

- Howard, M. W., & Kahana, M. J. (1999). Contextual variability and serial position effects in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 25, 923–941.
- Howard, M. W., & Kahana, M. J. (2002). A distributed representation of temporal context. *Journal of Mathematical Psychology*, 46, 269–299.
- Howard, M. W., Vankatadass, V., Norman, K. A., & Kahana, M. J. (2007). Associative processes in immediate recency. *Memory & Cognition*, 35(7), 1700–1711.
- Howard, M. W., Wingfield, A., & Kahana, M. J. (2006). Modeling the age-related associative deficit in self-initiated recall. *Psychonomic Bulletin & Review*, 13(3), 439–445.
- Jang, Y., & Huber, D. (2008). Context retrieval and context change in free recall: Recalling from long-term memory drives list isolation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34(1), 112–127.
- Kahana, M. J., Dolan, E. D., Sauder, C. L., & Wingfield, A. (2005). Intrusions in episodic recall: Age differences in editing of overt responses. *Journal of Gerontology: Psychological Sciences*, 60, 92–97.
- Kahana, M. J., Howard, M. W., & Polyn, S. M. (2008). Associative retrieval processes in episodic memory. In J. Byrne (Series Ed.) & H. L. Roediger, III (Vol. Ed.), *Cognitive psychology of memory: Vol. 2. Learning and memory: A comprehensive reference* (pp. 467–490). Oxford, England: Elsevier.
- Kahana, M. J., Howard, M. W., Zaromb, F., & Wingfield, A. (2002). Age dissociates recency and lag recency effects in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 28, 530–540.
- Laming, D. (1999). Testing the idea of distinct storage mechanisms in memory. *International Journal of Psychology*, 34, 419–426.
- Lohnas, L., Polyn, S. M., & Kahana, M. J. (2008). *Expanding the scope of memory search: Intra-list and inter-list effects in free recall*. Manuscript in preparation.
- Marois, R., & Ivanoff, J. (2005). Capacity limits of information processing in the brain. *Trends in Cognitive Sciences*, 9(6), 296–305.
- Mensink, G.-J. M., & Raaijmakers, J. G. W. (1988). A model for interference and forgetting. *Psychological Review*, 95, 434–455.
- Murdock, B. B. (1962). The serial position effect of free recall. *Journal of Experimental Psychology*, 64, 482–488.
- Murdock, B. B. (1974). *Human memory: Theory and data*. Potomac, MD: Erlbaum.
- Murdock, B. B. (1997). Context and mediators in a theory of distributed associative memory (TODAM2). *Psychological Review*, 104, 839–862.
- Murdock, B. B., & Okada, R. (1970). Interresponse times in single-trial free recall. *Journal of Verbal Learning and Verbal Behavior*, 86, 263–267.
- Murdock, B. B., & Walker, K. D. (1969). Modality effects in free recall. *Journal of Verbal Learning and Verbal Behavior*, 8, 665–676.
- Nieuwenstein, M. R., & Potter, M. C. (2006). Temporal limits of selection and memory encoding: A comparison of whole versus partial report in rapid serial visual presentation. *Psychological Science*, 17(6), 471–475.
- Polyn, S. M., & Kahana, M. J. (2008). Memory search and the neural representation of context. *Trends in Cognitive Sciences*, 12, 24–30.
- Polyn, S. M., Norman, K. A., & Kahana, M. J. (2008). *Episodic and semantic organization during free recall: The control of memory search*. Manuscript submitted for publication.
- Postman, L., & Phillips, L. W. (1965). Short-term temporal changes in free recall. *Quarterly Journal of Experimental Psychology*, 17, 132–138.
- 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: Academic Press.
- Raaijmakers, J. G. W., & Shiffrin, R. M. (1981). Search of associative memory. *Psychological Review*, 88, 93–134.
- Schwartz, G., Howard, M. W., Jing, B., & Kahana, M. J. (2005). Shadows of the past: Temporal retrieval effects in recognition memory. *Psychological Science*, 16, 898–904.
- 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.
- Shiffrin, R. M. (1970, June). Forgetting: Trace erosion or retrieval failure? *Science*, 168, 1601–1603.
- Sirotin, Y. B., Kimball, D. R., & Kahana, M. J. (2005). Going beyond a single list: Modeling the effects of prior experience on episodic free recall. *Psychonomic Bulletin & Review*, 12(5), 787–805.
- Usher, M., Davelaar, E. J., Haarmann, H. J., & Goshen-Gottstein, Y. (2008). Short-term memory after all: Comment on Sederberg, Howard, and Kahana (2008). *Psychological Review*, 115, 1108–1118.
- Ward, G., & Tan, L. (2004). The effect of the length of to-be-remembered lists and intervening lists on free recall: A reexamination using overt rehearsal. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 30(6), 1196–1210.
- Waugh, N. C., & Norman, D. (1965). Primary memory. *Psychological Review*, 72, 89–104.
- Zaromb, F. M., Howard, M. W., Dolan, E. D., Sirotin, Y. B., Tully, M., Wingfield, A., & Kahana, M. J. (2006). Temporal associations and prior-list intrusions in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 32(4), 792–804.

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Postscript: Distinguishing Between Temporal Context and Short-Term Store

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Space does not allow us to make detailed rebuttals to Davelaar, Usher, Haarmann, and Goshen-Gottstein's (2008) criticisms of the temporal context model's (TCM-A's) ability to account for disso-

ciations between immediate and delayed recall nor to explain how TCM could account for list discrimination experiments. We agree that future work is needed to reach a satisfactory conclusion to these issues. Here we focus on their larger point that temporal context in TCM (Howard & Kahana, 2002) is best thought of as a new form of short-term store (STS). The designation STS carries with it connotations that are inconsistent with properties of temporal context that endows TCM with considerable explanatory power. We close with a proposal for a better way to reconcile Sederberg, Howard, and Kahana's (2008) TCM-A model and the Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, and Usher (2005) model.

For the purposes of this discussion, we focus on two properties of STS common to dual-store models (Atkinson & Shiffrin, 1968;

Davelaar et al., 2005; Raaijmakers & Shiffrin, 1980). Property 1: STS is a store or repository into which “items” are placed. Property 2: At the early stages of immediate free recall (IFR), the subject consciously “examines the contents of the store” to select items for recall. Although there are other common properties, these assumptions are at the core of what is meant by STS in common usage.

Temporal context shares neither property. Whereas the information that enters STS is the same across multiple presentations of an item, the input to temporal context caused by an item changes across repetitions. In particular, a repeated item can recover the state of temporal context present when it was learned. Because the information entering temporal context caused by an item changes across repetitions, temporal context is not a store that holds (static) items, violating Property 1. In TCM, the subject never directly “examines the contents” of temporal context. Rather, the current state of temporal context is used to cue retrieval of items, violating Property 2. Because the entire state of context is used as a cue for retrieval in TCM, the presence of information caused by *other* items can determine the availability of an item. In retrieval from STS, an item is available to the extent that *it* is active in STS.

In TCM, the repetition of an item causes a change in the availability of other items—the definition of association. Taken together, Properties 1 and 2 prevent retrieval from STS from exhibiting associations between items. Properties 1 and 2 thus prevent STS from providing a complete description of immediate recency. Howard, Venkatadass, Norman, & Kahana (2007) studied IFR of lists in which an item from the middle of the list was repeated just before IFR was initiated. They found an advantage for *neighbors* of the initial presentation of the repeated item in the initiation of IFR. Properties 1 and 2 preclude associations between items in STS, which means that other processes are responsible for initiating IFR. The cost of parsimony incurred by adding a traditional STS to a theory buys the ability to describe effects in immediate recency. If STS is not sufficient to account for the initiation of IFR, then perhaps these benefits are not worth the cost. The effect observed by Howard et al. (2007) was a straightforward prediction of temporal context, particularly in the way in which it violates Properties 1 and 2.

Rather than temporal context, STS closely resembles the *accumulators* in TCM-A (Usher & McClelland, 2001). Both describe a set of coupled differential equations, with the same functional form, that keep track of an item-specific activation. The most

salient difference is that the Sederberg et al. (2008) accumulators were silent during list presentation but were meaningfully active during retrieval; in Davelaar et al. (2005), the situation is reversed. If this identification is made, the difference between the role of STS in the models amounts to our choice to keep the accumulators silent during list presentation to reflect the procedures of free-recall experiments that attempt to focus subject’s attention on only the currently presented item (e.g., Howard et al., 2007). Viewed in this light, our work suggests that, although there is a memory store with the properties of STS, it is neither necessary nor sufficient to account for immediate nor delayed recency effects. Temporal context is able to account for episodically formed associations, observed in both immediate and delayed recall, specifically because it violates core properties of STS. We conclude that it is not productive to equate temporal context with STS.

References

- Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation* (Vol. 2, pp. 89–105). New York: Academic Press.
- 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*, 3–42.
- Davelaar, E. J., Usher, M., Haarmann, H. J., & Goshen-Gottstein, Y. (2008). Postscript: Through TCM, STM shines bright. *Psychological Review*, *115*, 1116–1118.
- Howard, M. W., & Kahana, M. J. (2002). A distributed representation of temporal context. *Journal of Mathematical Psychology*, *46*, 269–299.
- Howard, M. W., Venkatadass, V., Norman, K. A., & Kahana, M. J. (2007). Associative processes in immediate recency. *Memory & Cognition*, *35*, 1700–1711.
- 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: Academic Press.
- 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.
- Usher, M., & McClelland, J. L. (2001). The time course of perceptual choice: The leaky, competing accumulator model. *Psychological Review*, *108*, 550–592.