Memory, Recall Dynamics

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How do we search our memories to recall information that occurred in a given temporal context? In the laboratory, this basic question concerning human memory is addressed by asking people to study a sequence of individually presented items (typically words) and then to try to recall all of the items they can remember in any order. This task, first introduced by E.A. Kirkpatrick in 1894, is termed free recall.

By analyzing the order in which participants freely recall list items, one can gain considerable insight into the nature of the recall process. The analysis of recall dynamics in free recall reveals several striking regularities. This entry first reviews five major phenomena that govern the way people search their memories: the effects of recency, primacy, contiguity, forward asymmetry, and semantic proximity. Subsequent sections discuss how these phenomena occur both in the patterns of correct recalls and recall errors, as well as in the latencies measured between successively recalled items. This entry closes with a brief discussion of the theoretical implications of these phenomena.

Recency

In immediate free recall, participants are far more likely to begin recall with the final list item than with an item from any other list position (Figure 1a). This tendency persists for the first several responses, after which recalls tend to come from more distributed list positions. Participants' tendency to begin recall at the end of the list has been strongly linked to the well-known *recency effect*—the increased probability of recalling items from the end of the list. The striking recency effect seen in the data (Figure 1b) is greatly reduced when participants are asked to perform an unrelated cognitive task, such as mental arithmetic, in between list presentation and the recall period (delayed recall). Although the recency effect is easily disrupted in delayed free recall, other manipulations that influence overall recall performance have little effect on the recency effect.

Dissociations between recall of recency and pre-recency effects have led some theorists to argue for a fundamental distinction between short-term and long-term memory. In this view, recency arises due to retrieval from a limited capacity short-term store (STS) whose contents are easily displaced by new information. In contrast, recall of pre-recency items arises from a search of associative memory, where associations between items reflect both newly formed associations between items that were together in STS and long-standing associative knowledge concerning the items themselves. If, however, recency depends exclusively on the operation of STS, then one would not expect to find recency in continual distractor free recall—a task where participants perform a distracting task (e.g., mental arithmetic) after every list item, including the last one. According to the STS account of recency, the final distractor should greatly attenuate the recency effect, as in delayed free recall. However, in continual-distractor free recall, one observes a strong recency effect and participants are nearly as likely to initiate recall with the final list item as in immediate free recall. This "long-term recency" has been taken to support the view that recency reflects a more general forgetting process that operates at both short and long time scales.

Primacy

In addition to the recency effect, one also observes a *primacy effect* in free recall, whereby the first few list items are remembered better than items from the middle of the list. This is seen both in the overall probability of recalling list items and in an increased tendency to initiate recall with the first list item (Figure 1a,b). The primacy effect is largely attenuated when participants are discouraged from rehearsing list items throughout list presentation. This is because early list items tend to be rehearsed more frequently than other items (they have more rehearsal opportunities), and they also tend to be rehearsed throughout the input sequence, thus giving them a recency advantage. Unlike the recency effect, the primacy effect is not reduced in delayed free recall.

Contiguity

Because in free recall the order of recall reflects the order in which items come to mind, recall transitions reveal the organization of memory for the list items. Consider, for example, that a participant has just recalled an item from serial position i, and that the next recall is from serial position j. To examine the effects of the temporal organization of the list on free recall transitions, one can measure the relation between recall probability and the *lag* between i and j, defined as $j-i$. This measure is called the *conditional-response probability as a function of lag*, or *lag-CRP*.

Given that the participant has just recalled the item from serial position i, the lag-CRP indicates the probability that the next item recalled comes from serial position $i+\text{lag}$ given the possibility of making a transition to that serial position. Lag-CRP analyses have shown that the *contiguity effect*, a tendency for participants to recall items from nearby in the

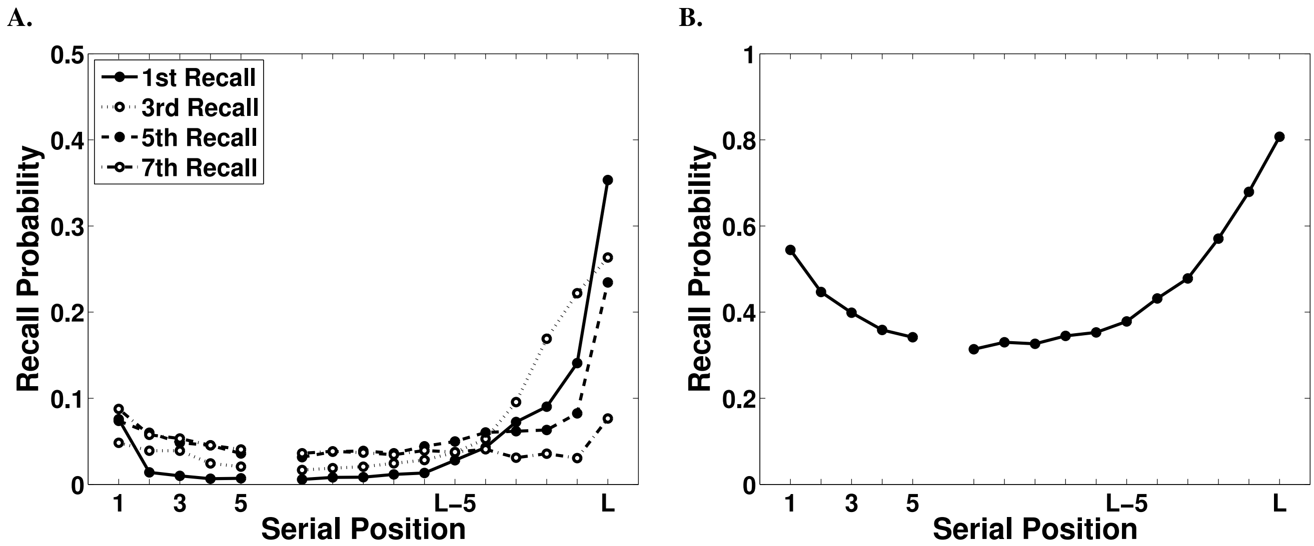

Figure 1. *Serial Position Effects.* **A**. The probability of recalling a list item from each list position in output positions 1, 3, 5 and 7. **B**. The probability of recalling list items in any output position (the serial position curve) for data from the same immediate free recall studies. "L" represents the last serial position of a list (thus, "L-5" is the fifth to last serial position). The x-axis is not continuous because the studies analyzed differ in the number of items presented per list, though all were between 15 and 30 items. Source: Figure created for this entry.

list to the just-recalled item, and the *asymmetry effect*, a tendency for participants to recall items in the forward direction, are extremely robust properties of free recall.

Figure 2a illustrates these phenomena. Positive values of *lag* = $(j-i)$ correspond to forward recalls; negative values of *lag* correspond to backward recalls. Large absolute values of *lag* correspond to words spaced widely in the list; small absolute values correspond to words spaced closely together in the list. The *contiguity effect* seen in these data also appears in the form of shorter inter-response times (IRTs) between recall of items from neighboring list positions. This can be seen in the conditional response latency (lag-CRL) function shown in Figure 2b.

The contiguity effect in free recall is also related to participant's overall ability to recall list items. For example, older adults, who recall significantly fewer correct items than younger adults exhibit significantly reduced contiguity effects. Moreover, the magnitude of each participant's contiguity effect is positively correlated with that participant's recall performance.

Associative Asymmetry

An interesting feature of the contiguity effect, as seen in Figure 2, is the strong forward asymmetry, with recall transitions being nearly twice as likely in the forward than in the backward direction. This tendency to make forward transitions is also seen in serial recall (where it is more pronounced) and in the pattern of errors observed in probed recall of serial lists. However, the forward asymmetry effect in free recall contrasts with the finding that recall of words studied in pairs (e.g., *BOY–TREE*, *SHOE–CAR*, etc.) is almost perfectly symmetrical, with participants exhibiting nearly identical rates of forward and backward recall (*BOY* retrieves *TREE* just as easily as *TREE* retrieves *BOY*), and with forward and backward recall being highly correlated at the level of individual pairs. It may be that temporally segregated word pairs (as in paired associate memory tasks) are more likely to be encoded as distinct experiences than neighboring words in a list. Associative symmetry may thus be a property of well integrated pairs that is broken by interference among items from different list positions.

Semantic Proximity

Whereas the contiguity effect illustrates the temporal organization of memories, it is also well known that participants also make use of pre-existing semantic associations among list items. This can be seen in people's tendency to make recall transitions among semantically related items, even in random word lists that lack obvious semantic associates. This *semantic proximity effect* can be seen in Figure 3a, which shows how the probability of making a recall transition among two items increases with their semantic relatedness. Not only are people more likely to make recall transitions among semantically-related items; they also make those transitions more quickly than transitions among less strongly related items (Figure 3b). Both of these effects are evident even at low levels of semantic similarity (e.g., NUMBER and JOURNAL have a LSA-similarity of 0.11, while PONY and FOREHEAD have an LSA-similarity of 0.21). Analyses of recall dynamics reveal how even modest semantic relations can exhibit a powerful influence on the way people search their memories. Even when lists lack any strong associates or any obvious categorical organization, recall transitions are driven by the relative semantic strengths among the stored items.

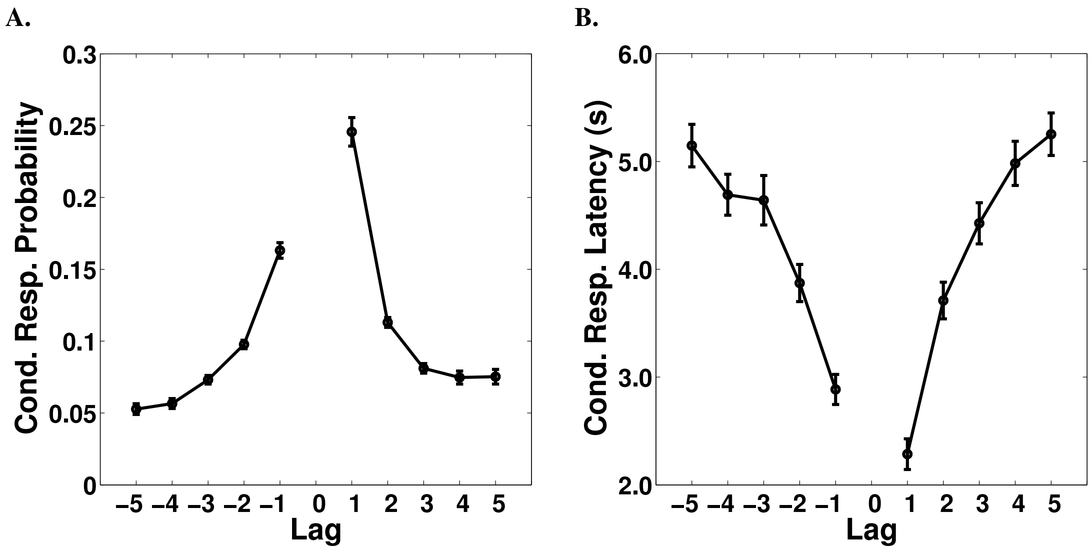

Figure 2. *Temporal contiguity effect.* **A.** The conditional-response probability as a function of lag (or lag-CRP) shows the probability of recalling an item from serial position *i* + lag immediately following an item from serial position *i*. **B.** Conditional-response latency (CRL) functions. Inter-response time between recall of items from serial positions *i* and *i* + lag. Error bars represent Loftus-Mason corrected error. Source: Figure created for this entry.

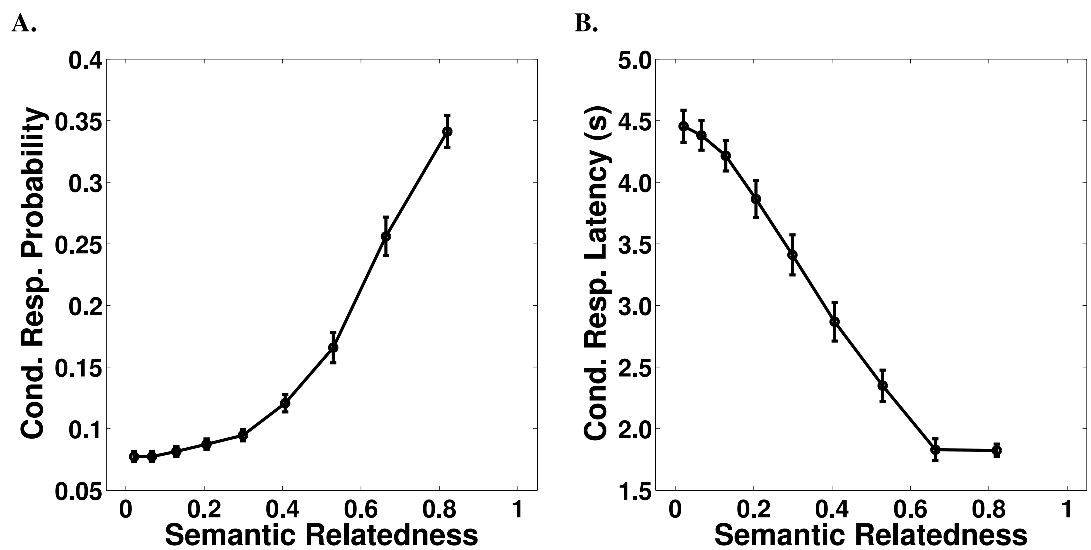

Figure 3. *Semantic proximity effect.* **A**. Conditional response probability as a function of semantic relatedness. **B**. Conditional response latency as a function of semantic relatedness. Semantic relatedness is determined using latent semantic analysis (LSA), which derives relatedness from the co-occurrence statistics of words that appear in a large corpus of text. Error bars represent Loftus-Mason corrected error.

Recall Errors

Temporal contiguity and semantic proximity not only dictate the dynamics of correct responses in free recall; they also influence the kinds of recall errors people make. When recalling a list of words, participants occasionally recall items that were not on the target list. By examining the dynamics of recall, one can show that these intrusion errors exhibit the same three basic properties described above. First, they tend to be items that were studied on recent lists. Second, they tend to be semantically related to the just recalled (correct) item. Third, when participants commit two intrusions from the same prior list, they tend to be items that were studied in neighboring list positions. This latter result is another manifestation of the contiguity effect. Thus, the same three principles that govern the dynamics of correct recalls also help to explain the kinds of recall errors that people commit.

Source Clustering

One can also show that people exhibit clustering as a function of encoding task. Sean Polyn and colleagues asked participants to make either size or animacy judgments on different list items. During free recall, participants not only exhibited temporal and semantic clustering effects; they also exhibit clustering of responses based on the task in which the words were studied. That is, following recall of an item that was given a size judgment at encoding, participants were more likely to recall another item that was given a size judgment. Furthermore, this task clustering effect interacted with temporal clustering, being greater for items presented at neighboring list positions.

One may wonder whether the entire recall process can be described as a sequence of probabilistic draws influenced by temporal contiguity and semantic clustering effects, or whether there are changes in the dynamics of recall process over the course of the retrieval period. In immediate free recall, the contiguity effect is larger and the semantic proximity effect is smaller for the first few responses and then increases/decreases to a stable state for subsequent recalls. In delayed free recall, however, the contiguity effect and semantic proximity effect are relatively stable throughout the recall period.

Interresponse Times

In 1970, Ben Murdock and Ron Okada showed that interresponse times between successive recalls increase steadily throughout the recall period, growing as an exponential function of the number of items recalled. This increase in IRTs is highly predictive of recall termination—following an IRT of >10 seconds, people rarely recall further items. The dynamics of recall also appears to be significantly affected by recall errors. Following intrusions or repetitions of already recalled items, people have a significantly increased tendency to either commit further errors or terminate recall, a pattern that is true at all stages of the recall process. Although the exponential increase in IRTs during the recall period has been argued to support a model of recall in which items are randomly sampled with replacement from a set of available responses, this account is falsified by the strong dependencies in sequences of responses, including the temporal and semantic clustering effects, as reviewed above.

Retrieved Context Theory

Whereas the contiguity effect can be easily accommodated within the view that neighboring items become associated when they cooccupy a short-term buffer (or working memory system) several studies are hard to reconcile with this classic information-processing account. For example, Marc Howard and Michael Kahana found that separating items by an unrelated distractor task (mental arithmetic) did not disrupt the relative tendency to make transitions to neighboring items. This finding was further extended in 2008 by Marc Howard and colleagues who asked participants to free recall items from 48 previously studied word lists. Under these conditions, participants exhibited a significant contiguity effect even when making recall transitions among items that occurred on different lists. For instance, following recall of an item from list 5, participants were more likely to recall an item from lists 4 or 6 than from lists 3 or 7, etc. In 2008, Orin Davis and colleagues also found that in recalling lists of paired associates, recall errors exhibited a strong contiguity effect, extending across several intervening pairs. Since interpair rehearsal would be a major source of interference in this task, it is unlikely that the contiguity effect can be entirely explained on the basis of rehearsal strategies. Even in item recognition of lists of pictures, participants exhibit contiguity effects in which recognizing a picture makes it easier to subsequently recognize a picture studied in a nearby list position. On the basis of these results, the contiguity effect may be seen as reflecting a kind of mental time travel undertaken during memory search and retrieval. In recalling an item, the participant 'travels back' to the time of its presentation, making it more likely that subsequent recalls will come from neighboring list positions. According to this view, contiguity arises due to a contextual retrieval process in which recalling an item reinstates its associated temporal contexts, which in turn serve as a cue for neighboring items.

Summary

By analyzing the dynamics of memory retrieval in free recall, one can see how the search of episodic memories is a highly cue-dependent process. Five major principles govern the way people recall lists of studied items. First, people tend to initiate recall with recently studied items. Subsequent responses continue to show a bias towards recent items, but this recency effect rapidly dissipates over the course of retrieval (Figure 1). Second, recall of a given item tends to be followed by recall of an item from a neighboring (contiguous) list position—a phenomenon known as the contiguity effect (Figure 2). Third, the contiguity effect exhibits a strong forward asymmetry effect, with forward transitions being approximately twice as common as backward transitions (Figure 2). Fourth, recall of a given item tends to be followed by recall of a semantically related item (Figure 3). These principles not only govern correct responses; they also govern the errors people make during recall. A fifth principle is the tendency to make transitions to early list items, as seen in the primacy effect. Because primacy is not always observed and largely reflects people's use of rehearsal strategies, this principle may be considered secondary to the four major phenomena described above. By studying the order of recall responses, and not just whether or not items are recalled, one can observe the striking effects of temporal contiguity and semantic similarity on the accuracy and timing of both correct recalls and recall errors. The study of recall dynamics thus allows us to characterize the basic associative processes operating in recall and to test theories of these associative mechanisms.

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See Also

Memory; Modal Model of Memory; Semantic Memory; Serial Order Memory, Computational Perspectives; Sequential Memory, Computational Perspectives, Similarity; Rehearsal and Memory

Further Readings

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