Are associations formed across word pairs? A test of learning by temporal contiguity in
associative recognition

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Abstract

In models such as the search of associative memory (SAM: Gillund & Shiffrin, 1984) model, associations in paired associate tasks are only formed between the pair of to-be-remembered items. The temporal context model (TCM: Howard & Kahana, 2002) deviates from SAM by positing that long range associations are formed between the current item and all previously presented items, even in paired associate tasks, where cross-pair associations are formed in addition to within-pair associations (Davis, Geller, Rizzuto, & Kahana, 2002). We tested this proposal in an associative recognition task by constructing rearranged pairs where the distance in within-list serial position between the two pair members was manipulated between one and five pairs. Models such as TCM predict that FAR should be highest for rearranged pairs that are constructed from pair members that were adjacent to each other on the study list, while models such as SAM predict that FAR should be equal for rearranged pairs regardless of whether they're constructed from adjacent or remote pairs. Results from our experiment and from three archival datasets found that FAR for rearranged pairs did not depend on whether the constituent items came from nearby or remote pairs, suggesting that participants were not forming associations across pairs of items in the task.

Keywords: recognition memory; associative recognition; memory models; temporal contiguity

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How are associations formed among a set of to-be-remembered items? An early theoretical proposal came from dual store models, which proposed that associations are formed between items that co-occupy a capacity-limited short term memory buffer with the strength of association being proportional to the time spent within the buffer (Atkinson & Shiffrin, 1968), an account which was formalized within the search of associative memory model (SAM: Gillund & Shiffrin, 1984). If a list of items such as ABCDEF was studied and a participant's buffer capacity was four, upon presentation of D, items A, B, and C would already be present in the buffer and associations between A, B, C, and D would be formed.

What about when pairs of words such A-B, C-D, and E-F are presented for tasks such as associative recognition or cued recall? If pair C-D is presented and items A and B are in the buffer, both within-pair and cross-pair associations would be formed, increasing the likelihood of false alarming to a rearranged pair such as A-D in associative recognition or producing C if A were presented as a cue for cued recall. For that reason, it was proposed that the buffer is emptied between pair presentations such that only within-pair associations are formed (Gillund & Shiffrin, 1984).

In the temporal context model (TCM: Howard & Kahana, 2002), however, associations are always formed between temporally contiguous events even in paired associate tasks. In TCM, items are associated to a gradually changing context representation that is composed of the previously studied items. The representation is recency-weighted, such that the strongest associations are formed to the immediately preceding item, while weaker associations are formed to the earlier items. For example, for a list ABCDEF- a relatively strong association should be formed between F and E while the weakest association will be between F and A. TCM differs from buffer approaches because items never "drop out" of the temporal context vector - rather, associations are always formed between the current and previous items, but the strength of the association

falls off exponentially as items recede into the past. A great deal of evidence in free recall has supported the model's predictions across a range of conditions (e.g., Lohnas & Kahana, 2014; Sederberg, Miller, Howard, & Kahana, 2010).

Davis, Geller, Rizzuto, and Kahana (2008) found evidence for TCM's long-range association formation in a paired-associate cued recall task. Davis et al. reasoned that if long-range associations are formed between the pairs on the study list, participants should be more likely to make within-list intrusions from pairs that were studied near a cue word on the study list than from pairs that were more distally related. That is, for a list of pairs such as A-B, C-D, E-F, and G-H, when presented with the cue G, a higher likelihood of erroneously recalling a word from the adjacent E-F pair than from the distal A-B pair would be indicative of participants forming associations *across* word pairs. Data from Davis et al. supported TCM's predictions; within-list intrusions in cued recall tended to come from nearby pairs rather than distal pairs.

Recently, Hintzman (2016) offered a critique of models such as TCM and argued that association by temporal contiguity is unlikely to be a general learning mechanism in episodic memory, as there have been several failures to discover evidence for such a mechanism in paradigms outside of free recall. In particular, the studies of Thorndike (1931) used repeated paired associate learning, but found no evidence that associations had formed between items from different pairs. While such results are contradictory to the findings of Davis et al., Hintzman argued that the Davis et al. results may be due to the fact that auditory presentation was employed and pairs were separated by temporal gaps; thus participants may have mistakenly made associations between items from different pairs. Hintzman's criticism is somewhat unfair, as Caplan, Glaholt, and McIntosh (2006) found contiguity in within-list intrusions with visual presentation, although the effect was much weaker than reported by Davis et al.

Hintzman proposed that instead of learning by contiguity, participants tailor their learning to the requirements of the memory task. In free and serial recall, learning the

order of the study items is beneficial to reproducing the entire sequence, and thus participants may engage in learning strategies such as rehearsing the order of the items. Healey (2018) found evidence in free recall consistent with this proposal. When participants expected a free recall task, participants were very likely to follow recall of an item with a nearby item from the study list, suggesting that associations were formed between the list items. However, when an incidental learning procedure was used such that participants did not expect a free recall test, effects of temporal contiguity were considerably reduced and even eliminated in some cases, suggesting that participants are most likely to form associations between items when it is necessary for a later memory test.

In the present work, we aim to test Hintzman’s proposal in the domain of the associative recognition task. An illustration of the task can be found in Figure 1. During the study phase participants study pairs such as A-B, C-D, E-F, etc. and at test are presented with studied pairs such as A-B, which are referred to as *intact pairs* that they are asked to endorse, in addition to pairs that are composed of studied items in novel arrangements such as C-F, which are referred to as *rearranged pairs*, which they are asked to reject. A key aspect of the associative recognition task is that associations are only required to be formed *within* pairs. Forming *cross-pair* associations is not only unnecessary, but detrimental to task performance as it increases the likelihood of false alarming to rearranged pairs.

In most associative recognition tasks, the number of pairs that separate the two words to construct the rearranged pairs is uncontrolled. Figure 1 shows C-F which is an example of a rearranged pair separated by only a single pair (lag 1) while B-K is separated by five pairs (lag 5).

TCM’s learning mechanism consists of binding items to a temporal context layer that contains previously experienced items, with the strength of such items being an exponential function of their lag in pairs to the current trial. Thus, TCM predicts that each pair on the study list should be associated to members of preceding pairs, such that

Figure 1. Illustration of the study phase (top) and test phase (bottom) of the associative recognition task along with illustration of the different types of pair types. Intact pairs are identical to studied pairs, while rearranged pairs are constructed from two different words on the study list. "Lag" refers to the number of pairs that separate the rearranged pairs.

for a list A-B, C-D, and E-F, during presentation of E-F, E will be strongly associated to F, weakly associated to C and D, and receive even weaker associations to A and B. Thus, TCM predicts that the false alarm rate (FAR) to lag 1 pairs should be higher than to temporally separated pairs such as lag 5 pairs.

In models such as SAM, associations are only formed between members of a currently presented pair. Thus, the FAR to rearranged pairs from each lag should be identical regardless of whether the pairs were constructed from adjacent or remote pairs. SAM implements Hintzman's proposal of task-specific learning strategies because it states that

participants optimize their learning to fit the requirements of the memory task, and in paired associate tasks only within-pair associations are required. Several other models of associative recognition also restrict association formation to members of the currently presented pair, including REM (Shiffrin & Steyvers, 1997), TODAM (Murdock, 1982), and the models of Osth and Dennis (2015) and Cox and Shiffrin (2017).

We tested the predictions of each of these models using an experiment in associative recognition task where lag between members of rearranged pairs was controlled. We follow analysis of our new experiment with analysis of two archival datasets where lag was not controlled, but offer a wider range of lags than in the experiment we conducted. Because the null hypothesis is of theoretical interest, we analyze our data using Bayes Factors calculated from Bayesian ANOVAs in JASP, which enable the quantification of evidence for and against the null hypothesis.

Experiment 1

Participants were tested on associative recognition in a paradigm where rearranged pair lag was varied between 1 and 5 pairs, which is the range of lags in prior work testing contiguity effects in free and cued recall (Davis et al., 2008). We collected a relatively large set of participants (over 100) and a reasonable number of responses in each lag. We supplement analyses of FAR with analysis of how drift rates from the EZ diffusion model (Wagenmakers, Van Der Maas, & Grasman, 2007) vary across lag. Diffusion models offer the advantage of combining response latency and response proportions into a single measure that drives response accuracy, namely drift rates, and separate this influence from other factors that affect response time and accuracy, such as speed-accuracy thresholds and nondecision processes. While the conventional "full" diffusion model offers additional parameters for variability in drift rate and nondecision time, the EZ diffusion model has been found to have more power to detect true effects due to its relative simplicity (van Ravenzwaaij, Donkin, & Vandekerckhove, 2017). The data from this experiment can be

found on our Open Science Foundation (OSF) page (<https://osf.io/64qyf/>).

Method

Participants

Participants were 112 first year students participating in exchange for course credit.

Materials

The experiment used 1,151 words between 40 and 350 CELEX counts per million ($M = 102.26$) that were between 4 and 9 letters in length ($M = 5.89$ letters).

Procedure

During the study list, each word pair was presented in capital letters with three spaces between them. Sixty pairs were presented for 2,250 ms with a 250 ms blank interstimulus interval between presentations. Participants then engaged in a distracter task for 30 seconds that was composed of a card game.

Test lists were composed of 60 pairs, of which 30 were intact pairs and 30 were rearranged pairs. The between-pair lag for words within rearranged pairs was parametrically manipulated between one and five. 6 pairs were constructed for each lag. Responses faster than 200 ms and slower than 8,000 ms received a "TOO FAST" or "TOO SLOW" feedback and were excluded from analyses.

Prior to engaging in the main experiment, participants engaged in a short practice phase where they studied four word pairs were tested on two intact and two rearranged pairs with accuracy feedback.

Participants engaged in a total of eight study-test cycles, resulting in 240 intact and 240 rearranged trials, with 48 observations for each rearranged pair lag.

Results

For each analysis throughout the article, we omitted any participants at or below chance ($d' \leq 0$) along with participants that had 0% FAR to avoid floor effects. This resulted in the omission of two participants with $d' = -.24$ and $-.19$. In addition, we omitted responses with latencies ≤ 500 ms, as accuracy of these responses did not exceed chance. This exclusion is sensible when one considers that performance in associative recognition does not begin to rise above chance until about 550-600 ms (Gronlund & Ratcliff, 1989). Finally, we excluded pairs from the first two serial positions, as inspection of serial position data revealed a slight primacy effect where both intact and rearranged pairs from primacy positions were endorsed more frequently.

Overall hit rates and FAR collapsed across all lags can be seen in panel A of Figure 2. FAR for each lag can be seen in panel B. FAR did not differ across lags, $BF_{01} = 8.60$. Panel C shows drift rates for each lag calculated from the EZ diffusion model, which is calculated from the mean correct rejection rate and the variance of the correct response time distribution for each lag. These drift rates did not differ across lags, $BF_{01} = 100.86$. Jeffreys (1961) suggested that BF_{01} in the range of 3-10 indicates substantial evidence for the null hypothesis and $BF_{01} > 100$ is considered extreme evidence. Thus, the present results do not provide evidence for the hypothesis that participants form associations across pairs of items.

Re-analyses of Archival Datasets

We additionally analyzed results from several archival datasets. Because lag was uncontrolled, there was insufficient data in some cells to obtain stable estimates of the variance of the RT distribution, so we restricted analyses to FAR in these datasets.

The maximum possible lag in each dataset was the list length (L) minus one. Following the analyses in Experiment 1, we excluded the first two pair positions due to possible primacy effects, making the maximum lag $L - 3$. Considerably fewer observations

Figure 2. Data from Experiment 1. Panel A shows overall hit and false alarm rates, where the FAR are collapsed across lag. Panel B shows FAR for each lag condition, and Panel C shows drift rates for each lag condition calculated from the EZ diffusion model. Error bars indicate 95% within subjects confidence intervals calculated using the method of Morey (2008).

are available at the highest lags due to a restriction on the possible serial positions that can contribute to such lags. For this reason, we excluded the three highest lags due to few observations and a more restricted set of serial positions contributing. Each of these datasets can be found on our OSF page (<https://osf.io/64qyf/>).

Cox, Hemmer, Aue, and Criss (2018)

Four hundred and sixty two participants did a total of five tasks - in addition to associative recognition (AR), they performed item recognition, free recall, cued recall, and the lexical decision task, but only the AR data was tested here. Participants studied 20 pairs without any advance knowledge of which memory test they would be given. During AR tests, participants were tested on 10 intact and 10 rearranged pairs. Participants did three study-test cycles of AR, producing a total of 30 rearranged pair tests per participant.

We excluded 10 participants for having $d' \leq 0$ and 47 participants for not false alarming. Overall HR and FAR can be seen in Figure 3. FAR for each lag can be seen in Panel A of Figure 4. FAR showed little change across lags, $BF_{01} = 355,406.27$, with the BF showing extreme evidence for the null hypothesis.

Figure 3. Overall HR and FAR (collapsed across rearranged pair lags) for the data from Cox et al. (2018), Popov et al.’s (2017) Experiment 1, and Pantelis et al.’s (2008) Experiment 3.

Popov, Hristova, and Anders’s (2017) Experiment 1

Forty participants studied 21 word pairs. At test, participants were presented with seven intact pairs and 14 rearranged pairs, of which seven shared a relation with one of the intact pairs (e.g., *book-writer* and *meal-chef* share the relation "is created by") and seven which did not. Our analysis collapsed across both pair types. Participants completed three study-test cycles for a total of 42 rearranged pair trials.

One participant was excluded for poor performance ($d' = -.03$) and three were excluded for not false alarming. FAR for each lag can be seen in panel B of Figure 4. Again, FAR did not differ across lag conditions, $BF_{01} = 26.10$.

Pantelis, van Vugt, Sekuler, Wilson, and Kahana’s (2008) Experiment 3

Thirty six participants studied 16 pairs of 16 synthetic faces and names. At test, participants were tested on sixteen pairs, of which eight were rearranged pairs. Responses were given in the form of six point confidence responses which ranged from one (sure incorrectly paired) to six (sure correctly paired). Participants completed a total of 10 study-test cycles for a total of 80 rearranged pair observations per participant.

Figure 4. FAR at each rearranged pair lag for the data from Cox et al. (A), Popov et al. (B), and Pantelis et al. (2008). Panel D shows mean confidence ratings at each rearranged pair lag for the data from Pantelis et al. (2008).

We defined false alarms as confidence responses of 4 or higher to rearranged pairs. Two participants were excluded for not false alarming. FAR for each lag can be seen in panel C of Figure 4. FAR again showed little change across lags, $BF_{01} = 36.26$, with the BF showing strong evidence for the null hypothesis. We additionally subjected each participant's mean confidence rating at each lag (Panel D of Figure 4) to the same analysis - these additionally showed little change across lags, $BF_{01} = 36.84$.

General Discussion

Theories such as TCM posit that learning occurs by binding items to an exponentially weighted representation of recently experienced items. TCM claims that in

paired associate tasks, upon presentation of a pair learning should not just occur between members of the presented pair, but there should additionally be associations to words from previous pairs and this learning should be stronger for temporally adjacent pairs than remote pairs. We tested this possibility in associative recognition by evaluating the extent to which the distance between members of rearranged pairs on the study list affects FAR. Both a new experiment where lag between rearranged pair members was controlled and analysis of three archival datasets revealed that FAR were unaffected by rearranged pair lag: FAR are roughly equivalent for rearranged pairs constructed from temporally adjacent pairs as opposed to temporally remote pairs. These results suggest that participants were not forming associations across pairs of items on the study list.

These results dovetail with findings from the literature on recognition memory for faces. Several studies have conducted experiments presenting participants with lures composed of morphs of two different studied faces. While these studies have found higher FAR for face morphs than novel faces, there are no differences in FAR for face morphs when the two studied faces were adjacent on the study list versus morphs where the studied faces were remote (Busey & Tunnicliff, 1999; Reinitz & Hannigan, 2001). Busey and Tunnicliff (1999) found virtually identical FAR to face morphs that were constructed from adjacent faces and from faces that were separated by 20 faces on the study list.

The lack of evidence for cross-pair associations in the present work is consistent with the majority of current models of associative recognition. Models such as SAM, REM, and other current models assume that associations are only formed between members of the currently presented pair. These models embody Hintzman's (2016) proposal that encoding strategies are adapted to the nature of the task. In associative recognition, forming associations between different pairs is not only unnecessary to perform the task, it is detrimental to task performance as it increases the likelihood of false alarming to rearranged pairs.

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