item is apparently expected to be zero, therefore, the *Fnew*[*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:

F\_CMpureCM\_O-iO = F\_CMpureCM\_O-iN < F\_ANpureAN\_O-iO = F ANpureAN\_O-iN

L\_CMpureCM\_O-iO = L\_CMpureCM\_N-iN < L\_VMpure

L\_CMpureCM\_O-iN = L\_CMpureCM\_N-iO < L\_VMpure,...

F\_VMpure < F\_ANpureAN\_O-iO = F\_ANpureAN\_O-iN

L\_MIX8-CM\_O-iO = L\_MIX8-CM\_N-iN < L\_MIX8-CM\_O-iN = L\_MIX8-CM\_N-iO,

L\_MIX4-CM\_O-iO = L\_MIX4-CM\_N-iN < L\_MIX4-CM\_O-iN = L\_MIX4-CM\_N-iO

F\_MIX8-CM\_O-iO = F\_MIX8-CM\_O-iN < F\_MIX8-AN\_OiO = F\_MIX8-AN\_OiN,

F\_MIX4-CM\_O-iO = F\_MIX4-CM\_O-iN < F\_MIX2an\_ooon, F\_MIX2cm\_ooon-F\_MIXcm\_ooon

In this case, the notations of, for example, F\_CMpureCM\_O-iO means the familiarity that drives to the old condition for old items, when it is the CM pure condition, and the test item was CM.

1. In the following, learning represents item-response learning. [↑](#footnote-ref-1)