Journal of Experimental Psychology:
Learning, Memory, and Cognition
2013, Vol. 39, No. 1, 297–303

0278-7393/12/$12.00 DOI: 10.1037/a0028463

RESEARCH REPORT

A Causal Contiguity Effect That Persists Across Time Scales

Asli Kiliç and Amy H. Criss
Syracuse University

Marc W. Howard
Boston University

The contiguity effect refers to the tendency to recall an item from nearby study positions of the just recalled item. Causal models of contiguity suggest that recalled items are used as probes, causing a change in the memory state for subsequent recall attempts. Noncausal models of the contiguity effect assume the memory state is unaffected by recall per se, relying instead on the correlation between the memory states at study and at test to drive contiguity. We examined the contiguity effect in a probed recall task in which the correlation between the study context and the test context was disrupted. After study of several lists of words, participants were given probe words in a random order and were instructed to recall a word from the same list as the probe. The results showed both short-term and long-term contiguity effects. Because study order and test order are uncorrelated, these contiguity effects require a causal contiguity mechanism that operates across time scales.

Keywords: episodic memory, temporal contiguity effect, probed recall, memory models

Episodic memory has been defined as memory for contextual details in which a person re-experiences a specific event (Tulving, 1983). In the laboratory, episodic memory is often studied using the free recall task. After studying a list of words, participants are asked to generate the studied words in the order they come to mind. The sequence in which words are recalled tends to reflect the sequence in which the words were studied. In particular, the probability of recalling a word that was presented in a neighboring study position with respect to the previously recalled word is higher than the probability of recalling a word from a remote study position (Kahana, 1996). This tendency is known as the *contiguity effect*.

The contiguity effect in free recall is persistent across different time scales (Howard, Youker, & Venkatadass, 2008; Unsworth, 2008). For instance, Howard et al. (2008) presented participants with multiple lists of words with an immediate free recall task following each list. At the end of the experiment, an additional final free recall task was given. Results showed that when participants recalled a word from a particular list, the next-recalled word tended to come from a neighboring study position from the same list. However, if the next-recalled item did not come from the same list, the participants tended to recall another word from a nearby list (see also Unsworth, 2008). In the current study, we measured short- and long-term contiguity effects in a task designed to discriminate between causal and noncausal models of the contiguity effect in episodic recall.

Two classes of models have been proposed to explain the contiguity effect in free recall: Noncausal and causal models. Noncausal models of the contiguity effect (Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005; Grossberg & Pearson, 2008; Farrell, 2012) propose that the contiguity effect is observed due to the similarity between the memory state at study and the memory state at test. For example, in the Davelaar et al. (2005) model, items are encoded with a one-dimensional contextual state that changes gradually over time in a random fashion. During retrieval from long-term memory, the current contextual state is used as the only probe to retrieve items. In delayed free recall, the current context is reset to the study context at the beginning of the list and it changes with the same probabilistic dynamics as it did during study. As a consequence, the contextual state that is used as a probe is correlated with the contextual state at study. As a result, items that are encoded at nearby study positions will tend to be recalled in a correlated order. This concept of autonomously changing context that replays during retrieval is also a common feature in serial recall models (e.g., Farrell & Lewandowsky, 2002; Brown, Preece, & Hulme, 2000; Burgess & Hitch, 1999) that seek, in part, to explain the finding that errors in serial recall tend to come from nearby serial positions, an analog of the contiguity effect in free recall.

Causal models, on the other hand, posit that recalling a word causes the participant to recall another word from a nearby study position. For example, the search of associative memory (SAM) model (Raaijmakers & Shiffrin, 1980) consists of a short-term store with a limited capacity and a long-term store. Associations between items are formed to the extent that those items are in the short-term store at the same time. After recovery of an item, the recalled item becomes part of the cue for the subsequent retrieval

This article was published Online First May 14, 2012.

Asli Kiliç and Amy H. Criss, Department of Psychology, Syracuse University; Marc W. Howard, Department of Psychology and Center for Memory & Brain, Boston University.

This research was supported by National Science Foundation Grant 0951612 to Amy H. Criss and Air Force Office of Scientific Research Grant FA9550-10-1-0149 to Marc W. Howard.

Correspondence concerning this article should be addressed to Asli Kiliç, Department of Psychology, Syracuse University, 430 Huntington Hall, Syracuse, NY 13244. E-mail: akilic@syr.edu

attempt. Since the interitem association between items studied contiguously tends to be strong, the next recalled item tends to come from a study position near that of the previously recalled item. Similarly, in chaining models of serial recall (e.g., Lewandowsky & Farrell, 2008), each item is associated with the preceding item during study. At retrieval, memory is probed with the recovered item, which serves as a cue for the next recall attempt.

The temporal context model (TCM; Howard & Kahana, 2002) is also a causal account of the contiguity effect. According to TCM, study context changes during encoding; items that are studied at nearby positions have a similar study context. At retrieval, the context at the time of test is used as a probe for recall and items are retrieved as a function of how similar their study context is to the probe context. After retrieval of an item, the retrieved context of the just-recalled item changes the current context; this updated context is used as a probe to recall additional items. As a result, the next item retrieved tends to come from a nearby study position. Because context changes gradually rather than dropping out abruptly from a fixed-capacity short-term store, TCM can account for the persistence of recency and contiguity across time scales (Howard & Kahana, 2002; Sederberg, Howard, & Kahana, 2008).

The critical difference between causal and noncausal models of the contiguity effect is how the memory state at test changes on the basis of recall success. Causal models assume that the just-recalled items cause a change in the memory state at test, which causes contiguity. Noncausal models of the contiguity effect assume that the change in the memory state at test is autonomous of the recalled items. The contiguity effect in free recall does not differentiate between these two classes of models. In free recall, both short- and long-term contiguity effects have been observed. It is possible that these reflect a mixture of memory processes—perhaps short-term contiguity effects are causal but long-term contiguity effects are noncausal. Such a result would provide strong evidence for the view that distinct processes account for short-term and long-term contiguity effects (e.g., Davelaar et al., 2005). In contrast, if both short- and long-term contiguity effects are causal (or noncausal), this would be consistent with a unified account of short- and long-term contiguity effects (Howard & Kahana, 2002; Sederberg et al., 2008).

To distinguish between causal and noncausal models of contiguity, it is necessary to disrupt the correlation between the memory states at encoding and retrieval. In probed recall, participants are given a probe (e.g., serial position, preceding item) to recall a target item. This task is different from free recall due to the requirement that participants should use the probe word provided to them rather than recalling the list in an internally generated order. Probed recall tasks have been studied in conjunction with serial order memory (Kahana & Caplan, 2002; Murdock, 1968; Raskin & Cook, 1937). A contiguity effect has also been observed in item recognition, which is another task involving a probe to cue memory (Schwartz, Howard, Jing, & Kahana, 2005). However, all of these studies differ from free recall along multiple methodological dimensions. Moreover, none of these studies have established a causal contiguity effect across both short and long time scales. In the current study, participants studied multiple lists of words and at the end of study they were given probe words from each list in a random order. They were asked to use the probe word to recall another word from the list in which the probe was presented. Because the study position of the probes was randomized at test, the contextual state at study and test were not correlated. Noncausal models of contiguity do not predict a contiguity effect in the probed recall task; causal models of contiguity do.

Method

Participants

Two hundred twenty-three Syracuse University undergraduates participated in exchange for course credits. Data from 36 participants were excluded from the analysis because those students never responded to the recall task ($n = 1$), because they repeated a single word more than three times ($n = 26$), or because of technical difficulties ($n = 9$). All of the participants were instructed individually and were guided through a practice list.

Materials

The word pool was constructed from the nouns in the MRC database with a range of concreteness value between 200–443 and 473–700, Kucera and Francis (1967) written frequency value between 1–500, and the number of letters between four and eight (Coltheart, 1981). Words with high emotional content (e.g., HATRED), multiple forms of the same word (e.g., CHILD or CHILDREN), and words with ambiguous parts of speech (e.g., GUESS) were removed from the pool. The resulting 1,642 words made up the word pool. Two hundred eighty-eight words were randomly chosen for each individual such that the words in each study list were controlled for semantic similarity, which was calculated by Latent Semantic Analysis (LSA) model (Landauer & Dumais, 1997) on the TASA corpus using the SEMMOD package (Stone, Dennis, & Kwantes, 2008). The cosine between pairs of words in the study lists did not exceed 0.15 (e.g., CAT has a cosine value of 0.16 with BEAST and 0.145 with CHAIR).

Procedure

Participants completed two blocks of study and test. In each study block, participants were presented with six lists of 21 words. As the words appeared on the screen the participants engaged in an orientating task in which they decided whether the word was abstract or concrete. Participants had up to 3 s to give a response. In order to prevent rehearsal, the list continued immediately after the participants responded to the orienting task. Hence, the study time was self-paced with an upper limit of 3 s per word. After studying each list, participants were given an arithmetic distractor task for 75 s. A break for 75 s followed the distractor task.

The test lists were constructed from 18 probe words from the study lists and nine new words. To eliminate concerns about primacy and recency, one probe word was selected from each list randomly from each of the three study position bins: 4–6, 10–12, and 16–18. Additionally, two probe words from the same list were not allowed to occur successively at test. During the test phase, participants were given one probe word at a time. In order to make sure that participants remembered the probe words, they were asked to make a recognition memory confidence judgment on a scale from 1 (*sure new*) to 9 (*sure old*) for every presented word.

For all the probe words (i.e., the old words), participants were additionally required to generate another word from the same study list, regardless of their confidence rating.

Results

Recognition

The mean response distribution for the recognition task is plotted in Figure 1A. Eighty-three percent of the probe words received the most confident rating. Mean d', which is an estimate for recognition accuracy, was 1.83 (Macmillan & Creelman, 1991). These results suggest that participants successfully discriminated old probe words from new words.

If participants were randomly generating words from the experiment, the probability of recalling a word from the correct list would be 16.7%. Participants recalled words from the correct list 18% ($SD = 9\%$) of the time. While the difference between this value and chance was modest in absolute terms, Wilcoxon signed ranks test indicated that the median proportion (18%) was significantly above chance ($Z = -1.92$, $p = .03$). Figure 1B plots the proportion of words recalled as a function of recognition confidence ratings. The figure suggests that although participants had successful recognition memory for a large number of probes, they successfully recalled a word from the same study list for only a small subset of those probes. Figure 1B also plots the proportion of extra-list responses and the responses that came from Block 1 when participants were probed with words from Block 2. In the subsequent analyses, only the recall responses that came from within-list and across-list were included regardless of the confidence ratings that the preceding probes received.

Short-Term Contiguity

In order to measure the short-term contiguity effect, we analyzed the responses that came from the same list as the probe word. We used a conditional response probability (CRP) analysis (Kahana, 1996). Let us define lag as the difference between the serial position of the probe word and the response word. The lag-CRP, the probability of giving a response conditional on the serial position of the probe word, is plotted as a function of the response lag. The lag-CRP controls for the difference in the total number of possible responses that can come from a certain lag. For example, any probe word can trigger a response with lag 1 because all the possible probes were followed by another item in the study list. However, only the probe word that is studied at the serial position of 4 could trigger a response with a lag of 17. This same probe word, on the other hand, could not possibly trigger a response with a lag of −4. To calculate the CRP for each lag, the total number of responses observed with that lag was divided by the total number of possible responses that could have been observed from that lag. Figure 2A depicts the lag-CRP for the within-list responses. Lag 0 is the probe word itself, and the lags 6–10 and 11–17 were binned due to the lower number of total possible responses.

The results from the lag-CRP analysis showed a within-list contiguity effect. A Wilcoxon signed ranks test indicated that the proportion of responses with lag ±1 ($M = 0.09$, $SE = 0.009$) was significantly higher than the proportion of responses with lag ±2 ($M = 0.04$, $SE = 0.006$), $Z = -3.87$, $p < .001$. The results also show both forward and backward effects when considered separately. The proportion of responses with lag 1 ($M = 0.08$, $SE = 0.01$) was significantly higher than the proportion of responses from lag 2 ($M = 0.04$, $SE = 0.007$), $Z = -3.17$, $p = .001$. Similarly, the proportion of responses from lag −1 ($M = 0.1$, $SE = 0.01$) was significantly higher than the proportion of responses from lag −2 ($M = 0.05$, $SE = 0.008$), $Z = -2.69$, $p < .01$. When participants were able to recall a word from the same list, the response was about twice as likely to be the word that either preceded or followed the probe word at the study list than a word from a more remote study position. Additional analyses showed that this short-term contiguity effect appeared more pronounced in the second study-test block. The serial position curves

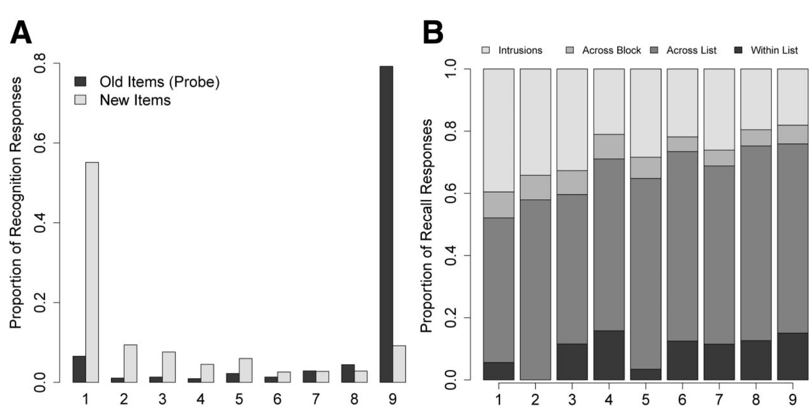

Figure 1. A: Response distribution for recognition confidence ratings. B: The breakdown of responses as a function of recognition confidence ratings. Intrusions = the response words that were not studied in the experiment. Across block = the words that were presented at the first block but given as a response at the second block. Across list = the response words that were given from the same block but from a different list than the probe word. Within-list = the response words given from the same list as the probe word.

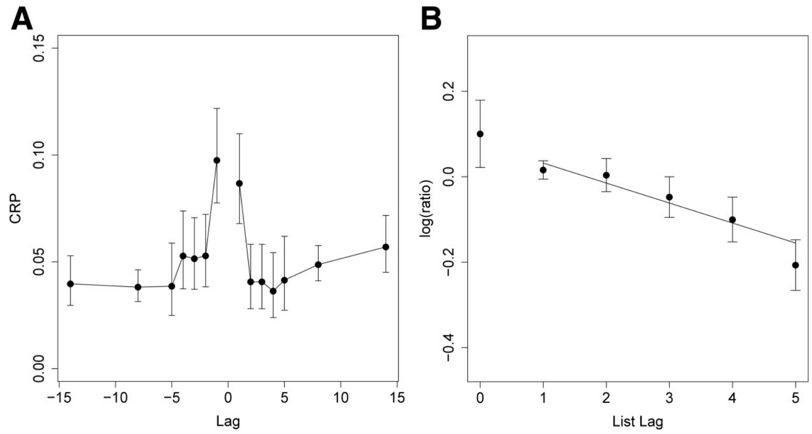

Figure 2. A: Within-list conditional response probability as a function of lag. Lag is the difference between the study position of the probe word and the study position of the response when the response comes from the list in which the probe word was presented. The error bars are 95% confidence intervals from the binomial distribution. There is a contiguity effect such that the probability of generating a response from lag −1 and lag 1 are significantly higher than the probability of generating a response from the remote lags. B: Across-list mean log(ratio) as a function of list lag. List lag is the absolute value of the difference between the list number of the probe and the list number of the response. Log(ratio) is the natural logarithm of the ratio of observed responses to expected responses. The line is obtained from the linear regression excluding lag 0.

are plotted in Figure 3; no evidence of primacy or recency was observed as a function of the study position of the response or the study position of the probe.

Long-Term Contiguity

The upper section of Table 1 displays the frequency of responses collapsed across participants as a function of the study list number of the response and the study list of the probe. The number of possible responses was 6,732 (187 participants × 18 probes × 2 blocks), and the total number of responses from the correct study-test block was 3,889 when collapsed across all participants. These data show that 58% of the probe words received a response from the correct study-test block. The responses on the diagonal are the within-list responses that were analyzed in the previous section. If the participants performed perfectly, all the responses would be on the diagonal since they were asked to generate a word from the same list. There is an across-list contiguity effect to the extent that there is a decrease in the number of responses as their study list becomes farther from the list of the probe.

Participants were equally likely to provide a response to a probe from each list (i.e., the average in each row of the upper section of Table 1 is 16%–17%). The responses they provided showed an across-list recency effect; more generated responses came from the sixth list than from other lists (i.e., 22% or 838 of 3,889 responses).

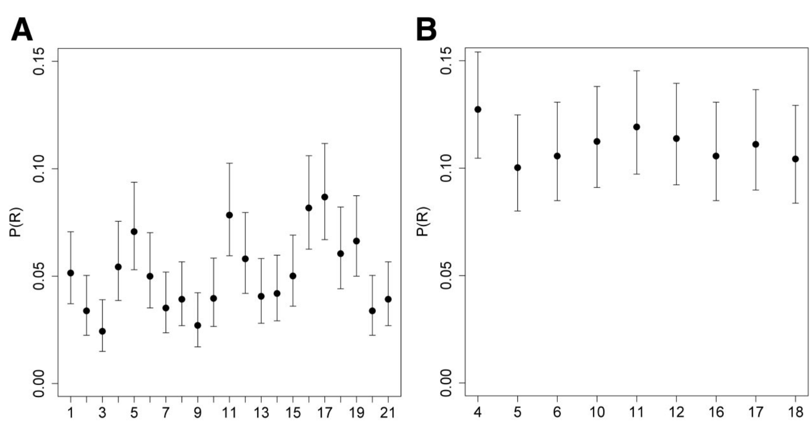

Figure 3. A: Probability of recall as a function of the study position of the response word. The error bars are 95% confidence intervals (CI) from the binomial distribution. The response serial position curve shows that both primacy and recency effects were absent in within-list responses. B: Probability of recall as a function of the study position of the probe to which response was given. The error bars are 95% CI from the binomial distribution.

Table 1
Contingency Table for the Observed and Expected Frequencies

	Response list							
Probe list	1	2	3	4	5	6	Total	P(R)
Observed frequency								
1	152	95	89	80	102	118	636	0.16
2	113	91	85	127	101	131	648	0.17
3	102	97	80	118	97	131	625	0.16
4	102	94	101	113	104	131	645	0.17
5	87	106	118	108	118	143	680	0.17
6	82	89	100	94	106	184	655	0.17
Total	638	572	573	640	628	838	3889	
P(R)	0.16	0.15	0.15	0.16	0.16	0.22		
Expected frequency								
1	104	94	94	105	103	137	637	0.16
2	106	95	95	107	105	140	648	0.17
3	103	92	92	103	101	135	626	0.16
4	106	95	95	106	104	139	645	0.17
5	112	100	100	112	110	147	681	0.17
6	107	96	97	108	106	141	655	0.17
Total	638	572	573	641	629	839	3892	
P(R)	0.16	0.15	0.15	0.16	0.16	0.22		

Note. The frequencies are the total number of responses collapsed across all participants and trials that received a response. The rows show the responses that were given to probes from Lists 1 to 6. The columns show the responses that came from Lists from 1 to 6. The diagonal of the upper section of the table represents the responses that came from the same list as the probe word. Expected frequencies were calculated by multiplying the marginal probabilities for each cell. These values are the expected frequencies if participants were generating responses independently from the probe word. The observed frequencies across the diagonal are on average greater than the expected frequencies, which shows that participants responded from the correct list above chance. On the other hand, the observed frequencies are on average lower than the expected frequencies for greater list lags (e.g., number of responses that were given from List 1 when probed with a word from List 6).

In order to control for this list position effect, the response frequencies (observed frequencies) were compared with expected frequencies. Expected frequencies refer to the performance that would be expected if participants' responses were independent of the probe word. The lower section of Table 1 shows the expected frequency for each cell, which has been calculated by multiplying marginal probabilities of the corresponding cell—that is, the frequency that would be expected if the response list was independent of the probe list. An across-list contiguity effect would result in a systematic deviation from these expected frequencies. We used the ratio of observed frequencies to expected frequencies to quantify this deviation. For example, the observed probability of recalling a word from List 1 when probed with a word from List 1 was 0.238 [$P(R1|P1) = 152/636$]. The expected probability of recalling a word from List 1 when probed with a word from List 1 is 0.163 [$P(R1|P1) = 104/637$]. The ratio of observed probability to expected probability is 1.46; if the ratio is greater than 1, then it means that participants recalled more words from that list than would be expected if the list of the response word was independent of the list of the probe word; a ratio lower than 1 means that the number of words recalled is less than would be expected if they were independent. For example, when probed with a word from List 1, participants were 46% more likely to give a response from List 1 than expected. Since the distribution of the ratios was positively skewed, the ratios were log transformed. Figure 2B plots the mean log transformed ratios as a function of list lag. A linear function was fit to mean log ratio as a function of the absolute value of the list lag. Lag 0 was excluded from the linear regression in order to estimate the across-list effect. The intercept was 0.078, $t(34) = 2.167$, $p = .038$, and the slope was -0.047, which was significantly different from 0, $t(34) = -3.4$, $p < .01$. As the list lag increased, the log(ratio) was more negative, which suggests that for every increase in list lag, the likelihood of recalling a word from that list lag decreased 5%.[1] This shows that participants generated fewer words from the remote lists as a response to the probe word compared with their expected values. Similar to the within-list analysis, these results were more pronounced in the second study block.

Discussion

In a probed recall task where study and test order were uncorrelated, we found both short-term and long-term contiguity effects. The data presented here provide evidence for simultaneous causal short- and long-term contiguity effects. The short-term contiguity effect shows that when the participant generated a word from the same list as the probe, the word tended to come from immediate neighbors of the probe word. The long-term contiguity effect shows that when the participant generated a response from the experiment that did not come from the same list as the probe, the word tended to come from nearby lists.

[1] For the slope, $e^{-0.05} \simeq 0.95$, which indicates a 5% decrease in the observed recall compared with the expected.

Noncausal accounts of the contiguity effect fall short of explaining these findings. For example, the Davelaar et al. (2005) model accounts for the contiguity effect by using the current context as a probe to recall items. It assumes a correlated drift in context at both study and test. However, in this experiment participants used the probe they were provided, and the probe words were randomly ordered. According to the Davelaar et al. (2005) model, the probe should not cause a contiguity effect for the response word because the drift in the current context happens autonomously from the probe. However, the results show a contiguity effect. Other noncausal models of contiguity (Burgess & Hitch, 1999; Farrell & Lewandowsky, 2002; Grossberg & Pearson, 2008) are also challenged by these data for similar reasons. The Davelaar et al. (2005) model could, in principle, be altered to account for a causal contiguity effect by enabling associations between items in short-term memory to be altered using a Hebbian rule. Indeed, associations between items in short-term memory were utilized by Davelaar, Haarmann, Goshen-Gottstein, and Usher (2006) to account for semantic retrieval effects.

The contiguity effects we observed require that the probe word can cause information retrieval and changes to the current memory state, as predicted by causal models. For example, short-term contiguity effects can be explained with the associations formed between items (Lewandowsky & Farrell, 2008; Raaijmakers & Shiffrin, 1980; Solway, Murdock, & Kahana, 2012). However, the long-term contiguity effect represents a challenge for chaining models with fixed scale. In order to account for the long-term contiguity effect, items presented in the same list might be assumed to be associated with a hierarchical representation for that list. For example, Hintzman, Block, and Summers (1973) showed temporal grouping of items such that participants preserved the within-list position of items even when they failed to correctly attribute the across-list position. The underlying mechanism could be similar to that of chunking, which is described in serial recall models (e.g., Lee & Estes, 1977).

TCM can explain the existence of both short-term and long-term contiguity effects with the retrieval of context principle. According to TCM, during study, both item-to-context and context-to-item associations are formed. In a probed recall test, the context of the probe word can be retrieved via an item-to-context association. Unlike SAM, TCM does not rely on a limited-capacity short-term store and instead of interitem associations, the retrieved context drives the contiguity effect in TCM. Since nearby lists also share similar contexts, the retrieved context can still be used as a cue to recall words from nearby lists. The finding that contextual retrieval appears to be better for the first and the last lists is not predicted by TCM. Recalling a word from the same list as the probe word was on average 40% more likely than chance for the first and the last lists. TCM does not explain why contextual retrieval appears to be better at the extreme lists.

The present findings do not rule out noncausal models of the contiguity effect in free recall. It is possible that the probed recall task is different in some fundamental way from free recall that gives rise to a causal contiguity effect in probed recall while the contiguity effect in free recall is strictly noncausal. This seems unlikely given the extensive evidence for effects in free recall that require a causal retrieval process. For instance, there is strong evidence that the contiguity effect in the earliest stages of free recall is causal. Howard, Venkatadass, Norman, and Kahana (2007) presented lists for immediate free recall in which an item from the middle of the list was repeated at the end of the list. They found a boost in the probability of recalling the neighbors of the first presentation of the repeated item, not only in early recall attempts but also in the very first retrieval attempt. Because this finding requires that accessibility of those items be increased as a consequence of the identity of the repeated item, strictly noncausal accounts of this short-term contiguity effect are excluded.

Our findings, coupled with findings from other tasks (Kahana & Caplan, 2002; Raskin & Cook, 1937; Schwartz et al., 2005) rule out the possibility that contiguity effects result only from noncausal processes. However, this body of data does not exclude the possibility that the contiguity effect in free recall is a mixture of causal processes, which are also manifest in the probed recall task, and noncausal processes, which are disrupted in probed recall. The relatively small number of probes that generated within-list responses makes this possibility viable. However, it is also possible that disrupting the list order so dramatically affects the efficacy of causal processes. For example, changing the environmental context in which items are recalled is sufficient to substantially impair free recall (e.g., Smith, 1979). Indeed, order of output during recall affects accuracy. For example, Dalezman (1976) instructed participants to first recall items from a specific subset of the study list (in any order), followed by recall of the remaining items from the list. Instructions to start at the beginning enhanced the primacy effect and diminished the recency effect. Instructions to start at the end had the opposite effect, and instructions to begin midlist enhanced recall of the middle items. This output interference has been replicated in recognition, where order of the test is usually random with respect to study order (Criss, Malmberg, & Shiffrin, 2011; Malmberg, Criss, Gangwani, & Shiffrin, 2012).

Another potential puzzle raised by the present findings is our failure to observe asymmetry in the short-term contiguity effect. In free recall, the short-term contiguity effect has been found to be robustly asymmetric (e.g., Unsworth, 2008; Ward, Tan, & Grenfell-Essam, 2010). After recalling an item, the probability of generating the next item in the study list is higher than the probability of generating the previous item. However, in this probed recall task, we failed to observe this asymmetric contiguity effect. This absence of evidence for the forward preference could be a result of the lower performance of the participants during the recall task. One of the limitations of this study is that the average number of responses from the same study list was relatively low—7 of 36 (19%) possible responses. Thus, there might not have been enough responses to show an asymmetry effect in the short-term contiguity effect even if there was some tendency for forward associations. Spillers and Unsworth (2011) showed that participants who scored lower in working memory span tasks did not show an asymmetric contiguity effect after a delayed free recall compared with participants who scored higher in working memory span tasks. Moreover, they found that overall accuracy was also lower for the low working memory span participants (23%) compared with high working memory span participants (39%). Thus, these findings may also suggest that the symmetric within-list contiguity effects might be associated with overall lower accuracy. Asymmetry has not been observed across lists in free recall (Howard et al., 2008; Unsworth, 2008), so the fact that we did not observe an asymmetry across lists does not contradict those findings.

References

Brown, G. D. A., Preece, T., & Hulme, C. (2000). Oscillator-based memory for serial order. *Psychological Review, 107*(1), 127–181. doi:10.1037/0033-295X.107.1.127

Burgess, N., & Hitch, G. (1999). Memory for serial order: A network model of the phonological loop and its timing. *Psychological Review, 106*(3), 551–558. doi:10.1037/0033-295X.106.3.551

Coltheart, M. (1981). The MRC psycholinguistic database. *The Quarterly Journal of Experimental Psychology, Section A, 33*(4), 497–505.

Criss, A. H., Malmberg, K. J., & Shiffrin, R. M. (2011). Output interference in recognition memory. *Journal of Memory and Language, 64*(4), 316–326. doi:10.1016/j.jml.2011.02.003

Dalezman, J. (1976). Effects of output order on immediate, delayed, and final recall performance. *Journal of Experimental Psychology: Human Learning and Memory, 2*(5), 597–608. doi:10.1037/0278-7393.2.5.597

Davelaar, E. J., Goshen-Gottstein, Y., Ashkenazi, A., Haarmann, H. J., & Usher, M. (2005). The demise of short-term memory revisited: Empirical and computational investigations of recency effects. *Psychological Review, 112*(1), 3–42. doi:10.1037/0033-295X.112.1.3

Davelaar, E. J., Haarmann, H. J., Goshen-Gottstein, Y., & Usher, M. (2006). Semantic similarity dissociates short- from long-term recency effects: Testing a neurocomputational model of list memory. *Memory & Cognition, 34*(2), 323–334. doi:10.3758/BF03193410

Farrell, S. (2012). Temporal clustering and sequencing in short-term memory and episodic memory. *Psychological Review, 119,* 223–271. doi:10.1037/a0027371

Farrell, S., & Lewandowsky, S. (2002). An endogenous distributed model of ordering in serial recall. *Psychonomic Bulletin & Review, 9*(1), 59–79. doi:10.3758/BF03196257

Grossberg, S., & Pearson, L. R. (2008). Laminar cortical dynamics of cognitive and motor working memory, sequence learning, and performance: Toward a unified theory of how the cerebral cortex works. *Psychological Review, 115*(3), 677–732. doi:10.1037/a0012618

Hintzman, D. L., Block, R. A., & Summers, J. J. (1973). Contextual associations and memory for serial positions. *Journal of Experimental Psychology, 97*(2), 220–229. doi:10.1037/h0033884

Howard, M. W., & Kahana, M. J. (2002). A distributed representation of temporal context. *Journal of Mathematical Psychology, 46*(3), 269–299. doi:10.1006/jmps.2001.1388

Howard, M. W., Venkatadass, V., Norman, K. A., & Kahana, M. J. (2007). Associative processes in immediate recency. *Memory & Cognition, 35,* 1700–1711. doi:10.3758/BF03193503

Howard, M. W., Youker, T. E., & Venkatadass, V. (2008). The persistence of memory: Contiguity effects across several minutes. *Psychonomic Bulletin & Review, 15,* 58–63. doi:10.3758/PBR.15.1.58

Kahana, M. J. (1996). Associative retrieval processes in free recall. *Memory & Cognition, 24,* 103–109. doi:10.3758/BF03197276

Kahana, M. J., & Caplan, J. B. (2002). Associative asymmetry in probed recall of serial lists. *Memory & Cognition, 30*(6), 841–849. doi:10.3758/BF03195770

Kucera, F., & Francis, W. N. (1967). *Computational analysis of present-day American English.* Providence, RI: Brown University Press.

Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychological Review, 104*(2), 211–240. doi:10.1037/0033-295X.104.2.211

Lee, C. L., & Estes, W. K. (1977). Order and position in primary memory for letter strings. *Journal of Verbal Learning and Verbal Behavior, 16,* 395–418. doi:10.1016/S0022-5371(77)80036-4

Lewandowsky, S., & Farrell, S. (2008). Short-term memory: New data and a model. In B. H. Ross (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 49, pp. 1–48). Oxford, England: Elsevier.

Macmillan, N. A., & Creelman, C. D. (1991). *Detection theory: A user's guide.* New York, NY: Cambridge University Press.

Malmberg, K. J., Criss, A. H., Gangwani, T. H., & Shiffrin, R. M. (2012). Overcoming the negative consequences of interference from recognition memory testing. *Psychological Science, 23,* 115–119. doi:10.1177/0956797611430692

Murdock, B. B., Jr. (1968). Serial order effects in short-term memory. *Journal of Experimental Psychology, 76*(4, Pt. 2), 1–15. doi:10.1037/h0025694

Raaijmakers, J. G. W., & Shiffrin, R. M. (1980). SAM: A theory of probabilistic search of associative memory. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 14, pp. 207–262). New York, NY: Academic Press.

Raskin, E., & Cook, S. W. (1937). The strength and direction of associations formed in the learning of nonsense syllables. *Journal of Experimental Psychology, 20,* 381–395. doi:10.1037/h0061612

Schwartz, G., Howard, M. W., Jing, B., & Kahana, M. J. (2005). Shadows of the past: Temporal retrieval effects in recognition memory. *Psychological Science, 16*(11), 898–904. doi:10.1111/j.1467-9280.2005.01634.x

Sederberg, P. B., Howard, M. W., & Kahana, M. J. (2008). A context-based theory of recency and contiguity in free recall. *Psychological Review, 115,* 893–912. doi:10.1037/a0013396

Smith, S. M. (1979). Remembering in and out of context. *Journal of Experimental Psychology: Human Learning and Memory, 5*(5), 460–471. doi:10.1037/0278-7393.5.5.460

Solway, A., Murdock, B. B., & Kahana, M. J. (2012). Positional and temporal clustering in serial order memory. *Memory & Cognition, 40*(2), 177–190. doi:10.3758/s13421-011-0142-8

Spillers, G. J., & Unsworth, N. (2011). Variation in working memory capacity and temporal-contextual retrieval from episodic memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(6), 1532–1539. doi:10.1037/a0024852

Stone, B., Dennis, S., & Kwantes, P. J. (2008, July). A systematic comparison of semantic models on human similarity rating data: The effectiveness of subspacing. *Proceedings of the 30th Annual Conference of the Cognitive Science Society,* Washington, DC.

Tulving, E. (1983). *Elements of episodic memory.* New York, NY: Oxford University Press.

Unsworth, N. (2008). Exploring the retrieval dynamics of delayed and final free recall: Further evidence for temporal-contextual search. *Journal of Memory and Language, 59,* 223–236. doi:10.1016/j.jml.2008.04.002

Ward, G., Tan, L., & Grenfell-Essam, R. (2010). Examining the relationship between free recall and immediate serial recall: The effects of list length and output order. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*(5), 1207. doi:10.1037/a0020122

Received September 17, 2011
Revision received March 21, 2012
Accepted March 22, 2012 ■