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Age Dissociates Recency and Lag Recency Effects in Free Recall

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The temporal relations among word-list items exert a powerful influence on episodic memory retrieval. Two experiments were conducted with younger and older adults in which the age-related recall deficit was examined by using a decomposition method to the serial position curve, partitioning performance into (a) the probability of first recall, illustrating the recency effect, and (b) the conditional response probability, illustrating the lag recency effect (M. W. Howard & M. J. Kahana, 1999). Although the older adults initiated recall in the same manner in both immediate and delayed free recall, temporal proximity of study items (contiguity) exerted a much weaker influence on recall transitions in older adults. This finding suggests that an associative deficit may be an important contributor to older adults' well-known impairment in free recall.

This article examines the temporal associative processes governing memory retrieval in free recall by using a decomposition technique that elucidates the distinct contributions of recency and contiguity (Howard & Kahana, 1999; Kahana, 1996). *Recency* refers to the pervasive finding that the retrievability of previously experienced stimuli or events diminishes with the passage of time and the concomitant presence of interfering activity. Temporal contiguity of events also influences the ease of memory retrieval. If two events, A and B, are experienced in temporal proximity, information about A facilitates retrieval of B, and vice versa.

To introduce our dissociation technique, we first illustrate how free recall can be decomposed into separable recency and contiguity components. We then introduce the notion of scale invariance and the idea that contiguity effects in free recall could be a consequence of the retrieval of temporal context. Finally, we introduce the notion that a comparison of younger and older adults—two groups well-known to differ in episodic memory performance—may inform this theoretical distinction between recency and contiguity processes in free recall.

Recency and Lag Recency Effects in Free Recall

The effect of recency on memory performance is striking in the free-recall task. In this task, participants attempt to recall a list of studied items in any order. Plotting recall accuracy as a function of input (serial) position reveals that participants almost always successfully recall the last two or three list items but that memory for earlier list items is much worse. A benefit for the first few list items, the primacy effect, is much smaller than the recency effect and depends critically on rehearsal (Brodie & Murdock, 1977; Rundus, 1971; Tan & Ward, 2000). Figure 1A illustrates the primacy effect, the recency effect, and the flat interior portion of the serial position curve called the asymptote.

Examining the order of recalling list items, Deese and Kaufman (1957) observed that participants begin recall with the last few list items. In fact, the tendency to begin recall at the end of the list provides an excellent index of the recency effect observed in the serial position curve (see Figure 1A). This tendency can be measured by plotting the probability of first recall (PFR) curve, which is a serial position curve for just the first item recalled (Hogan, 1975; Howard & Kahana, 1999; Laming, 1999). Figure 1B shows the PFR curve for data from Murdock (1962).

Temporally defined, interitem associations exert a strong influence on output order in free recall (Kahana, 1996). These associations are inferred from participants' tendency to successively recall items from nearby list positions. Given that a participant has just recalled an item from Serial Position i, and that the next recall is from Serial Position j, Kahana (1996) plotted the relationship between recall probability and the lag (separation, in items) between i and j. This measure, the *conditional response probability as a function of lag*, or lag–CRP, measures the distribution of successive recalls as a function of *lag*.

Figure 1C shows the lag–CRP function calculated from data collected by Murdock (1962). Positive values of $lag = (i - j)$ 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 close together in the list. For example, if the list had contained the subsequence *absence hollow pupil* and a participant recalled *hollow* followed by *pupil*, the recall of *pupil* would have a lag of $+1$. If, instead, the participant recalled *hollow* followed by *absence*, the recall of *absence* would be associated with a lag of -1. In this case, the participant would be moving backward in the list. *Absence* followed by *pupil* would yield a lag of $+2$.

The lag–CRP shows that successively recalled items are more likely to come from nearby serial positions than from remote serial positions. We refer to this phenomenon, illustrating the effect of contiguity on retrieval transitions, as the *lag-recency effect* (Howard & Kahana, 1999; Kahana, 1996). Whereas the standard

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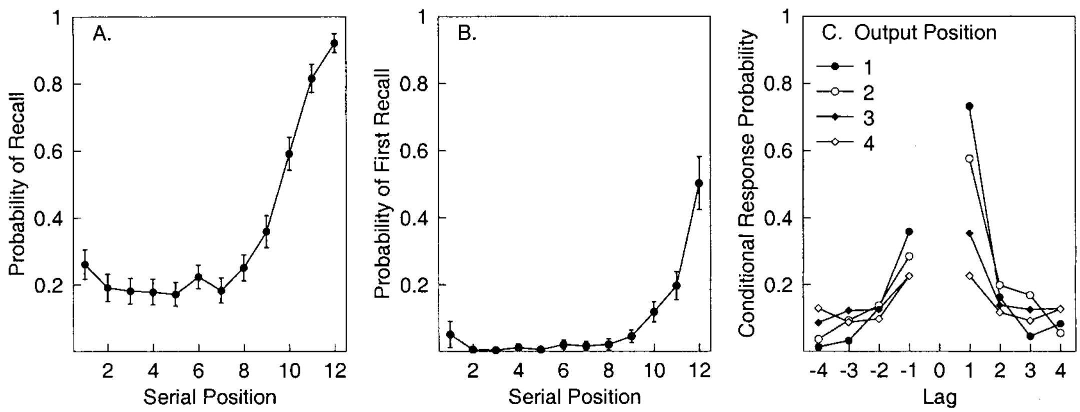

Figure 1. The decomposition of free recall. A: A standard serial position curve for the immediate condition of Experiment 1 of Howard and Kahana (1999). The use of an orienting task to inhibit rehearsal in this experiment accounts for the small primacy effect. B: The probability of first-recall function, illustrating participants' tendency to begin recall with end-of-list items. Error bars in Panels A and B are 95% confidence intervals. C: The conditional response probability functions for each of the first four output positions. See Howard and Kahana for further details.

end-of-list recency effect relates performance to the temporal proximity of a study item to the time of test, the lag recency effect relates performance to the temporal proximity of a study item to the just-recalled item. We use the term *temporal proximity* in this context to mean the number of items, or the amount of distracting activity, intervening between two study events (Howard & Kahana, 1999).

The tendency for the lag–CRP to be greater for positive values of lag than for negative values of lag indicates that the associative process in free recall is asymmetric, favoring forward associations over backward associations. Indeed, the ubiquity of this asymmetry in both free recall (Howard & Kahana, 1999; Kahana, 1996) and serial recall (Kahana & Caplan, in press; Raskin & Cook, 1937), in contrast to the symmetry in cued recall of paired items (Kahana, 2001; Rizzuto & Kahana, 2001), presents a puzzle for theories of episodic association.

The serial position curve, which has played a key role in almost all theories of human memory function (Anderson, 1976; Anderson, Bothell, Lebiere, Matessa, 1998; Atkinson & Shiffrin, 1968; Metcalfe & Murdock, 1981; Murdock, 1960; Raaijmakers & Shiffrin, 1980), reflects the end product of a complex and dynamic process. A weakness in traditional serial position analyses is in the way they have focused on the probability of recall as a function of order of presentation, disregarding the order of recall. As such, they have discarded information about sequential dependencies in retrieval. Such information, we argue, is crucial for understanding the process of self-initiated memory retrieval.

Howard and Kahana (1999) argued for the decomposition of free-recall performance, using the PFR as a measure of how participants initiate recall and the lag–CRP as a measure of recall transitions. In immediate free recall, the PFR illustrates the recency effect in participants' tendency to begin by recalling end-of-list items (see Figure 1B). The lag–CRP illustrates the lag recency effect in participants' tendency to successively recall items that come from nearby list positions. As shown in Figure 1C, the lag–CRP is more peaked at early output positions than at later output positions. This is only true of immediate free recall; in delayed free recall, the lag–CRP remains constant over all output positions (Howard & Kahana, 1999). Together, these two measures uncover a detailed picture of retrieval in free recall that is obscured by standard serial position analyses, which disregard output order (see Figure 1A).

The Scale Invariance of Recency and Lag Recency in Free Recall

Numerous dissociations between recall of the last few items (recency) and earlier items (prerecency) led early investigators to embrace the notion of distinct memory systems: a short-term or primary memory store responsible for the recency effect and a long-term or secondary memory store responsible for the primacy effect and the level of recall for items from asymptotic serial positions (Glanzer & Cunitz, 1966; Waugh & Norman, 1965).

Although recent evidence has challenged this traditional two-store model (Greene, 1986; Howard & Kahana, 1999; Neath, 1993; Neath & Crowder, 1990), the dissociations between recall of recency and prerecency items, previously used to support that duality, remain robust findings. Experimental manipulations of list length (Murdock, 1962), presentation rate (Glanzer & Cunitz, 1966; Murdock, 1962), word frequency (Raymond, 1969; Sumby, 1963), stimulus type (Raymond, 1969), and intralist-item semantic similarity (Craik & Levy, 1970; Glanzer, 1976; Glanzer & Schwartz, 1971) affect recall probabilities for prerecency items only. Conversely, when incorporating an end-of-list distractor task (Glanzer & Cunitz, 1966), manipulating list-item phonological similarity (Craik, 1968; Shallice, 1975), or varying modality of presentation (Murdock & Walker, 1969), only recall for end-of-list items is affected.

In addition to these functional dissociations, a number of neuropsychological and pharmacological dissociations distinguish recall of recency and prerecency items. For instance, pure amnesics show a normal recency effect in free recall, yet their recall of prerecency items is impaired relative to control participants (Baddeley & Warrington, 1970). Studies have reported similar results for individuals with mental retardation (Ellis, 1970), degenerative dementia (Spinnler, Della Sala, Bandera, & Baddeley, 1988), and closed-head injuries (Brooks & Baddeley, 1976). Further, impaired recency, but not prerecency, is seen in normal participants under the influence of diazepam, a dopaminergic antagonist (Mewaldt, Hinrichs, & Ghoneim, 1983).

In more recent years, investigators have shown that recency effects in free recall exhibit an approximate time-scale invariance. The recency effect, which is greatly attenuated by giving participants a short-distractor task (e.g., solving arithmetic problems for 10 s) at the end of the study list, resurfaces in the continuous-distractor paradigm, in which the same distractor task is given after each study item. Manipulating the length of this distractor (the interpresentation interval [IPI]) alters the absolute time between list items although preserving the relative spacing of the list. The relative size of the recency effect depends primarily on the relative spacing of the items and not on the absolute time since the last item was encoded (Bjork & Whitten, 1974; Howard & Kahana, 1999). This finding is extremely difficult to reconcile with the dual-store framework (Howard & Kahana, 1999).

Howard and Kahana (1999) examined the lag recency effect in the continuous-distractor paradigm (Bjork & Whitten, 1974). Figure 2A illustrates the lag recency effect for IPIs ranging from 0 s (standard delayed free recall) to 16 s. As can be seen in the figure, the lag recency effect was relatively constant across this wide range of IPIs. Although 16 s of a taxing arithmetic task had virtually no impact on the lag recency effect, the same amount of distractor activity, presented at the end of the list, was sufficient to eliminate the end-of-list recency effect (Howard & Kahana, 1999).

To quantify this effect, we separately fit power functions of the form $CRP\ (lag) = a|lag|^b$ to each participant's data for the forward and backward directions. Figure 2B shows the average exponent (collapsing the forward and backward transitions across all participants) as a function of the IPI. Insofar as the lag recency effect is insensitive to the absolute delay between list items, it can be said to exhibit a scale-invariance with respect to time.

Prior to this discovery, the lag recency effect was interpreted as evidence for associations formed in short-term memory (Kahana, 1996). If short-term memory is the locus for episodically formed associations (as postulated by Atkinson & Shiffrin, 1968; Glanzer, 1972; Raaijmakers & Shiffrin, 1980), then this would predict the lag recency effect, because nearby items presumably spend more time together in short-term memory than do remote items. However, because a long interitem distractor should disrupt short-term memory, the scale invariance of the lag recency effect requires an alternative explanation.

Retrieved Temporal Context

In the free-recall task, as in any episodic-memory task, participants are challenged with remembering the occurrence of well-known items in a particular context—typically, the just-presented group of items designated as "the list." To describe episodic memory, we thus need to introduce some time-varying representation of context. This representation allows participants to differentiate the occurrence of a common word on one list from the occurrence of that word on some other list.

Following Estes's (1955a, 1955b) studies and others (e.g., Mensink & Raaijmakers, 1988; Murdock, 1997), one can define context as a collection of (abstract) features that change slowly over the course of item presentation. If context is associated with each list item, and if time-of-test context is used to cue recall, one can account for the scale invariance in the recency effect. Because end-of-list context is most similar to the contexts of recently studied items, the model predicts a recency effect that is sensitive to the relative recency of different list items.

Although this variable-context model (Glenberg & Swanson, 1986; Mensink & Raaijmakers, 1988) neatly predicts the scale invariance of recency effects, it has no mechanism for generating the lag recency effect seen prominently in immediate, delayed, and continuous-distractor free recall (Howard & Kahana, 1999). To explain the lag recency effect, one can resort to direct interitem

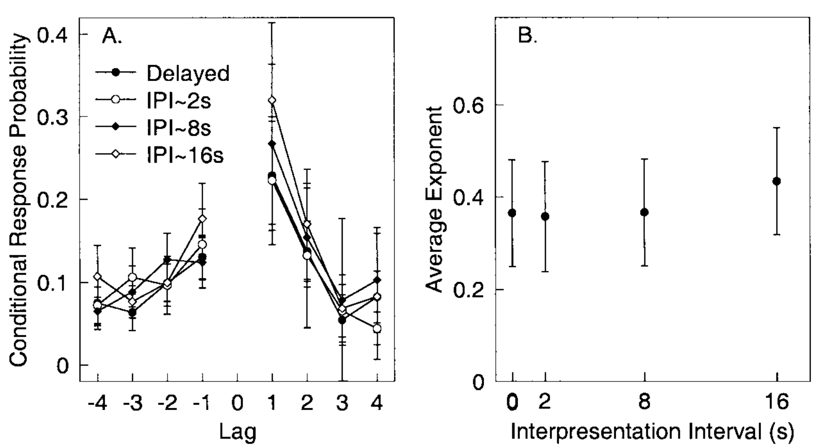

Figure 2. The scale-invariance of associative memory. Data are from a reanalysis of Experiment 2 of Howard and Kahana (1999). Their experiment had four conditions, which varied in the amount of distractor activity between each of the items in the list. Error bars in both panels are 95% confidence intervals calculated according to the method of Loftus and Masson (1994). A: The conditional response probability (CRP) curves from each of the four conditions. IPI = interpresentation interval. B: To quantify the tendency to make adjacent recalls, power functions were fit to each arm of the CRP curve and averaged for each participant for each condition.

associations (e.g., Kahana, 1996). This view, although appealing, cannot explain the scale-invariance in the lag recency effect. It would seem that interitem associations should at least be partially disrupted by a demanding interitem distractor.

An alternative, proposed by Howard and Kahana (1999), is the idea that recall of an item results in a partial reinstatement of the context that obtained when that item was studied. This *retrieved context* serves as a retrieval cue for subsequent items, producing the lag recency effect. Because it is the relative similarity in the temporal context to different list items that drives retrieval transitions, the lag recency effect is scale invariant.

Within the retrieved-context framework, the recency effect, as seen in participants' tendency to begin recalling items from the end of the list, and the lag recency effect, as seen in participants' tendency to recall nearby items successively, reflect two distinct memory processes. To initiate recall, the retrieval cue is the state of context at the end of the study list. This contextual state will be more similar to the states that were associated with recent list items than to those associated with earlier list items. As mentioned above, this produces the recency effect in that these end-of-list items tend to be recalled first and with highest probability. After successful recall of an item, the participant retrieves the state of context that obtained when that item was originally presented. This retrieved context then serves as a retrieval cue for subsequent recalls. Because the retrieved context will be similar to the context of nearby list items, it will serve as a stronger cue for these items, generating a lag recency effect.

Dissociating Recency and Lag Recency

The retrieved-variable-context framework offers an alternative to the traditional explanation of recency and lag recency in terms of the operation of short-term and long-term memory. The retrieved-variable-context approach, unlike that of the two-store model, naturally predicts the observed scale invariance in both recency (Bjork & Whitten, 1974) and lag recency (Howard & Kahana, 1999).

The retrieved-variable-context approach also predicts that two processes drive retrieval in free recall. However, instead of these processes being retrieval from short-term and long-term memory, they are retrieval using time-of-test context and retrieved context, respectively, as the cues. These two processes are measured by the probability of first recall and the lag–CRP (described above).

It is tempting to ask whether these two measures can be experimentally dissociated. To answer this question, we examined the well-known age-related deficit in free recall (Ceci & Tabor, 1981; Craik, Byrd, & Swanson, 1987; Laurence, 1967). We chose to examine age-related changes in performance because the lag–CRP is a measure of temporal association and recent work by Naveh-Benjamin (2000) suggested that older adults have a specific deficit in their ability to form new associations. Also, unlike other variables that clearly dissociate recency from prerecency, the age-related deficit in free recall is seen at all serial positions (Capitani, Della Sala, Logie, & Spinnler, 1992; Foos, Sabol, Corral, & Mobley, 1987; Parkinson, Lindholm, & Inman, 1982; Poitrenaud, Moy, Girousse, Wolmark, & Piette, 1989; Rissenberg & Glanzer, 1987).

Within free recall, an age-related deficit may reflect impairment in either the processes responsible for the recency effect, those responsible for the lag recency effect, or both. A deficit in the recency effect would pose a challenge to the widely held belief that short-term memory processes remain intact with aging, whereas a deficit in the lag recency effect would be consistent with the associative deficit hypothesis of Naveh-Benjamin (2000). Our goal here was to use data on output order in free recall to partition retrieval into recency and lag recency components and to see whether older adults were specifically impaired in one or the other process or whether they were impaired in both.

In Experiment 1, we used immediate free recall to demonstrate the dissociation procedure and evaluate age differences in recency and lag recency effects. Because recency dominates much of the data in immediate free recall, we used delayed free recall in Experiment 2 to eliminate the recency effect and focus our attention on the possibility of an age-related deficit in lag recency. Furthermore, we examined participants' intrusions on each free recall trial for both experiments, partitioning these inappropriate recalls into repetitions, prior-list intrusions (items from previous lists), and extralist intrusions (items not on any list).

Experiment 1

Method

Participants. The older participants were 28 community-dwelling adults, 14 men and 14 women, with ages ranging from 69 to 84 years ($M = 75$, $SD = 5.4$). The older group had a mean of 16 years of formal education ($SD = 2.6$) and a mean Wechsler Adult Intelligence Scale—Revised (WAIS–R; Wechsler, 1981) vocabulary score of 56 ($SD = 6.8$).

The younger participants were 31 university undergraduates, 13 men and 18 women, with ages ranging from 17 to 21 years ($M = 18$, $SD = 1.0$). At time of testing, the group had a mean of 12 years of formal education ($SD = 0.7$) and a mean WAIS–R vocabulary score of 58 ($SD = 5.0$). As a group, the older participants thus had an average of 4 more years of formal education than the younger participants at the time of testing, $t(57) = 6.27$, $p < .01$, but the two groups did not differ on WAIS–R vocabulary, $t(57) < 1.0$. Both participant groups reported themselves to be in good health and to have no difficulty reading the words as they would be presented on the computer screen.

Procedure. Participants studied lists of words for an immediate free-recall test. Lists were composed of 10 common, two-syllable nouns chosen at random and without replacement from the Toronto Noun Pool (Friendly, Franklin, Hoffman, & Rubin, 1982). Randomization of list items was done both across trials (within a testing session) and across participants. A computer controlled stimulus presentation and recorded participants' vocal responses. At the start of each trial, a fixation cross served as a warning signal for list presentation. This cross appeared for 1.4 s, followed by a 100-ms blank interstimulus interval (ISI). Then, the computer displayed each list item in capital letters for 1.4 s, followed by a 100-ms blank ISI. During list presentation, participants were required to say each word aloud. Immediately following the presentation of list items, a row of asterisks accompanied by a tone (lasting 300 ms) signaled that participants should begin recalling the list items in any order. We gave participants 30 s to recall list items. During this time, they were to recall as many items as possible from the list in any order. We made clear to our participants that they need not attempt to recall the items in order of presentation. (Although our instructions attempted to make clear that participants could recall items in any order, some older participants consistently recalled items in serial order on many trials. Participants whose probability of beginning their recall with the first list item exceeded two standard deviations above the median were excluded from these and all subsequent analyses. Using this criterion, 8 older participants but no younger participants were excluded. These excluded participants were replaced to bring the total number of older participants to 28.) Participants were tested on a total of 33 lists; the first three lists were considered as practice and not included in the analyses reported. Each session lasted approximately 1.5 hr.

Results

Figure 3 shows recall probability as a function of input serial position for younger and older participants. The performance for both younger and older adults generated the classic serial position function with a more pronounced recency effect than primacy effect (Glanzer & Cunitz, 1966; Murdock, 1962). Consistent with Capitani et al. (1992), the age-related deficit in free-recall performance could be seen at all serial positions but especially in the middle portion of the serial position curve.

Going beyond the serial position curve, we examined the age-related deficit in recency and lag recency effects. In Figure 4, the PFR is plotted, and in Figure 5, the lag–CRP is plotted. To illustrate the calculation of PFR and lag–CRP, Table 1 shows four trials of actual data taken from Experiment 1. The first line below the trial number shows the 10 words presented to the participant in their presentation order. The second line reports the words recalled in their output order. Finally, the third line gives the serial position within the presented list of each of the recalled words.

To calculate probabilities of first recall for these four trials, we tallied the number of times the first recall came from a certain serial position in the presented word list and then divided the tally by the number of times the first recall could have come from that serial position. Here, we see that Serial Position 10 (the final list item) was recalled first 3 out of 4 possible times. Serial Position 8 (the third-to-last list item) was recalled first 1 out of 4 possible times. Therefore, the probabilities of first recall were .75 for Serial Position 10, .25 for Serial Position 8, and 0 for the remaining eight serial positions.

To calculate conditional response probabilities for the first recall transition in these four trials, one would tally the number of times a transition of a certain lag was made and then divide this tally by the number of times that type of transition could have been made. Here, we see that the lags between the first two words recalled on Trials 1–4 were −1, −1, −2, and −1, respectively. Because all of the first-recalled items of Trials 1–4 were either at or near the end of the list, the participant could have made recall transitions of either −1 or −2 between the first two words recalled on each trial. Thus, the conditional response probabilities for lags of −1 and −2 were .75 and .25, respectively. The conditional response probabilities were 0 for all remaining possible forward and backward recall transitions.

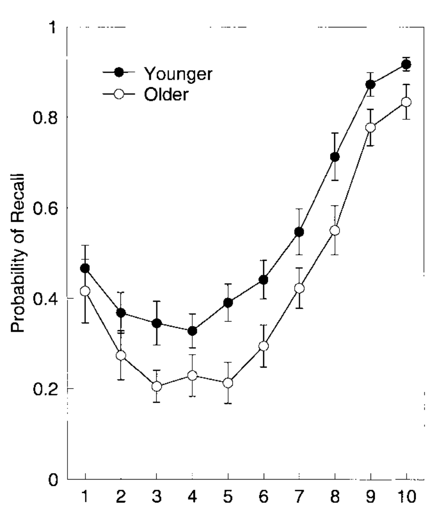

Figure 3. Traditional serial position curve, showing the probability of recall of items in each of 10 serial positions for younger and older adults. Error bars are 95% confidence intervals.

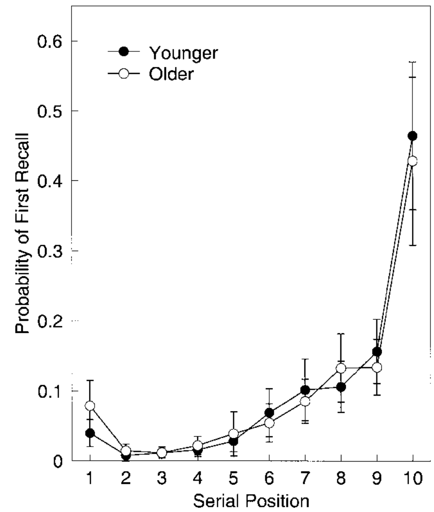

Figure 4. Probability of first-recall curves for younger and older adults in immediate free recall. Error bars are 95% confidence intervals.

Figure 4 shows the calculated PFR functions for younger and older participants. Participants in both groups exhibited a striking tendency to begin recall toward the end of the list. Furthermore, younger and older adults did not differ in the PFR at any serial position. That is, both younger and older adults exhibited an equal tendency to begin recalling items from a given serial position.

Figure 5 shows the lag–CRP functions for younger and older participants separately for Output Positions 1–4. Although there appear to be age-related differences in the quantitative levels of these functions, the same basic form is observed for both young and older adults. After recalling an item, both younger and older participants tended to recall items from nearby list positions with a bias toward going in the forward direction. At early output positions, the lag–CRP was more sharply tuned than at later output positions for both groups. This result is consistent with previous work with young adults (e.g., Howard & Kahana, 1999; Kahana, 1996).

Ideally, one would like to compare the lag–CRP functions for younger and older adults to assess the age-related deficit in the lag recency effect. However, because younger and older adults differ in their overall levels of recall, one cannot collapse their data over output position, and at the late output positions, in which the lag–CRP functions begin to asymptote, older adults give too few correct recalls to provide the statistical power to compare them with their younger counterparts. This difficulty is circumvented in Experiment 2.

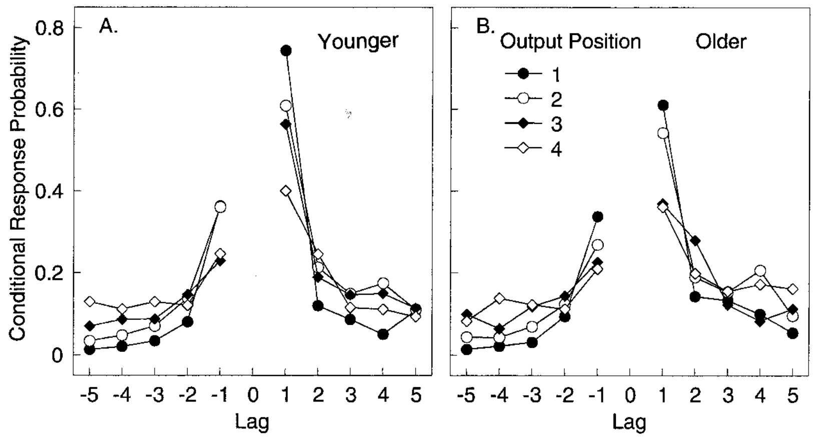

Figure 5. Conditional response probability as a function of lag for the first four output positions. A: Data from younger adults. B: Data from older adults.

In addition to recalling fewer items, older adults produced both a greater proportion and even a larger number of repetitions and intrusions than did younger adults. On average, older adults recalled 4.2 list items, made 0.40 repetitions, and 0.79 intrusions (0.39 of these were from prior lists, with the remainder being extralist intrusions). Younger adults, on average, recalled 5.4 list items, made 0.20 repetitions, and 0.54 intrusions (0.27 of these were from prior lists). That is, although older adults recalled fewer list items than did younger adults, $t(57) = 6.38, p < .01$, they made more repetitions, $t(57) = 2.75, p < .01$, more intrusions from prior lists, $t(57) = 2.12, p < .05$, and more extralist intrusions, $t(57) = 2.36, p < .05$. For both younger and older adults, about half of all prior-list intrusions came from the immediately preceding list. In addition, prior-list intrusions for both younger and older adults tended to come late in output, with at least 4 times as many prior-list intrusions in the fifth output position than in the first output position.

Discussion

The decomposition of free recall reveals that younger and older adults initiate recall in the same way, with a strong tendency to begin recall with items near the end of the list. Both younger and older adults also make extensive use of episodically formed associations in driving their subsequent recalls. Both groups exhibit the hallmark lag recency effects of adjacency and asymmetry, with the lag–CRP function being most peaked at early output positions.

The change in the tuning of the lag–CRP function with output position makes it hard to assess a possible age-related deficit in the lag recency effect in this experiment. This prevents us from col-

Table 1
Sample Free Recall Trial Information Used to Calculate Probabilities of First Recall and Conditional Response Probabilities

Trial 1										
List	Event	Painting	Outline	Question	Temple	Party	Fountain	Commerce	Mixture	Monkey
Recall	Monkey	Mixture	Commerce	Question	Temple	Outline				
SP	10	9	8	4	5	3				
Trial 2										
List	Elbow	Wrinkle	Model	Limit	Hero	Channel	Program	Comrade	Cherry	Building
Recall	Building	Cherry	Comrade	Model	Limit	Channel				
SP	10	9	8	3	4	6				
Trial 3										
List	Illness	Circuit	Mother	College	Senate	Soldier	Chapel	Instant	Cousin	Candle
Recall	Candle	Instant	Illness	College	Soldier					
SP	10	8	1	4	6					
Trial 4										
List	Lemon	Onion	Boundary	Evening	Acid	Level	Anchor	Paper	Hatred	Current
Recall	Paper	Anchor	Hatred	Current						
SP	8	7	9	10						

Note. SP = serial position.

lapsing data across output positions because older adults' memory deficit leads to the production of fewer responses in late output positions. In Experiment 2, we used delayed free recall to attenuate the recency effect and thereby obtained lag–CRP functions that were stable over output position (see Howard & Kahana, 1999; Kahana, 1996). In this way, we hoped to make more refined measurements of the lag recency effect by including all output positions in the analysis.

Experiment 2

Method

Participants. The older participants were 25 community-dwelling adults, 10 men and 15 women, with ages ranging from 66 to 88 years ($M = 74$, $SD = 5.5$). The older group had a mean of 16 years of formal education ($SD = 3.1$) and a mean WAIS–R vocabulary score of 51 ($SD = 8.5$). The younger participants were 25 undergraduates, 5 men and 20 women, with ages ranging from 18 to 21 years ($M = 19$, $SD = 0.8$). At time of testing, the group had a mean of 12 years of formal education ($SD = 0.5$) and a mean WAIS–R vocabulary score of 52 ($SD = 5.7$). As a group, the older participants thus had an average of 4 more years of formal education at the time of testing, $t(48) = 6.28$, $p < .01$, but did not differ on WAIS–R vocabulary, $t(48) = 0.45$.

All participants reported themselves to be in good health and were tested to ensure they had no difficulty reading the words as they would be presented on the computer screen. Using the same serial-recall criterion as in Experiment 1 led to the exclusion of 1 older and 1 younger participant. These excluded participants were replaced to maintain 25 younger and 25 older participants.

Procedure. Participants studied lists of words for a delayed free-recall test. As in Experiment 1, lists were composed of 10 words from the Toronto Noun Pool. The timing and method of list selection and presentation was identical with Experiment 1. In this case, however, immediately following the list presentation participants were given a 16-s arithmetic distractor task. During this task, arithmetic problems of the form "A + B + C = ?" were shown one at a time. Participants were required to say the answer out loud. For each arithmetic problem, participants could take as much time as they needed, and errors were rare. After the participants performed this distractor task for 16 s, a row of asterisks accompanied by a tone signaled them to begin recalling list items. We instructed participants to try to recall as many items as possible from the list in any order. Participants were given 45 s to recall list items. This recall period was longer than that used in Experiment 1, because preliminary studies showed that participants took longer to respond in delayed than in immediate free recall. Responses were rarely made at the end of this recall period, indicating that 45 s was sufficient time for both younger and older adults to give their recall of list items. Participants were tested on 23 lists; the first three lists were considered practice and not included in the analyses reported.

Results

Figure 6 shows the serial position functions for younger and older participants. As we expected, the recency effect is greatly diminished in this delayed-recall task (Glanzer & Cunitz, 1966; Postman & Phillips, 1965). The age-related deficit is apparent at all serial positions.

Figure 7 shows PFR functions for younger and older participants, which in contrast to Experiment 1 results, display a marked shift from recency toward primacy. This shift reflects the sharp reduction in recency associated with delayed free recall. In concordance with Experiment 1, the PFR functions are nearly matched at every serial position, demonstrating that both young and older adults are equally likely to begin recall from any given serial position.

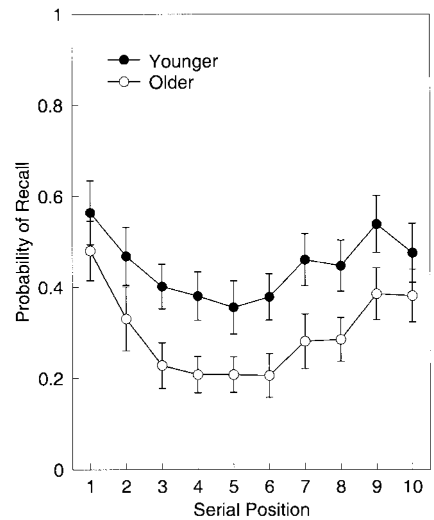

Figure 6. Serial position curves for younger and older adults in delayed free recall. Error bars are 95% confidence intervals.

Figure 8 reports lag–CRP functions for younger adults (Panel A) and older adults (Panel B). Separate analyses of lag–CRP functions at each output position showed that, as in previous studies (e.g., Howard & Kahana, 1999), the lag–CRP curves in delayed recall do not change with output position. Although the lag–CRP functions of older adults are similar in form to those of younger adults, older adults' lag–CRP functions are less sharply tuned. This flattening of the lag–CRP reveals that older adults are less likely to successively recall items from neighboring input positions. Because transitions in recall are indicative of associative processing, this reduction in the lag recency effect indicates that a deficit in episodic association is one important factor underlying the age-related impairment in free recall.

To quantitatively assess older adults' deficit in the lag recency effect, we fit power functions of the form CRP (lag) $= a|lag|^b$ to each participant's data separately for the forward and backward directions. The forward and backward exponents were 0.82 ($\pm$0.09) and 0.50 ($\pm$0.09) for younger adults and 0.37 ($\pm$0.10) and 0.26 ($\pm$0.07) for older adults. The age-related impairment in the lag–CRP was thus statistically significant in both the forward direction, $t(48) = 3.52$, $p < .01$, and the backward direction, $t(48) = 2.26$, $p < .05$.

Consistent with this, a 2 (lag: adjacent, remote[1]) × 2 (age: younger, older) mixed-design analysis of variance showed significant main effects of age, $F(1, 48) = 6.12$, $MSE = 0.00086$, $p < .02$; lag, $F(1, 48) = 153.30$, $MSE = 0.002$, $p < .01$; and most important, a significant Age × Lag interaction, $F(1, 48) = 7.26$, $MSE = 0.00086$, $p < .01$.

Despite recalling fewer items, the older adults again produced both a greater proportion and a larger absolute number of repeti-

[1] For the analysis of variance, we defined *adjacent* as the average of lags +1 and −1. We defined *remote* as the average of all lags with absolute values between 3 and 5.

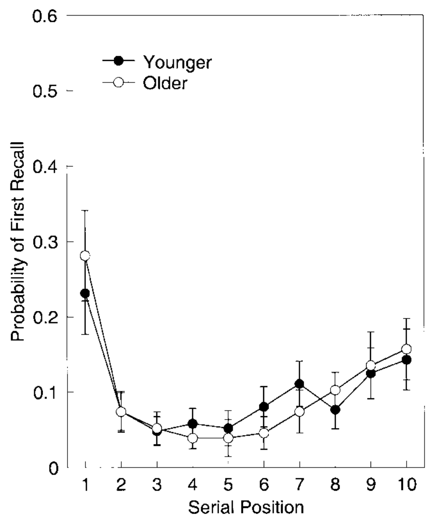

Figure 7. Probability of first-recall curves for younger and older adults in delayed free recall. Error bars are 95% confidence intervals.

tions and intrusions than did the younger adults. Older adults, on average, recalled 3.0 list items, and they made 0.15 repetitions and 0.95 intrusions (0.52 of these were from prior lists, with the remainder being extralist intrusions). Younger adults, on average, recalled 4.4 list items, and they made 0.05 repetitions and 0.35 intrusions (0.15 of these were from prior lists). That is, although older adults recalled fewer list items than did younger adults, $t(48) = 6.39$, $p < .01$, they made more repetitions, $t(48) = 2.63$, $p < .01$, more intrusions from prior lists, $t(48) = 5.40$, $p < .01$, and more extralist intrusions, $t(48) = 3.32$, $p < .01$. As in Experiment 1, approximately half of all prior-list intrusions for both younger and older adults came from the immediately preceding list. Similarly, prior-list intrusions for both younger and older adults came late in output, with about 4 times as many prior-list intrusions in the fifth output position than in the first output position. Thus, although the older adults did make a greater proportion of intrusions in both immediate and delayed free recall, the overall output pattern of intrusions was quite similar.

Discussion

In delayed free recall, as in immediate free recall, older adults recalled significantly fewer items than did younger adults, with the deficit appearing at all serial positions. Decomposing free recall into PFR and lag–CRP measures revealed that younger and older adults did not differ in the way they initiated recall but that the older adults made far less use of contiguity in their retrieval than did the younger adults. This latter finding indicates that a temporal association deficit is contributing to older adults' impairment in free recall.

General Discussion

We examined the recency and lag recency effects in free recall for younger and older adults. Because participants' output stream in free recall contains a great deal of information not seen by standard serial-position analyses, we used a decomposition technique that separates performance into two measures. The first measure specified the probability that the first recalled item comes from a given list (serial) position. In immediate free recall, this measure reveals participants' tendency to begin recalling items from the end of the list.

The second measure specified the probability that two successively recalled items come from neighboring list positions. This measure captures participants' tendency to associate nearby items within the study list. We have referred to this tendency as a *lag recency effect*, because it represents enhanced recall of items that were studied close in time (i.e., recent) to the item just recalled.

In immediate free recall, participants' tendency to begin recalling items from the end of the list coupled with their tendency to successively recall nearby list items produced the classic recency effect (Howard & Kahana, 1999). Occasionally, participants began recalling items from the beginning of the list. Both measures provide information on the order of recall that is obscured by more traditional serial position analyses.

Age-Related Changes in Recency and Lag Recency

Consistent with previous work (Howard & Kahana, 1999; Kahana, 1996), younger adults showed a strong recency effect in

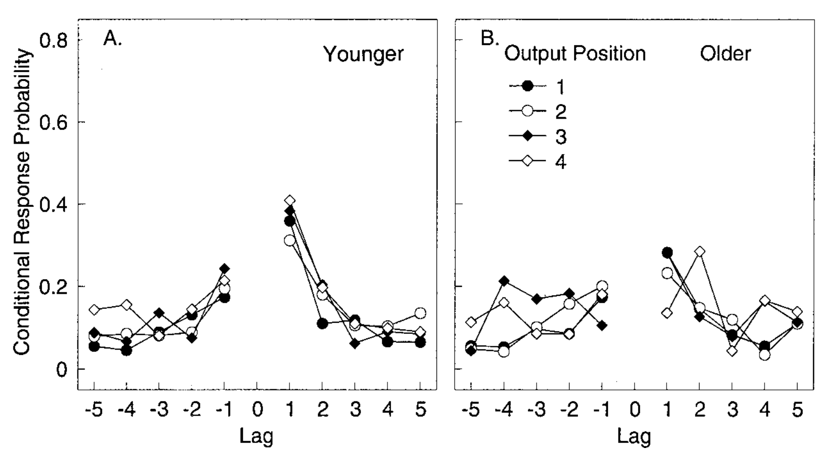

Figure 8. Conditional response probability as a function of lag for the first three output positions. A: Data from younger adults. B: Data from older adults.

immediate but not delayed free recall. This was revealed both by the standard serial position curve (compare Figures 3 and 6) and by the probability of first recall (compare Figures 4 and 7). Younger participants tend to begin recall with end-of-list items in immediate but not delayed free recall. Younger adults also show a strong lag recency effect (e.g., Howard & Kahana, 1999) with recall of an item following recall of an adjacent item on a large proportion of trials and with forward transitions being about twice as likely as backward transitions. This was true for both immediate (Figure 5, Panel A) and delayed (Figure 8, Panel B) free recall.

Older adults recalled items in a qualitatively similar manner to that of younger adults. They exhibited striking recency, as seen in their tendency to begin recall with the last few list items, and they exhibited a lag recency effect, as revealed by their tendency to successively recall items from neighboring list positions. However, the decomposition of recall performance into these two measures illustrates a striking dissociation between younger and older adults. Whereas the function describing the manner in which the younger and older adults initiate recall is nearly identical, older adults' recall transitions were much less influenced by the temporal relations among items at study.

The Temporal Context Framework

To better understand these results, one needs to consider the processes that generate these two measures. As mentioned in the introduction, Howard and Kahana (1999) found that a retrieved-variable context model could account for the observed scale invariance of recency and lag recency effects. Other formal models of free recall (e.g., Raaijmakers & Shiffrin, 1980, 1981) could not handle these results.

Within the temporal context framework (e.g., Estes, 1955a, 1955b; Howard & Kahana, 1999; Murdock, 1997), each item is associated with a representation that changes gradually with time. By this we mean something similar to time tags (Yntema & Trask, 1963), but rather than coding time like a clock, context drifts gradually as a consequence of changing mental activity or perceptual input. The temporal context model of Howard and Kahana (in press) proposes a specific mechanism for contextual drift and contextual retrieval that accounts for the asymmetry in contiguity effects seen in both free recall (see Figures 1, 2, 5, and 8) and serial recall (Kahana & Caplan, in press; Raskin & Cook, 1937). For the present discussion, we consider the more general conceptual framework only, as presented in Howard and Kahana (1999).

At test, two different types of cues drive recall: Time-of-test context drives the first recall, and retrieved context guides subsequent recalls. A participant who is impaired in episodic memory may be impaired in one or both of these processes (or in some other aspect of memory retrieval). An impairment in the use of time-of-test context would reduce the end-of-list recency effect in immediate free recall. Similarly, an impairment in the use of retrieved context would be seen as a reduction in the lag recency effect in delayed free recall.

Insofar as younger and older adults initiate recall in the same manner, as seen in the equivalence of their PFR functions (see Figures 4 and 7), time-of-test context serves as an equally effective cue across list items for each age group. Within the temporal context framework, the shape of the PFR function reflects the similarity of time-of-test context to the context associated with each list item. The equivalence of younger and older adults' PFR functions suggests that temporal context during study changes at the same rate for younger and older adults.

If, indeed, context changes at the same rate for younger and older adults, then any deficit observed in the lag recency effect (see Figure 8) must be a consequence of a difference in the process of contextual retrieval. Therefore, we conclude that the age-related deficit seen in the lag recency effect reflects a deficit in contextual retrieval but not in contextual coding.

The age-related impairment in the lag recency effect but not in the end-of-list recency effect, as reported in these experiments, can also be seen as consistent with a simple interitem associative framework, as formalized for example, in the classic two-store search of associative memory (SAM) model (e.g., Kahana, 1996; Raaijmakers & Shiffrin, 1980, 1981). In that model, one can selectively impair the formation of interitem associations in short-term memory (reducing the value of the b parameter for older adults), without changing the mean buffer size or the rule for buffer retrieval. Although this could explain the basic pattern of our results, two-store models, such as SAM, are unable to capture previously published findings on the scale invariance of episodic association (Howard & Kahana, 1999) or on the scale invariance of recency (Glenberg et al., 1980; Nairne, Neath, Serra, & Byun, 1997).

The decomposition of free recall, as described above, provides important information about episodic retrieval. Its focus is on the role of temporal factors in guiding recall, both using time-of-test and retrieved context as cues. It does not, however, consider the role of semantic factors in guiding recall (e.g., Wingfield, Lindfield, & Kahana, 1998).

Semantic similarity's effect on recall sometimes asserts itself in the form of intrusion errors—recall of items that were not presented in the target list. Such responses are typically items that are structurally related to one or more list items, either in terms of semantics or phonology. Intrusions may be items that appeared on earlier lists (prior-list intrusions), or items that were not presented in the experiment (extralist intrusions).

Our finding that older adults produce more prior- and extralist intrusions in both immediate and delayed free recall is consistent with arguments that older adults have a poorer ability to inhibit activated responses (Zacks & Hasher, 1997). Within the retrieved context framework, such an inhibition deficit would directly impair free recall performance, because recall of an item that was not on the study list would recover an inappropriate representation of its context, which would fail to help participants recall other current list items. However the lack of information on semantic and phonological similarity limits these analyses. An examination of both temporal and semantic factors in free recall would improve our understanding of the age-related deficit in episodic memory.

Conclusions

Retrieval from episodic memory is impaired in older adults. This deficit is especially pronounced in free recall and paired-associate learning tasks. The deficit in paired associates has been used to argue that older adults have a specific associative deficit (e.g., Naveh-Benjamin, 2000), whereas the deficit in free recall has been used to argue for a deficit in self-initiated or contextually mediated retrieval.

Using a new decomposition method, we can partition free-recall performance into two measures. The probability of first recall illustrates participants' tendency to begin recall with recent items in immediate but not delayed free recall. The conditional response probability as a function of lag illustrates the lag recency effect—the tendency for participants to successively recall items from nearby list positions.

Younger and older adults initiate recall in the same manner, beginning with end-of-list items in immediate but not delayed free recall. The equivalence of the probability of first recall functions across age groups suggests that both groups effectively use time-of-test context to aid recall. However, the lag recency effect, which measures the effect of temporal association at encoding after subsequent retrieval, was markedly impaired in older adults. We see this associative deficit as a consequence of older adults' impairment in retrieving the temporal context associated with list items.

References

Anderson, J. R. (1976). *Language, memory, and thought.* Hillsdale, NJ: Erlbaum.

Anderson, J. R., Bothell, D., Lebiere, C., & Matessa, M. (1998). An integrated theory of list memory. *Journal of Memory and Language, 38,* 341–380.

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.

Baddeley, A. D., & Warrington, E. K. (1970). Amnesia and the distinction between long- and short-term memory. *Journal of Verbal Learning and Verbal Behavior, 9,* 176–189.

Bjork, R. A., & Whitten, W. B. (1974). Recency-sensitive retrieval processes in long-term free recall. *Cognitive Psychology, 6,* 173–189.

Brodie, D. A., & Murdock, B. B. (1977). Effects of presentation time on nominal and functional serial position curves in free recall. *Journal of Verbal Learning and Verbal Behavior, 16,* 185–200.

Brooks, D. N., & Baddeley, A. D. (1976). What can amnesic patients learn? *Neuropsychologia, 14,* 111–122.

Capitani, E., Della Sala, S., Logie, R. H., & Spinnler, H. (1992). Recency, primacy, and memory: Reappraising and standardising the serial position curve. *Cortex, 28,* 315–342.

Ceci, S. J., & Tabor, L. (1981). Flexibility and memory: Are the elderly really less flexible? *Experimental Aging Research, 7,* 147–158.

Craik, F. I. M. (1968). Two components in free recall. *Journal of Verbal Learning and Verbal Behavior, 7,* 996–1004.

Craik, F. I. M., Byrd, M., & Swanson, J. M. (1987). Patterns of memory loss in three elderly samples. *Psychology and Aging, 2,* 79–86.

Craik, F. I. M., & Levy, B. A. (1970). Semantic and acoustic information in primary memory. *Journal of Experimental Psychology, 86,* 77–82.

Deese, J., & Kaufman, R. A. (1957). Serial effects in recall of unorganized and sequentially organized verbal material. *Journal of Experimental Psychology, 54,* 180–187.

Ellis, N. R. (1970). Memory processes in retardates and normals: Theoretical and empirical considerations. In N. Ellis (Ed.), *International review of research in mental retardation* (Vol. 4, pp. 1–32). New York: Academic Press.

Estes, W. K. (1955a). Statistical theory of distributional phenomena in learning. *Psychological Review, 62,* 369–377.

Estes, W. K. (1955b). Statistical theory of spontaneous recovery and regression. *Psychological Review, 62,* 145–154.

Foos, P. W., Sabol, M. A., Corral, G., & Mobley, L. (1987). Age differences in primary and secondary memory. *Bulletin of the Psychonomic Society, 25,* 159–160.

Friendly, M., Franklin, P. E., Hoffman, D., & Rubin, D. C. (1982). The Toronto Word Pool: Norms for imagery, concreteness, orthographic variables, and grammatical usage for 1,080 words. *Behavior Research Methods and Instrumentation, 14,* 375–399.

Glanzer, M. (1972). Storage mechanisms in recall. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation* (pp. 129–193). New York: Academic Press.

Glanzer, M. (1976). Intonation grouping and related words in free recall. *Journal of Verbal Learning and Verbal Behavior, 15,* 85–92.

Glanzer, M., & Cunitz, A. R. (1966). Two storage mechanisms in free recall. *Journal of Verbal Learning and Verbal Behavior, 5,* 351–360.

Glanzer, M., & Schwartz, A. (1971). Mnemonic structure in free recall: Differential effects on STS and LTS. *Journal of Verbal Learning and Verbal Behavior, 10,* 194–198.

Glenberg, A. M., Bradley, M. M., Stevenson, J. A., Kraus, T. A., Tkachuk, M. J., & Gretz, A. L. (1980). A two-process account of long-term serial position effects. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 355–369.

Glenberg, A. M., & Swanson, N. G. (1986). A temporal distinctiveness theory of recency and modality effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 3–15.

Greene, R. L. (1986). Sources of recency effects in free recall. *Psychological Bulletin, 99,* 221–228.

Hogan, R. M. (1975). Interitem encoding and directed search in free recall. *Memory & Cognition, 3,* 197–209.

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. (in press). A distributed representation of temporal context. *Journal of Mathematical Psychology.*

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

Kahana, M. J. (2001). *Associative symmetry and memory theory.* Manuscript submitted for publication.

Kahana, M. J., & Caplan, J. B. (in press). Associative asymmetry in probed recall of serial lists. *Memory & Cognition.*

Laming, D. (1999). Testing the idea of distinct storage mechanisms in memory. *International Journal of Psychology, 34,* 419–426.

Laurence, M. (1967). Memory loss with age: A test of two strategies for its retardation. *Psychonomic Society, 9,* 209–210.

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review, 1,* 476–490.

Mensink, G.-J. M., & Raaijmakers, J. G. W. (1988). A model for interference and forgetting. *Psychological Review, 95,* 434–455.

Metcalfe, J., & Murdock, B. B. (1981). An encoding and retrieval model of single-trial free recall. *Journal of Verbal Learning and Verbal Behavior, 20,* 161–189.

Mewaldt, S. P., Hinrichs, J. V., & Ghoneim, M. M. (1983). Diazepam and memory: Support for a duplex model of memory. *Memory & Cognition, 11,* 557–564.

Murdock, B. B. (1960). The distinctiveness of stimuli. *Psychological Review, 67,* 16–31.

Murdock, B. B. (1962). The serial position effect of free recall. *Journal of Experimental Psychology, 64,* 482–488.

Murdock, B. B. (1997). Context and mediators in a theory of distributed associative memory (TODAM2). *Psychological Review, 1997,* 839–862.

Murdock, B. B., & Walker, K. (1969). Modality effects in free recall. *Journal of Verbal Learning and Verbal Behavior, 8,* 665–676.

Nairne, J. S., Neath, I., Serra, M., & Byun, E. (1997). Positional distinctiveness and the ratio rule in free recall. *Journal of Memory and Language, 37,* 155–166.

Naveh-Benjamin, M. (2000). Adult-age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1170–1187.

Neath, I. (1993). Contextual and distinctive processes and the serial position function. *Journal of Memory and Language, 32,* 820–840.

Neath, I., & Crowder, R. (1990). Schedules of presentation and temporal distinctiveness in human memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 316–327.

Parkinson, S. R., Lindholm, J. M., & Inman, V. W. (1982). An analysis of age differences in immediate recall. *Journal of Gerontology, 37,* 425–431.

Poitrenaud, J., Moy, F., Girousse, A., Wolmark, Y., & Piette, F. (1989). Psychometric procedures for analysis of memory losses in the elderly. *Archives of Gerontology and Geriatrics, 1,* 173–183.

Postman, L., & Phillips, L. (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.

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.

Raymond, B. J. (1969). Short-term storage and long-term storage in free recall. *Journal of Verbal Learning and Verbal Behavior, 8,* 567–574.

Rissenberg, M., & Glanzer, M. (1987). Free-recall and word finding ability in normal aging and senile dementia of the Alzheimer's type: The effect of item concreteness. *Journal of Gerontology, 42,* 318–322.

Rizzuto, D. S., & Kahana, M. J. (2001). An autoassociative neural network model of paired associate learning. *Neural Computation, 13,* 2075–2092.

Rundus, D. (1971). An analysis of rehearsal processes in free recall. *Journal of Experimental Psychology, 89,* 63–77.

Shallice, T. (1975). On the contents of primary memory. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and performance* (Vol. 5, pp. 269–280). London: Academic Press.

Spinnler, H., Della Sala, S., Bandera, R., & Baddeley, A. D. (1988). Dementia, aging, and the structure of human memory. *Cognitive Neuropsychology, 5,* 193–211.

Sumby, W. (1963). Word frequency and serial position effects. *Journal of Verbal Learning and Verbal Behavior, 1,* 443–450.

Tan, L., & Ward, G. (2000). A recency-based account of the primacy effect in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1589–1626.

Waugh, N. C., & Norman, D. (1965). Primary memory. *Psychological Review, 72,* 89–104.

Wechsler, D. (1981). Wechsler Adult Intelligence Scale—Revised. New York: Psychological Corporation.

Wingfield, A., Lindfield, K. C., & Kahana, M. J. (1998). Adult age differences in the temporal characteristics of category free recall. *Psychology and Aging, 13,* 256–266.

Yntema, D., & Trask, F. (1963). Recall as a search process. *Journal of Verbal Learning and Verbal Behavior, 2,* 65–74.

Zacks, R., & Hasher, L. (1997). Cognitive gerontology and attentional inhibition: A reply to Burke and McDowd. *Journals of Gerontology: Series B: Psychological Sciences & Social Sciences, 52*(B), 274–283.

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