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The interpretation of temporal isolation effects

Stephan Lewandowsky, Tarryn Wright and Gordon D. A. Brown

At first glance, there appears to be no doubt that time is an important determinant of memory. Whether time spans are measured in seconds, minutes, or years, the pervasive decline of performance with delay is obvious and nearly always inescapable (e.g., Brown and Chater 2001). Accordingly, the field abounds with theories that accord a central and causal role to time in memory (e.g., Brown, Neath and Chater 2002; Brown, Preece and Hulme 2000; Burgess and Hitch 1999; Page and Norris 1998). Here, we focus on one class of time-based theories known as 'distinctiveness models', according to which memory for events is determined by the extent to which they are temporally distinct from other items in memory (e.g., Bjork and Whitten 1974; Brown *et al.* 2000; Burgess and Hitch 1999; Crowder 1976; Glenberg and Swanson 1986; Neath 1993). Although there is considerable variation among implementations of the distinctiveness notion, the models share a crucial common prediction: all other things being equal, temporally isolated events in memory (e.g., where I parked my car in an unfamiliar car park in a strange city) are necessarily better remembered than events that are temporally crowded (e.g., where I parked my car today, as I do every other day, in the university car park outside the Psychology building). Temporal distinctiveness theories would have considerable difficulty accommodating the absence of a temporal isolation effect. This chapter examines the extent to which this core prediction holds in immediate memory for serial order, the hallmark paradigm of short-term memory research. To foreshadow our main conclusion, we find little support for a role of temporal distinctiveness in immediate memory for serial order.

The structure of this chapter is as follows: we begin by reviewing some of the existing evidence that has been advanced in support of temporal distinctiveness and argue that there are two non-temporal alternative explanations for the observed apparent temporal isolation effects; namely, rehearsal and selective encoding. We then present two experiments in which temporal gaps between list items were predictable and in which a temporal isolation effect was observed, such that recall was better for items that were surrounded by longer pauses, even when rehearsal was eliminated. This eliminates the first alternative explanation and suggests that rehearsal is not a major contributor to isolation effects. We next show by simulation that those results, like the outcomes of previous related studies, are nonetheless ambiguous and can be handled by the second alternative explanation, which assumes that people selectively encode those portions of the list that they know to be temporally well separated. We conclude the chapter by reviewing a number of recent studies in which both rehearsal and selective encoding strategies were eliminated, and which uniformly found that temporal isolation had no beneficial effect on immediate memory for serial order.

We close by drawing three principal conclusions:

1. Temporal separation at encoding need not play a role in short-term serial recall.
2. Previous experiments that purport to show effects of temporal isolation in serial recall are ambiguous.
3. Any known effects of temporal isolation at encoding can be ascribed to strategic effects such as selective encoding.

Although temporal distinctiveness models of free recall have enjoyed considerable empirical support (e.g., Bjork and Whitten 1974; Glenberg and Swanson 1986; Nairne, Neath, Serra, and Byun 1997), until recently only two studies extended the concept to serial recall by varying the temporal intervals between list items during presentation. Neath and Crowder (1996) systematically varied interitem intervals during rapid presentation of five-item lists of two-syllable words. In the two conditions of greatest interest, interitem intervals either increased or decreased consecutively across serial positions. In the increasing condition, the interitem interval increased from 50 (between the first two list items), to 100 (between items two and three), to 200, and then to 400 ms. The decreasing condition involved the reverse order of these intervals across serial position. In a third control condition, interitem intervals were a constant 50 ms.

The results supported the expectations of distinctiveness views, with serial recall performance for the last few items being significantly better for the increasing condition compared to the decreasing condition, whereas the reverse was true for the first few items. Performance on the constant-interval control list was in between these two conditions.

Similar results were reported by Welte and Laughery (1971) with slower presentation rates, suggesting that the results of Neath and Crowder (1996) were not tied to the use of very brief intervals. Welte and Laughery (1971) used lists of nine digits that were presented with either an increasing or a decreasing schedule of intervals. Intervals had a minimum duration of 500 ms with a uniform stepsize of 200 ms. The emphasis in Welte and Laughery's experiment was on examining the differences between serial recall and free recall. The results revealed the same beneficial pattern of temporal isolation for free recall as for serial recall, thus extending the generality of the finding by Neath and Crowder (1996). (See also Neath and Crowder 1990.)

At first glance, the studies by Neath and Crowder (1996) and Welte and Laughery (1971) provide strong support for the idea that temporal isolation benefits short-term memory for serial order. Irrespective of serial position, and with relevant variables such as retention interval and list length kept constant, recall was better for items that were widely separated from their neighbors than for items that were temporally crowded.

However, it turns out that the studies by Neath and Crowder (1996) and Welte and Laughery (1971) were characterized by two methodological features that prevent an unambiguous interpretation of the results and give rise to two alternative explanations. The first arises from the predictability of the list structure. On each list, the gap between the first two items predicted the duration of all following intervals: when the first interval was short, participants knew that the list would end with well-separated items, whereas when the first interval was long, participants knew that the list would end with items crowded together in time. This predictability may have encouraged participants to develop compensatory encoding strategies. For example, on an increasing list people may have chosen to await the well-separated terminal items for thorough encoding, and conversely on a decreasing list, they may have chosen to discontinue processing after encoding of the first few items. Any strategy of this type would also have given rise to the observed isolation effects, but of course it would have done so without any need to invoke the concept of temporal distinctiveness. We examine this potential alternative explanation further after presenting two experiments that addressed a second issue with the studies by Neath and Crowder (1996) and Welte and Laughery (1971).

This second problem is particularly obvious in the study by Welte and Laughery, in which participants could have readily used the moderately long interitem intervals to rehearse recently presented items. For example, on a list such as A.B..C. . .D. . . .E (where the letters represent arbitrary items and the dots represent units of time), people would have had considerably more opportunity to rehearse D than A.[1] Any strategy of this type would have produced the observed isolation effect; by implication, the potential presence of rehearsal renders the results of Welte and Laughery theoretically ambiguous. The problem of rehearsal was recognized by Neath and Crowder (1996), who sought to prevent rehearsal through the use of extremely brief intervals and short presentation durations (1100 ms for the entire list). However, for the word stimuli used by Neath and Crowder, articulation rates are known to be around three words per second (e.g., Hulme, Roodenrys, Brown *et al.* 1995), which implies that the longest interval (400 ms) in that study would have been sufficient for some limited rehearsal to take place. It follows that the possibility cannot be ruled out that rehearsal may have contributed to the isolation effects observed by Neath and Crowder.

We now present two experiments that resembled the studies by Neath and Crowder (1996) and Welte and Laughery (1971) but eliminated rehearsal by articulatory suppression (AS). AS is the repetitive vocalization of an irrelevant word by the participant during study and, by common agreement, is assumed to disrupt rehearsal (Saito 2000).

Experiment 1

Experiment 1 used increasing and decreasing presentation schedules in a quiet condition and with AS. It is known that AS significantly decreases performance without affecting the overall shape of the serial position curve (Anderson and Matessa 1997; Burgess and Hitch 1999; Hitch, Burgess, Towse *et al.* 1996). Temporal distinctiveness theories would expect the benefits of temporal isolation to be the same regardless of articulation, and would therefore expect both conditions to replicate the isolation effects just discussed. Alternatively, if the apparent effect of temporal distinctiveness found by Neath and Crowder and Welte and Laughery had been due to rehearsal during the intervals, then the effects of presentation schedule should be abolished by AS.

Method

Participants. Twenty-six first-year students from the University of Western Australia participated voluntarily in exchange for course credit. Two participants were removed from the analysis as they performed extremely poorly. This left 24 participants who were randomly allocated into either the AS or the quiet condition, 12 for each condition.

Design and materials. The experiment was computer controlled. Lists were constructed from 19 letters (all of the consonants except Q and Y) and items were randomly sampled without replacement for each list. The lists contained seven items and the total presentation duration was constant across all schedules. The increasing interitem intervals were set to 50, 100, 200, 400, 800 and 1200 ms, with the decreasing intervals in the reverse sequence and the interval in the constant presentation schedule set to 458 ms. Two independent variables were examined: presentation schedule (i.e., constant, increasing, or decreasing) was manipulated within participants, and articulation condition (either quiet or AS) was manipulated between participants.

[1] The term 'rehearsal' here is to be understood generically, to refer to any of a number of strategies that people may use during the gaps between items to consolidate already-presented information. For example, people might phonologically recode items (if they are visually presented); they might apply some mnemonic technique; or they might use the time for proper rehearsal.

Procedure. There were 40 trials for each presentation schedule, which were randomized into a contiguous sequence of 120 trials. Participants in the quiet condition quietly watched the presentation of the list, whereas participants in the AS condition repeated the word 'sugar' aloud during list presentation but not during recall. Participants' verbalizations were recorded to ensure that AS continued for the whole experiment.

Each trial commenced with a blank screen for 2000 ms, which was followed by the list with each item presented centrally for 300 ms. Items were separated by a blank screen for the time determined by the interval manipulation. After the last item, a blank screen of 100 ms and a mask of three asterisks appeared for 300 ms, which were followed by a '_' cursor to prompt recall via the keyboard. Responses remained on the screen until all items were entered but correction was not possible. The computer also recorded the latency of responses.

Participants were instructed to recall all of the items in the list in their presented order as accurately and as quickly as possible. Participants were instructed to guess if necessary or alternatively use the spacebar to indicate an omission. Emphasis was placed on ensuring that items were recalled in the correct position.

Results

Responses were scored as correct only if the item was recalled in its correct position. Performance of individual participants in both groups ranged from 0.21 to 0.78 (averaged across serial positions).

Figure 8.1 shows the serial position curves for both conditions and all presentation schedules. The figure suggests that an effect of presentation schedule was obtained for both the quiet and the AS group, with performance at early serial positions being better in the decreasing than the increasing conditions, and with a reverse difference between conditions at later serial positions.

A 2 × 3 × 7 (Condition × Presentation schedule × Serial position) between-within subjects ANOVA revealed main effects of condition, $F(1, 22) = 15.99$, MSe = 0.33, $p < 0.001$; presentation

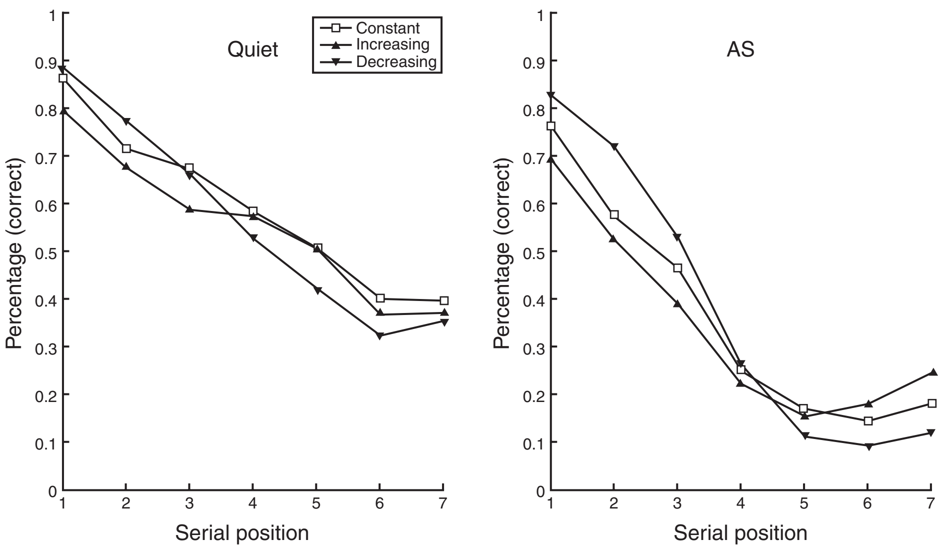

Figure 8.1 Serial position curves for all presentation schedules in both conditions in Experiment 1.

schedule, $F(2, 44) = 3.66$, MSe = 0.01, $p < 0.05$; and serial position, $F(6, 132) = 132.87$, MSe = 0.024, $p < 0.0001$. Serial position also interacted with condition, $F(6, 132) = 6.31$, MSe = 0.024, $p < 0.0001$, and, crucially, with presentation schedule, $F(12, 264) = 9.59$, MSe= 0.006, $p < 0.0001$. No other interactions, including the overarching three-way interaction between all variables, were significant.

The interaction between serial position and presentation schedule was further explored by two separate within-subjects Presentation schedule × Serial position ANOVAs for the quiet and AS condition, respectively. The interaction between presentation schedule and serial position condition was significant for the quiet condition, $F(12, 132) = 2.84$, MSe = 0.007, $p < 0.002$, as well as for the AS condition, $F(12, 132) = 8.53$, MSe = 0.006, $p < 0.0001$.

Discussion

The results of Experiment 1 are consonant with the predictions of temporal distinctiveness theories: irrespective of their serial position, items that were widely separated in time were remembered better than items that were temporally crowded. Experiment 1 thus replicated the results of Neath and Crowder (1996) and additionally extended their findings to longer lists (seven instead of five items), to a closed vocabulary set (letters instead of words), to significantly longer presentation durations and interitem intervals, and to situations when rehearsal at encoding was prevented by articulatory suppression.

The first experiment thus provided evidence against a possible role of rehearsal in producing temporal isolation effects. Moreover, contrary to the expectations of a rehearsal view, the magnitude of the isolation effect at early serial positions appeared to be greater in the AS condition than in the quiet condition. Figure 8.1 shows that performance at early serial positions for the decreasing schedule in the quiet condition was arguably close to ceiling, and this may have prevented the isolation effect from exhibiting its true magnitude. Experiment 2 explored this possibility by inserting a brief distractor task between list presentation and recall in the quiet condition.

Experiment 2

Experiment 2 was identical to the first study except for a brief distractor task between study and retrieval in the quiet condition. In addition, the constant presentation schedule was omitted, and participants were queried about their encoding strategies after completion of the experiment.

Method

Participants. Fourteen first-year students from the University of Western Australia participated voluntarily in exchange for course credit. Three participants were removed due to poor performance and one because the participant took almost three times as long as anyone else to complete the task. This left 10 participants, an equal number of whom were randomly assigned to the AS and quiet conditions.

Design and procedure. Lists were constructed in the same manner as for Experiment 1, except that the constant condition was not included. There were 40 trials of each presentation condition; increasing or decreasing. Presentation schedules were randomly intermixed.

In the quiet condition, participants repeated out aloud a random 3-digit number that was presented immediately after the list for 2,000 ms. In the AS condition, a blank screen of 100 ms followed by a mask of asterisks for 300 ms separated the last study item from the recall phase. After completion of the experiment, participants were queried about what strategies they used to perform the experiment.

Results

Correct-in-position performance for individual participants in both groups ranged from 0.24 to 0.48 (averaged across serial positions). The serial position curves for both conditions and both presentation schedules are presented in Figure 8.2.

A 2 × 2 × 7 (Condition × Presentation schedule × Serial position) between-within ANOVA revealed a significant main effect of presentation schedule, $F(1, 8) = 5.50$, $p < 0.05$, MSe = 0.019, and serial position, $F(6, 48) = 29.10$, $p < 0.0001$, MSe = 0.03. In addition, the interaction of presentation schedule and serial position was significant, $F(6, 48) = 7.81$, $p < 0.0001$, MSe = 0.008. No other effects reached significance.

Two separate 2 × 7 (Presentation schedule × Serial position) within-subjects ANOVAs within each condition confirmed the presence of the crucial presentation schedule × serial position interaction for the quiet condition, $F(6, 24) = 3.34$, $p < 0.02$, MSe = 0.01, as well as the AS condition, $F(6, 24) = 5.28$, $p < 0.002$, MSe = 0.006.

As for Experiment 1, the benefits for the decreasing interval were found at the beginning of the list for the first three serial positions, whereas the fifth and sixth serial positions benefited in the increasing condition. The crossover at serial position four is at roughly the same point as in Experiment 1 (see Figures 8.1 and 8.2). The apparent lack of difference between the decreasing and increasing condition for the terminal item in the quiet condition probably resulted from a suffix effect induced by the requirement to pronounce a random number at the end of the list. Suffix effects are a standard finding in serial recall (e.g., Greene and Crowder 1988; Hitch, Burgess, Towse *et al*. 1996) and this result is therefore not surprising.

The interview at the end of testing revealed that participants used a consistent encoding strategy. All participants, regardless of articulatory condition, reported that with decreasing presentation schedules they focused on remembering only the first three to fourI items. With increasing presentation schedules, all but two participants (both in the quiet condition) likewise reported that they focused only on the last three or four items during list presentation.

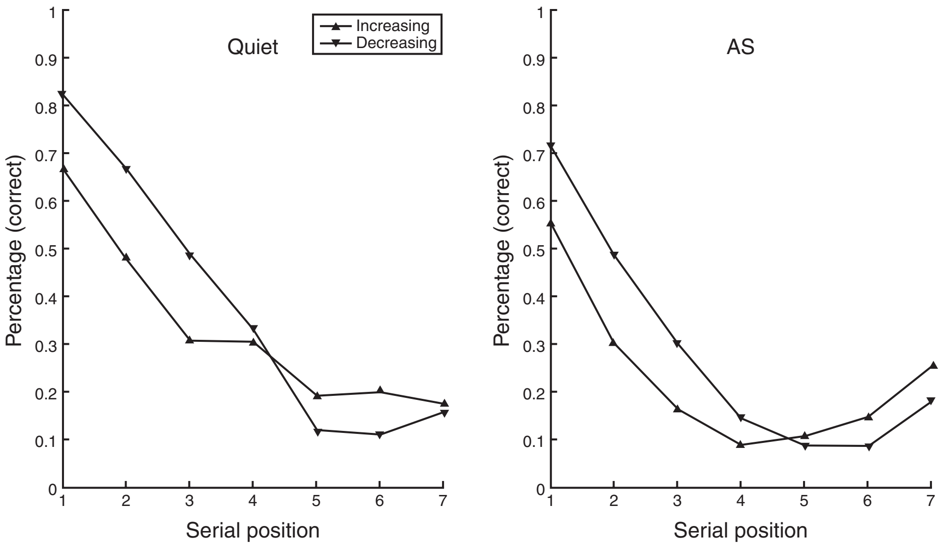

Figure 8.2 Serial position curves for all presentation schedules in both conditions in Experiment 2.

Discussion

Experiment 2 replicated the results of the first study even though performance in the quiet condition, including the first list item, could no longer be considered to be anywhere near ceiling. The results further weaken a rehearsal-based explanation for temporal isolation effects, and we give it no further consideration as a viable alternative explanation.[2]

The recall data are therefore compatible with a temporal distinctiveness notion, although the verbal reports by participants are supportive of the other alternative account of the data advanced at the outset; namely, that the predictability of intervals engendered selective encoding strategies. On this account, it was not temporal distinctiveness per se that produced the isolation effects at retrieval, but people's choice to memorize well-separated items at the expense of others that they found more difficult to encode. In order to confirm the viability of this alternative explanation, we now model the data from the first two experiments in two ways; within a conventional temporal distinctiveness framework and within a nontemporal account augmented by selective encoding.

Temporal distinctiveness vs selective encoding: the SIMPLE theory

A powerful recent instantiation of the temporal distinctiveness hypothesis is the SIMPLE theory (*S*cale *I*nvariant *M*emory, *P*erception, and *LE*arning) of Brown *et al.* (2002). At an intuitive level, SIMPLE postulates that the confusability between any two memory traces is related to the ratio of the time that has elapsed between their encoding and the time of recall. The lower that ratio, the lower the confusability among items and hence the more likely it is that an item is recalled correctly. This mechanism favors recent items over more distant events. For example, items that were encoded 1 s and 2 s ago are less confusable (ratio of 0.5) than are items from 5 and 6 seconds ago (0.83). The mechanism also favors items that were separated in time over others that occurred in close succession. For example, items that occurred 5 s and 10 s ago (ratio 0.5) are less confusable than items that occurred 7 s and 8 s ago (0.88), notwithstanding the fact that the average retention interval is equal for both pairs of items. It follows that items from further in the past, and items that occurred near each other in time, will be more difficult to recall (see Brown *et al.* 2002 for further details).

More formally, SIMPLE rests on three principal assumptions:

1. Items are represented by their position within a potentially multidimensional psychological space, with one of those dimensions necessarily devoted to representing time. Here, the temporal dimension was accompanied by a second, positional dimension that corresponded to the list position of items.
2. The similarity between any two items in memory is a declining function of the distance separating them in psychological space.
3. The probability of recalling an item is inversely proportional to that item's summed similarity to all other response alternatives, as just illustrated by the ratios between elapsed times of item pairs.

The SIMPLE architecture

Encoding in multidimensional space. Memory representations are organized along a primary temporal dimension that reflects the (logarithmically transformed) time since encoding. Retrieval can

[2] This conclusion stands in contrast to our interpretation of an earlier study (Lewandowsky and Brown 2005), in which we ascribed an apparent isolation effect to rehearsal. Upon reexamination, that effect was more likely to be the product of a grouping strategy, similar to the strategic explanation advanced here for the present experiments. See Lewandowsky, Brown, Wright *et al.* (2005) for details.

be cued by the remembered location of an item along this dimension. In the present case, a second dimension represents within-list position, coded by ordinal numbers (i.e., position 1, 2,…). There is ample evidence that positional information – which can be decoupled from elapsed time – is relevant in serial recall (Henson 1999; Ng and Maybery 2002).

To illustrate, consider the representation of a two-item list after a 6 s retention interval (with items being separated by 1 s on the list): the two items would be in locations {log(7), 1} and {log(6), 2}, respectively, in the {time, position} space. The relative importance of the two dimensions at retrieval is determined by the parameter *wt*, which is the attentional weight paid to the temporal dimension. The weight given to the positional dimension is given by 1-*wt*, and therefore:

$$d_{i,j} = wt\left|Log(T_i) - Log(T)_j\right| + (1 - wt)\left|P_i - P_j\right|$$

where $d_{i,j}$ is the psychological distance between stimulus *i* and stimulus *j*, T_i is the temporal distance of stimulus *i* from the time of retrieval (logarithmically transformed to capture the fact that temporally distant events are more compressed than recent ones), and P_i is the ordinal position of item *i*. The attentional parameter *wt* (see, e.g., Nosofsky 1992) can be thought of as stretching (shrinking) the psychological space along the most (least) important dimension. In the present case, if *wt* is unity, the simulations implement an exclusively time-based representation (for the earlier two-item list, the representation reduces to {log(7)} and {log(6)}). Conversely, as *wt* approaches zero, the representation is no longer time-based but positional and the representation of the list becomes {1} and {2}.

Similarity-distance metric. Following much precedent in the categorization literature, SIMPLE assumes that the similarity of any two items in memory is a reducing exponential function of the distance between them in psychological space:

$$\eta_{i,j} = e^{-cd_{i,j}}$$

where $\eta_{i,j}$is the similarity between items *i* and *j* and $d_{i,j}$ the distance between them. It follows that items that are very close have a similarity approaching unity, whereas items that are more psychologically distant have a similarity that, in the extreme, approaches zero. The parameter *c* governs the rate of decline of similarity with distance. In conjunction with the logarithmic transformation of time, this similarity metric gives rise to the distinctiveness ratios mentioned earlier.

Similarity determines recall. The third assumption is that the probability of recalling item *i* is inversely proportional to the summed similarity of that item to every other potentially recallable item. Specifically, the discriminability of the memory trace for item *i*, D_i, is given by:

$$D_i = \frac{1}{\sum_{k=1}^{n}\left(\eta_{i,k}\right)}$$

where *n* is the number of available response alternatives, which in the present case is assumed to be equal to the number of list items.

Discriminability translates into recall probability by taking into account the possibility of omissions. Omissions arise from thresholding of low retrieval probabilities by a sigmoid function: if D_i is the discriminability given by the preceding equation, the recall probability P_i is derived as:

$$P_i = \frac{1}{1 + e^{-s(D_i - t)}}$$

where *t* is the threshold and *s* determines the slope (or noisiness) of the transforming function. Any D_i that falls below the threshold engenders an omission.

Model parameters. For the present simulations, we used a basic version of SIMPLE that did not incorporate mechanisms for extra-list intrusions or response suppression and that ignored possible phonological or semantic similarity between items. All of these mechanisms are necessary for modeling of a wider range of paradigms; however, they are not needed for (and indeed could potentially obscure) the core predictions that are of interest here.

The present basic version of SIMPLE thus has five free parameters:

1. *c* governs the rate at which the psychological similarity of two items decreases as a function of the distance between them in psychological space.
2. *wt* specifies the amount of attention paid to the temporal dimension (at the expense of attention paid to the positional dimension).
3. *s* (for 'slope') and
4. *t* (for 'threshold') relate to omissions as described above.
5. An additional parameter *o* is required to accommodate output interference. It is assumed that the memories of to-be-recalled items become progressively less distinctive as recall proceeds due to interference caused be each successive recall. The output interference parameter, *o*, reduces the value of *c* for the *n*th item recalled by multiplying it by o^{n-1}. Thus with $o = 1$, there is no output interference; as *o* reduces below 1 there is increasing output interference.

Two rival accounts for the data

All simulations implemented the exact presentation regime of the experiment(s) being modeled, using the experimental presentation duration, interitem intervals, and retention intervals. The best-fitting parameter estimates and R^2 values for all simulations reported in this article are summarized in Table 8.1.

Time-based account. The time-based account for Experiment 2 was straightforward, with the parameters being estimated from the data using the experimental presentation regime. Parameter values were estimated separately for the quiet and suppression conditions, but were held constant for the increasing and decreasing schedules within each articulation condition. The results are shown in the left panel of Figure 8.3, where it is evident that a good fit was obtained. Moreover, the parameter estimates were meaningful and consistent with a time-based interpretation of the

Table 8.1 SIMPLE parameter values used in all simulations

Experiment	Cond	*c*	*wt*	*o*	*t*	*s*	R^2
One	Quiet	9.37	0.74	0.75	0.56	3.79	0.960
(temporal)	Suppress	9.16	0.73	0.84	0.83	9.45	0.992
Two	Quiet	12.1	0.86	0.79	0.74	5.45	0.978
(temporal)	Suppress	5.49	0.67	0.91	0.84	9.78	0.988
One	Quiet	15.6	0	0.21	0.01	2.79	1.00
(encoding)	Suppress	9.87	0	0.40	0.68	21.0	0.990
Two	Quiet	5.36	0	0.50	0.61	4.18	0.990
(encoding)	Suppress	2.78	0	0.85	0.85	11.1	0.991

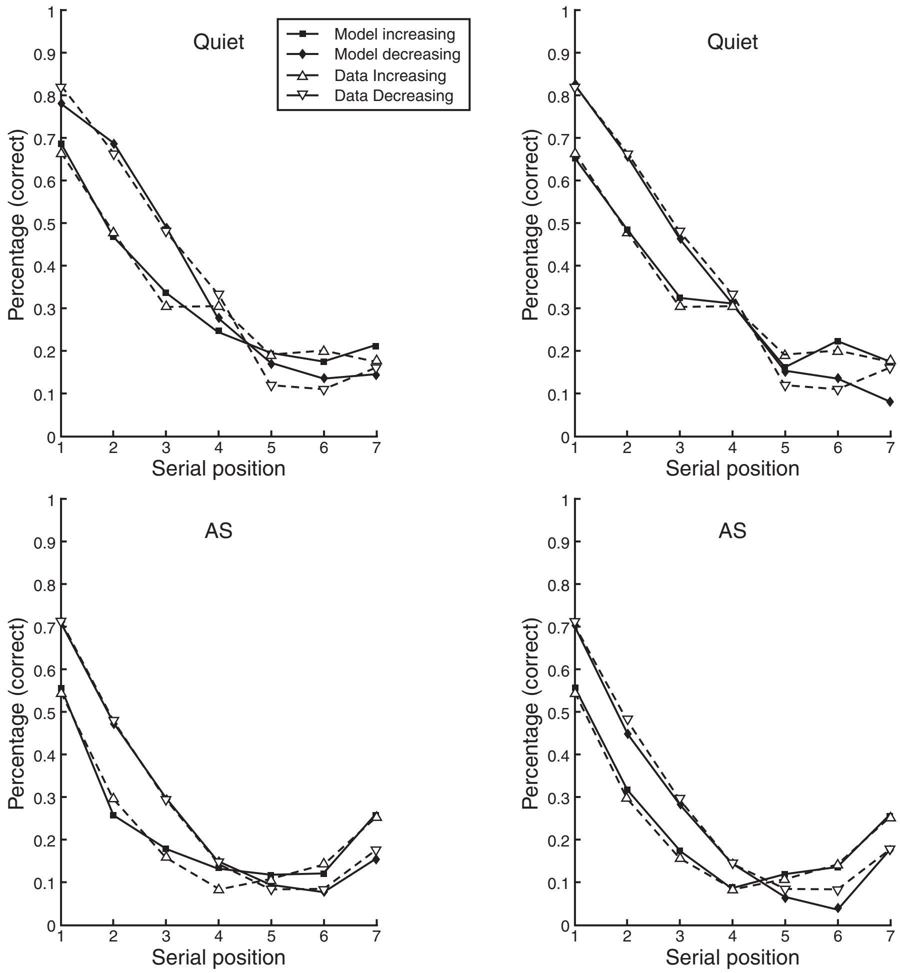

Figure 8.3 Fits of two versions of SIMPLE to the data of Experiment 2. The left panel shows the predictions of the time-based account and the right panel shows predictions of the event-based selective-encoding account. See text for explanation.

results (e.g., the distinctiveness parameter *c* was lower in the suppression condition). Of particular interest, the estimated weight on the temporal dimension, *wt*, was substantially greater than zero in both conditions, confirming that the model gives attentional weight to the temporal dimension in order to capture the effects of presentation schedule. Overall, then, the results are consistent with a time-based interpretation of the effects of increasing and decreasing presentation schedules, and with the Neath-Crowder interpretation.[3]

Selective-encoding account. For the alternative account based on selective encoding, the *wt* parameter was set to zero, which ensured that only position, and not time, played a role in memory. In addition, the probability of encoding of an item was hypothesized to be a function of its total

[3] Further simulations confirmed that the same temporal model could fit the data from Experiment 1; parameter and R2 values are shown in Table 8.1.

temporal isolation, such that terminal (early) list items in the decreasing (increasing) condition had little chance of being encoded, and conversely, early (terminal) items were certain to be encoded.[4] On each particular simulated trial, SIMPLE was presented with a list of only those items that were chosen for encoding according to those probabilities. In consequence, encoded lists were rarely of length seven and contained a variable number of items, with the majority of encoded items being those that were surrounded by longer intervals on the list. This encoding regime was thought to implement the strategies that participants in Experiment 2 reported during debriefing.

Because scoring of recall was with respect to the full seven-item lists, this mechanism necessarily produced a disadvantage for temporally crowded items. We estimated the encoding-probability parameter separately for each serial position, and then examined whether the resulting parameter estimates conformed to the prediction that encoding was less likely for items with reduced temporal isolation. Although the number of parameters is large compared to the number of data points, thus facilitating a good fit, the modeling strategy allows a test of the variable-encoding probability hypothesis without the need to make assumptions about exactly how encoding probability would change with temporal isolation.

The results, based on 5,000 replications in each case, are shown in the right panel of Figure 8.3. As expected, good fits were obtained.[5] Of greater interest is the set of estimated parameter values. For the middle five items (end items were not considered because they have only one neighbor), estimated encoding probabilities increased monotonically with temporal isolation, with the average estimates across conditions ranging from 0.56 and 0.57 for temporal isolations of 150 and 300 ms to 0.66, 0.68 and 0.70 for isolations 600, 1200 and 2000 ms, respectively. These estimates suggest that a total surrounding time of 0.5 s or greater substantially increased the probability that an item would be encoded.

Conclusions from modeling

The main role of the modeling was not to flesh out the particulars of each account, but to show that the data of Experiment 2 – and, by implication, the results of related precedents – are ambiguous and can be explained in two ways. Accordingly, we modeled the data in two ways with virtually equal quantitative precision: first, with a temporal-distinctiveness account as suggested by Neath and Crowder (1996), and second, with a selective-encoding account as suggested by the reports of our participants.

Although one may question the specific assumptions underlying our selective-encoding account, on the basis of the modeling there can be little doubt that predictable presentation schedules cannot provide unambiguous support for the role of temporal distinctiveness in short-term serial recall. Support for the notion of distinctiveness can only be drawn from studies in which selective encoding is disabled. An obvious way to disable selective encoding is by rendering

[4] Although we present this account by referring to selective *encoding*, we remain theoretically neutral as to whether the selectivity applies strictly to initial encoding or may involve some type of directed forgetting after initial registration of the stimulus. There is ample evidence that people can choose to discard information from memory after its initial registration (e.g., MacLeod 1998). Within SIMPLE, the two notions are indistinguishable and both converge on the representations that are being simulated here.

[5] The simulations required a very large amount of CPU time and in some cases it was necessary to terminate them when an R^2 value of 0.99 was reached. Further simulations confirmed that the same temporal model could fit the data from Experiment 1; parameter and R^2 values are shown in Table 8.1.

the interitem intervals within each list unpredictable. With unpredictable intervals, participants have no way of predicting whether particular serial positions will be well separated or crowded in time, thus preventing application of selective-encoding strategies. We next review a number of recent studies that have examined the role of temporal isolation with unpredictable intervals.

Unpredictable temporal isolation

Suppose a participant is presented with the list A. . . . .B. . .C. .D.E . . . .F, where the dots again correspond to units of time. According to a temporal distinctiveness theory, such as SIMPLE, recall of B should be better than recall of D because the former item is more temporally isolated than the latter. Suppose that list was followed by another one, such as A.B..C. . . ..D. . .E. . . .F, in which the intervals were unpredictably different. Again, the most isolated item should be recalled better than any of the others, even though the participant has no way of knowing ahead of time what interval to expect between items, thus precluding a strategic focus on well-separated portions of the list. A number of recent studies have used this paradigm in search of a temporal distinctiveness effect.

For example, Lewandowsky, Brown, Wright *et al.* (2005) used a methodology in their first study that was identical in most respects to the method of the present Experiment 1, except that participants were exposed to a different unique permutation of the six possible interitem intervals on each trial. In consequence, across replications, items in each serial position were preceded and followed by all possible intervals an equal number of times, thus permitting an unconfounded assessment of the effects of temporal isolation at each serial position. The results were quite clear: as shown by a regression analysis with interitem interval as the independent variable, performance generally did not improve with temporal isolation. Table 8.2 shows the estimated regression parameters, broken down by serial position and whether the interval in question preceded ('pre') or followed ('post') the item whose performance was predicted. The table also shows the range of intervals (in this case 50–1200 ms) by which items were separated. It will be noted that isolation did have an effect at serial position four; further analysis revealed that this effect was due to people's subjective grouping of the seven-item list with the item in position four at the group boundary. Only those participants who were identified by independent means as grouping the list contributed to the effect whereas those who did not group the list also did not show an isolation effect in position four.

Lewandowsky *et al.* reported a second experiment that also used unpredictable intervals, but in which participants on each trial were probed to recall only one randomly chosen item. This probed-recall procedure was used to eliminate output interference, which might have overshadowed any small effects of isolation in their first study. As shown in Table 8.2 (which also summarizes all remaining experiments), the elimination of output interference did not lead to the emergence of an isolation effect; performance continued to be unaffected by temporal isolation.

The intervals used by Lewandowsky *et al.* (ranged from 50 to 1200 ms. Although the present experiments confirm that this range was sufficiently large to create a reliable effect of isolation when intervals are predictable, the range may have been too constrained to permit an effect to emerge when intervals were unpredictable. Nimmo and Lewandowsky (in press b) addressed this possibility in a study with intervals spanning the range 50 ms through 4000 ms. Again, no effect of temporal isolation was observed; an item that was followed by a blank interval of 4 s was recalled as well as an item that was followed 50 ms later by another study item.

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There is some suggestion that temporal isolation effects are larger when material is presented auditorily than when it is presented visually (e.g., Glenberg and Swanson 1986). Although this

Table 8.2 Regression estimates for the effects of temporal isolation in studies with unpredictable interitem intervals

Study[a]	Experiment/ condition	Intervals (ms)	Serial position	Parameter estimate Pre	Post
LBWN	1/Quiet	50–1200	2	–0.0003	–0.0003
			4	–0.025	0.054*
			6	–0.014	–0.0008
	1/AS	50–1200	2	0.028	0.009
			4	0.060*	0.056*
			6	0.006	0.014
LBWN	2	50–1200	all	0.005	
NandL1	Quiet	50–4000	2	–0.003	–0.004
			4	–0.000	0.013
			6	–0.017	0.002
	AS	50–4000	2	–0.016	0.019
			4	0.05	0.019
			6	0.022	0.004
NandL2	1/Auditory	450–1600	all	0.016	0.018
	1/Auditory	450–4400	all	0.010	0.003
	2/Auditory	125–4000	all	0.003	0.008*
	2/Visual	125–4000	all	0.001	0.005
PKD	Auditory verbal	50–950	all	–0.36	0.11
	Spatial nonverbal	50–950	all	–0.27	–0.02
Average (SD)				–0.0289 (0.1036)	0.0165 (0.0289)

* $p < 0.05$.

[a] LBWN = Lewandowsky, Brown, Wright *et al.* (2005); NandL1 = Nimmo and Lewandowsky (in press b); NandL2 = Nimmo and Lewandowsky (in press a); PKD = Parmentier *et al.* (in press).

modality difference remains contentious because it is not supported by all available evidence (e.g., Crowder and Greene 1987; Neath and Crowder 1990), it must be noted that the present experiments and all studies reviewed this far have exclusively used visual presentation. Nimmo and Lewandowsky (in press a) addressed this issue by comparing auditory and visual presentation in several experiments with unpredictable interitem intervals. In neither study was there any difference between modalities: temporal isolation had no substantial effect on recall (although one of the experiments by Nimmo and Lewandowsky was powerful enough to detect an effect of the post interval with auditory presentation whose magnitude was 0.8 of a per cent performance improvement per second isolation. We do not consider this effect to be sufficiently large to provide strong support for the notion of distinctiveness).

The finding by Nimmo and Lewandowsky that temporal isolation has no effect even when stimulus presentation is auditory was replicated by Parmentier, King and Dennis (in press).

The study by Parmentier *et al.* also differed from related precedents in two important ways: first, they used a reconstruction task in all conditions. In a reconstruction task, the list items are re-presented in random order at retrieval, thus eliminating the need for item memory, and participants merely indicate (e.g., by mouse click) the order in which items were originally presented. Second, in one of their conditions, lists consisted not of verbal material but of short bursts of white noise that were presented in different spatial locations. Participants had to reconstruct the order of those locations, and performance was again found to be impervious to temporal isolation.

Overall, there is now considerable and wide-ranging evidence that temporal isolation does not benefit short-term memory for serial order. This conclusion holds regardless of modality (auditory vs visual); material (letters vs digits vs bursts of noise); type of retrieval task (serial recall vs probed recall vs reconstruction); and across a wide range of intervals (from 50 ms through 4.4 seconds). To provide a quantitative impression of this conclusion, Table 8.2 also reports the average estimates, across all analyses, of the regression parameters for the pre and post intervals together with their standard deviations. Although this average is not sensitive to variables such as sample size and other slight differences between experiments, it provides a useful summary of the results overall and provides a guide to the magnitude of the effect. In particular, the summary clarifies that there is no reason to suspect that a large and theoretically important effect of temporal isolation might be lurking underneath the repeated report of individual null results: if the overall estimates for pre and post are in turn averaged to provide a single index of the effect of temporal isolation, that index differs trivially (and negatively) from zero.

Conclusions

We close by drawing three principal conclusions:

1. A brief review of the recent relevant literature shows that temporal isolation does not play a role in memory for serial order over the short term.
2. Modeling using SIMPLE confirmed that previous experiments that purport to show effects of temporal isolation in serial recall are ambiguous, even though we report two studies that undermine the case for rehearsal as an alternative explanation of isolation effects.
3. On the basis of a comparison between the present studies and others in which intervals are unpredictable, we suggest that any existing effects of temporal isolation at encoding can be ascribed to strategic effects such as selective encoding.

The three preceding conclusions have associated with them at least one clear boundary condition: they are limited to situations in which memory for the order among items is important and in which participants have no control over the order in which items are reported. That is, all the material reviewed here involved either serial recall, in which items must be reported from the beginning of the list to its end, probed recall in which a single item must be reported in response to a cue (i.e., the preceding list item), or serial reconstruction in which people have to select items for report in the order in which they were initially presented. We make no claim that the observed absence of isolation effects would also occur in paradigms such as free recall, in which people are free to report items in any order. When report order is free, additional opportunities arise for isolation to have a beneficial effect. For example, people may choose to report isolated items first, thus protecting them against the effects of prolonged output interference. Given the rather large literature on isolation effects in free recall, there is every possibility that report order may turn out to be an important variable that determines whether or not temporal isolation benefits memory.

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