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Serial recall and presentation schedule: A micro-analysis of local distinctiveness

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According to temporal distinctiveness theories, items that are temporally isolated from their neighbours during presentation are more distinct and thus are recalled better. Event-based theories, which deny that elapsed time plays a role at encoding, explain isolation effects by assuming that temporal isolation provides extra time for rehearsal or consolidation of encoding. The two classes of theories can be differentiated by examining the symmetry of isolation effects: Event-based accounts predict that performance should be affected only by pauses following item presentation (because they allow time for rehearsal or consolidation), whereas distinctiveness predicts that items should also benefit from preceding pauses. The first experiment manipulated inter-item intervals and showed an effect of intervals following but not preceding presentation, in line with event-based accounts. The second experiment showed that the effect of following interval was abolished by articulatory suppression. The data are consistent with event-based theories but can be handled by time-based distinctiveness models if they allow for additional encoding during inter-item pauses.

Is the encoding of information in memory sensitive to time? Does it matter whether two events are presented in close succession or are spaced apart in time? What happens if an event is followed by a long pause? Or when a pause precedes presentation? The issue of what role, if any, time plays in memory is currently subject to intense debate (e.g., Brown & Chater, 2001; Nairne, 2002), with proponents arguing that timing and memory are closely and crucially linked (Brown & Chater, 2001) and others providing evidence against this proposition (e.g., Henson, 1999; Nairne, 2002). This article explores the issue further in two experiments that examined short-term serial recall performance as a function of the randomly varying temporal separation of items at study.

According to one class of memory models, labelled "temporal distinctiveness models" in this article (e.g., Baddeley, 1976; Bjork & Whitten, 1974; Brown, Preece, & Hulme, 2000; Crowder, 1976; Glenberg & Swanson, 1986; Neath, 1993), the temporal separation of events at encoding is a crucial determinant of memory performance. All other things being equal, distinctiveness models predict that the memorability of an event increases with its temporal separation from neighbouring events.

A variant of the temporal distinctiveness hypothesis was recently instantiated in the

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SIMPLE (*S*cale *I*nvariant *M*emory, *P*erception, and *LE*arning) model of Brown, Neath, and Chater (2002). In SIMPLE, items are confusable with other items in memory, and hence difficult to retrieve, to the extent that they are temporally close when considered from the retrieval perspective. More specifically, the confusability between any two memory items, $S_{i,j}$, is related to the (exponentiated) ratio of the time that has elapsed between their encoding and the time of recall. This mechanism favours recent items over more distant events, and it also favours items that were separated in time over others that occurred in close succession. Concerning recency, items that occurred 1 s and 2 s ago are less confusable ($.5^c$) than are items from 5 and 6 seconds ago ($.83^c$), where *c* is the main free parameter of the model. Concerning temporal separation, items that occurred 5 s and 10 s ago ($.5^c$) are less confusable than items that occurred 7 s and 8 s ago ($.88^c$), notwithstanding the equal average retention interval. Because confusability is inversely related to recall probability, items from further in the past, and items that occurred nearby in time, will be more difficult to recall (see Brown et al., 2002, for further details).

One critical feature of SIMPLE, which is at least tacitly shared by other distinctiveness models, is that temporal neighbours on both sides of an item will contribute to its distinctiveness. That is, an item's distinctiveness is a function of the temporal gap *preceding* its presentation as well as that following it. For example, consider the list A B . . . C . . . D E, where ''. . .'' represents a brief temporal gap, perhaps on the order of less than a second. According to SIMPLE, item C would be most distinctive because it was temporally isolated from both its predecessor and successor, and items B and D would be of intermediate distinctiveness (compared to A and E) because they were followed and preceded, respectively, by a temporal gap. (Here we ignore the complications of edge effects and the change of temporal distances throughout retrieval.)

These predictions are not unique to SIMPLE: Most models that acknowledge a role of time at encoding would expect recall to be better for items surrounded by pauses. For example, the model by Burgess and Hitch (1999) postulates that encoding and retrieval are governed by a context window that slides, over time, across a set of context units to which events are associated. It follows that the basic mechanism underpinning the Burgess and Hitch model should predict symmetrical isolation effects, although as we note below additional factors such as response suppression may influence detailed predictions. Similar arguments can be advanced for OSCAR (Brown et al., 2000), which also associates events to a timing signal. Because the similarity between two states of the timing signal decreases with temporal separation, OSCAR also predicts that gaps between items enhance their uniqueness—and hence potential retrievability.

Theories that acknowledge the role of time at encoding stand in contrast to another class of models, which we call ''event-based'', that assign little or no importance to the passage of time *per se* (e.g., Farrell & Lewandowsky, 2002; Henson, 1998; Lewandowsky & Murdock, 1989; Murdock, 1995; Nairne, 1990; Neath, 1999). That is, although these models acknowledge that many memory phenomena—such as forgetting—are observed over time, they consider the passage of time to be epiphenomenal rather than causal.

One recent instantiation of this view is the SOB (*S*erial *O*rder in a *B*ox) model of Farrell and Lewandowsky (2002). According to SOB, events are added to a composite distributed memory in the order of their occurrence, without regard to their temporal separation. The resulting composite trace is ahistorical and contains no temporal information. For a list such as the earlier A B . . . C . . . D E, event-based models might assume that people use the gaps during presentation 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 simply use the time for additional rehearsal. In this article, we are not concerned about the exact nature of such post-presentation consolidation process, and we refer to it generically as ''rehearsal''.

On the rehearsal view, in the preceding list item B (and perhaps A) would be given additional rehearsal before C is presented, and C would be rehearsed before D and E appear. It follows that B and C (and possibly A) would benefit from the extra rehearsal that is possible during the pauses in the list, whereas item D would not—because the interval preceding it is used for rehearsal of earlier items without contributing to better encoding of D.

The specific mechanism by which this account could be implemented varies between models. In SOB (Farrell & Lewandowsky, 2002), rehearsal would be assumed to increase the encoding strength of an item relative to others. Similarly, in SEM (Henson, 1998), the positional signal provided by the start and end markers could be elevated for items that had received additional rehearsal.

Although several studies have manipulated presentation schedules (e.g., Bjork & Whitten, 1974; Crowder & Neath, 1991; Neath & Crowder, 1990, 1996), none of them can serve to adjudicate between the two predictions just outlined. In the study by Bjork and Whitten, the pauses between all list-items were equal (negligible in one condition or 12 s of mental arithmetic in another), and in the studies by Neath and Crowder, inter-item intervals either systematically increased or decreased across serial position—the temporal isolation of any given item was thus perfectly correlated with its serial position and the duration of neighbouring intervals. We now present two experiments that deconfounded the duration of intervals preceding and following a given item.

EXPERIMENT 1

In Experiment 1, people had to recall nine-letter lists immediately upon presentation in the correct order. Intervals between list items randomly varied between 50 ms and 950 ms.

Method

Participants and apparatus. A PC presented lists, and scored and timed responses entered on the keyboard. The 12 participants received course credit or were remunerated at A$10/hr. The experiment lasted approximately 45 minutes.

Stimuli. The experiment involved 120 lists, each constructed by randomly sampling nine unique items from a set of 19 letters (all consonants except Q and Y).

Common to all lists was the total presentation duration of 5100 ms, which consisted of a constant 300 ms presentation time for each item, plus randomly varying inter-item intervals. Intervals were sampled from a uniform random distribution subject to the constraints that none could be less than 50 ms and that they had to sum to 2400 ms. The average inter-item interval across trials and participants ranged from 295 ms to 303.5 ms across serial positions (M = 299.5 ms). The shortest interval was 50 ms for all serial positions and the longest interval ranged from 796 ms to 937 ms across serial positions (M = 844.1 ms).

Procedure. Participants were tested individually in a sound-attenuating booth. The experimenter remained present during five initial practice trials.

Each trial was preceded by a 2000 ms blank screen, which was followed by the list items, presented one at a time in the centre of the screen for 300 ms. The last item was followed by a 150 ms blank screen and then a row of asterisks. After 900 ms, the asterisks were replaced by a blinking cursor to prompt keyboard recall. Responses remained visible as they were typed. After the last response, the screen was cleared and the next trial commenced.

Participants could not correct a response once entered. A self-paced break was provided after 60 trials. Instructions emphasised both accuracy and latency. Participants used the space bar to indicate an omission.

Results

For all analyses, responses in the first output position with a latency of less than 100 ms were considered ‘‘type-aheads’’ and were classified as an omission. Any non-zero latency was accepted for later responses. All analyses used strict positional scoring, such that a response was considered correct only if the item was recalled in its correct position.

Overall accuracy analysis. Figure 1 shows the serial position curve (top panel). The slight discontinuities at positions 3 and 6 suggest that people may have spontaneously grouped the lists into chunks of three items. In confirmation, the transposition error gradients (not shown) also showed the scalloped form characteristic of grouping (e.g., Ryan, 1969).

Accuracy and temporal distinctiveness. This analysis examined recall accuracy as a function of the time interval between the item in question and its preceding (‘‘pre’’) and following (‘‘post’’) list neighbour. A hierarchical regression model (also known as multi-level regression) was fitted to all participants simultaneously using pre and post as predictors.

The analysis focused on items in serial positions 2, 4, 6, 8, which ensured that each inter-item interval entered into a prediction once only. Thus, the interval between the first and second list item was used as a "pre" predictor for performance in serial position 2, whereas the interval between the second and third item was used as "post" predictor for the same serial position, and so on for the remaining critical items. Critical responses of each participant were classified according to their pre and post intervals into a 6 × 6 grid using a 100 ms stepsize. Thus, each cell of the grid was defined by a unique combination of pre and post intervals on a 100 ms timebase and contained the proportion of correct responses, which served as the dependent measure. Cells with fewer than eight observations (all involving pre or post in excess of 600 ms) were omitted from the analysis. This yielded between 21 and 27 usable records per participant ($M = 24$, $s = 1.65$, range 21–27).[1]

The data were analysed using hierarchical regression (Busing, Meijer, & van der Leeden, 1994), which permits analysis of the aggregate data without confounding between- and within-participant variability. Regression coefficients are estimated for each participant separately, but statistical significance relies on their overall pattern across individuals. This avoids potential pitfalls in situations in which a number of individuals contribute multiple observations each to a regression (Lorch & Myers, 1990).

The regression model examined here included an intercept plus parameters for pre and post. The maximum likelihood estimates of those parameters (see Busing et al., 1994, for computational details), averaged across participants, were 0.304, 0.001, and 0.012 for intercept, pre, and post, respectively. The associated t-values were 9.36 ($p < .0001$), 0.14 ($p > .10$), and 2.20 ($p < .03$), respectively. This indicates that the effect of temporal isolation was asymmetric: Recall of an item was not affected by a preceding pause, but it did benefit from delayed presentation of subsequent items. Specifically, every 100 ms of additional post-presentation pause increased recall by some 1.2%.

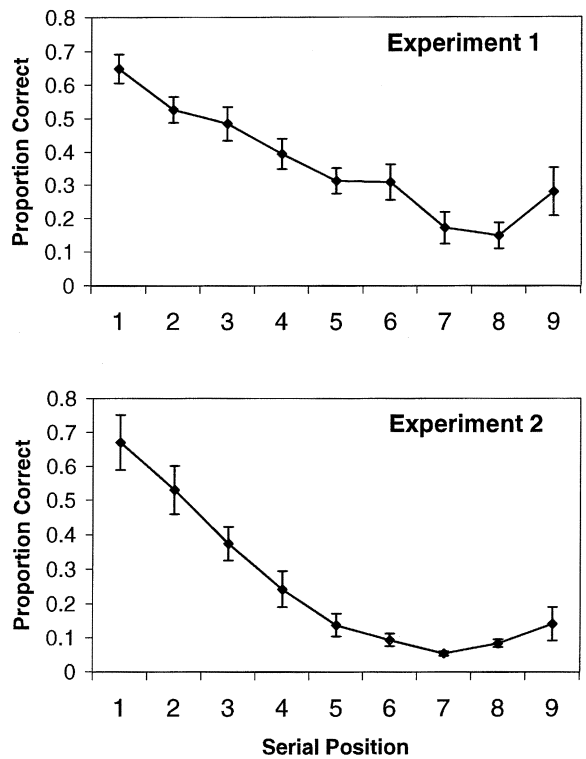

Figure 1. Accuracy serial position curves for Experiment 1 (top panel) and Experiment 2 (bottom panel).

The consistency and magnitude of this effect is illustrated in Figure 2, which shows the individual pre and post parameter estimates. The figure shows that the estimates for post were positive for 10 out of the 12 participants (and negative but close to zero for the remaining two), whereas the estimates for pre hovered near zero for all participants.[2]

The two participants (7 and 11) with negative estimates of post also had negative estimates for pre and the lowest intercepts (.192 and .184,

[1] The randomisation procedure was checked by computing average serial positions for each cell of the pre × post grid (aggregating across trials and participants). Perfect randomisation would correspond to a serial position of exactly 5 in each cell (given that positions 2, 4, 6, 8 were considered). The observed average across all cells in the grid was 4.98, with a standard deviation of 0.20. It follows that serial position was adequately controlled and could not affect the regression analysis.

As a further check, the number of cell entries in the pre × post grid was subjected to a χ^2 analysis. The randomisation procedure should have prevented any association between the pre and post durations. Accordingly, although the test statistic was significant, $\chi^2(25) = 274.8$, $p < .0001$, the degree of association between the two types of interval was low (Cramer's V = .107). Because χ^2 is notoriously sensitive to sample size, Cramer's V is considered a better measure of association (e.g., Howell, 2002).

[2] One might argue that the subjective grouping of the list into chunks of three items, which is suggested by the serial position curves and the transposition gradients, could somehow obscure or counteract an effect of pre. However, we consider this unlikely: One of the critical serial positions (position 4) was at the beginning of a subjective group and one was at the end (position 6). Hence subjective grouping had an equal chance to override an effect of pre as well as post—we nonetheless only observed an effect of post.

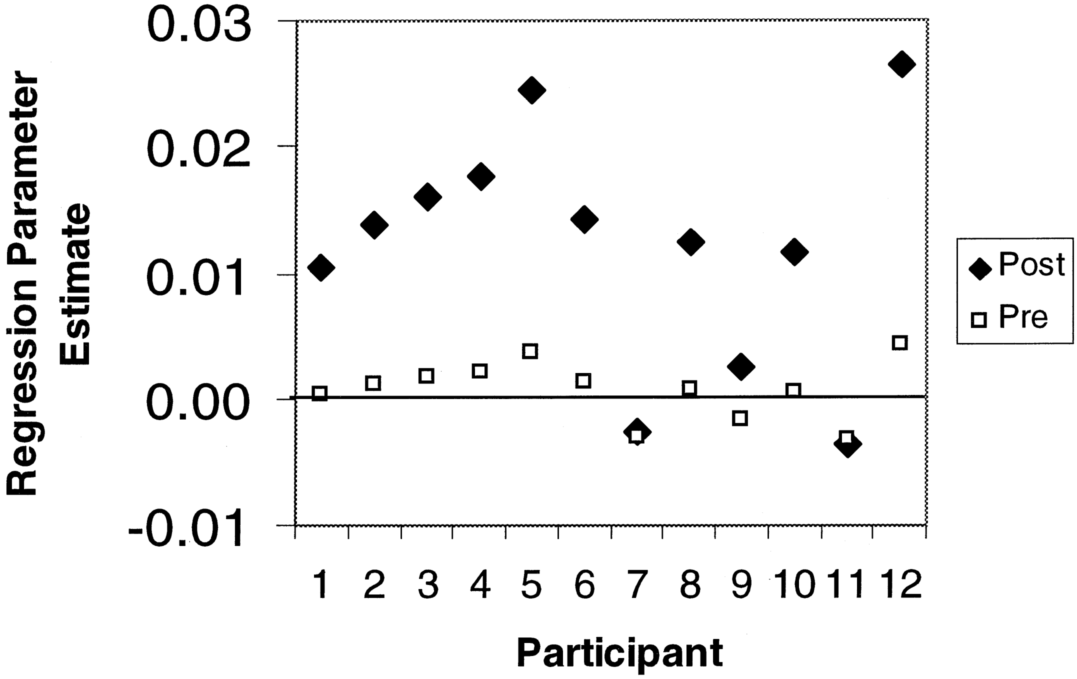

Figure 2. Individual hierarchical regression estimates of parameters (for pre and post) for all participants in Experiment 1.

respectively). These intercepts fell some 1.5 standards deviations below the mean of .304, raising the possibility that these two individuals did not show a post effect because their performance was, functionally, at floor. Indeed, the intercepts reveal an overall recall level of less than 20%, which must be considered marginal for a nine-item list (even though the first and last positions are not among the critical observations).

Discussion

The key novel finding from Experiment 1 is that the probability of item recall is affected by the duration of the gap following an item, but not by the duration of the gap preceding it. This result presents a particular challenge to SIMPLE (Brown et al., 2002) and has implications for temporal distinctiveness models generally. After presentation of the next experiment, we examine whether an augmented version of SIMPLE might account for our results.

The results are compatible with an event-based account, according to which temporal gaps after presentation of an item permit additional rehearsal, or further consolidation of encoding, of earlier information. According to the rehearsal account, but not temporal distinctiveness, the effect of post should be reduced when rehearsal and/or consolidation during the inter-item gaps is prevented. We therefore repeated Experiment 1 with the inclusion of just such a manipulation: Articulatory suppression during list presentation.

EXPERIMENT 2

Method

Participants and apparatus. A new sample of 12 members of the campus community participated for remuneration at the rate of A$10/hr.

Stimuli and procedure. The stimuli and procedure were identical to those of the first study with one exception. During list presentation, rehearsal was prevented by asking participants to repeat the word "sugar" out loud. Articulation commenced with the beginning of list presentation and ended with the recall prompt.

Results

Data from two participants had to be eliminated because they clearly did not attempt to recall the list on most trials. The data from the remaining 10 participants were analysed in the same manner as for the first study.

Overall accuracy analysis. The serial position curve is again shown in Figure 1 (bottom panel). Unlike the first experiment, neither the serial position curve nor the transposition gradient (not shown) suggested any spontaneous grouping of the list into identifiable chunks. This is consistent with previous results showing that articulatory suppression during visual presentation abolishes (or at least reduces) the effects of temporal grouping (Hitch, Burgess, Towse, & Culpin, 1996; however see Klapp, Marshburn, & Lester, 1983).

Accuracy and temporal distinctiveness. As for the first experiment, a hierarchical multiple regression model was fitted to all participants simultaneously using pre and post as the predictors of interest. Cells with fewer than eight observations were again omitted from the analysis. This yielded between 21 and 27 usable records per participant ($M = 23.7$, $s = 1.73$).

The average maximum likelihood estimates of the regression parameters were 0.237, 0.002, and −0.002 for intercept, pre, and post, respectively. The associated t-values were 5.22 ($p < .0001$), 0.38 ($p > .10$), and −0.23 ($p > .10$), respectively. The underlying individual parameter estimates for pre and post are shown in Figure 3. In contrast to the first experiment, there was no effect of either interval in this study. Articulatory suppression therefore abolished not only grouping but also any local effect of temporal distinctiveness.

It is tempting to question whether articulatory suppression might similarly abolish the temporal distinctiveness effects observed in the studies of Neath and Crowder (e.g., 1996) using increasing and decreasing presentation schedules. This would be particularly informative because Neath and Crowder (1996) argued that rehearsal played no role in their findings.

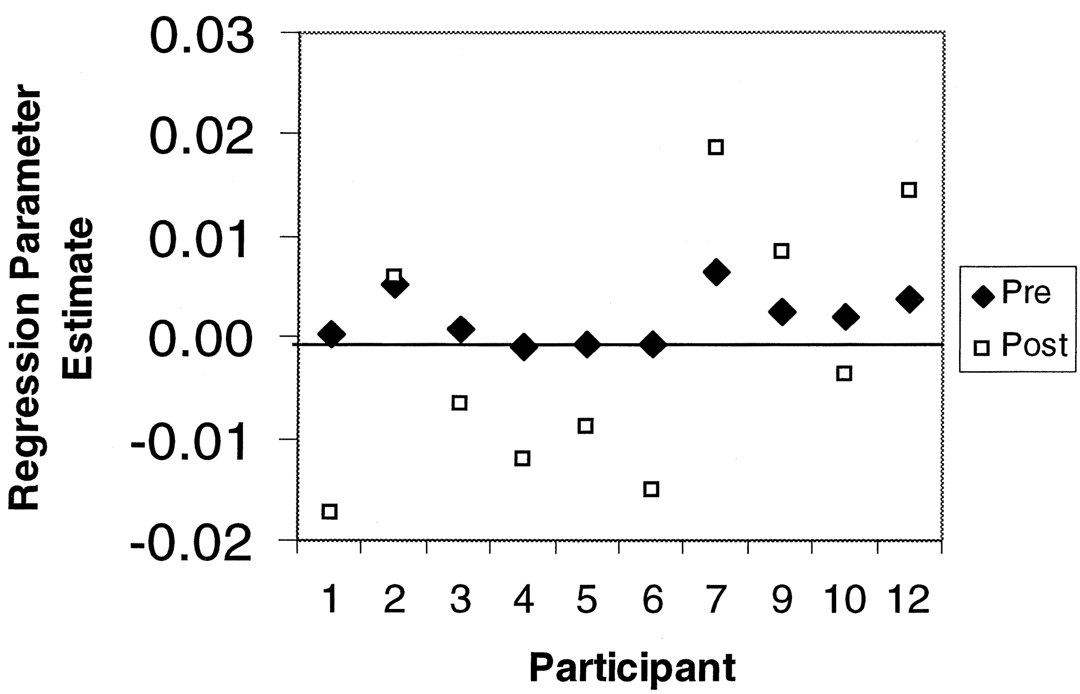

Figure 3. Individual hierarchical regression estimates of parameters (for pre and post) for all participants in Experiment 2.

Discussion and simulation

The results of Experiment 2 support an event-based account and are difficult to reconcile with an unmodified temporal distinctiveness model. Instead, the results highlight the potential importance of consolidation or rehearsal in determining performance. We therefore examined whether modifications to a temporal distinctiveness model (SIMPLE) might shed light on the observed pattern of pre and post correlations. More specifically, we explored the possibility that the inclusion of additional encoding in the gaps following an item might enable SIMPLE to account for the observed asymmetrical effect of inter-item pauses.

The complete implementation of SIMPLE incorporates a number of parameters to accommodate omissions, intrusion errors, the multi-dimensional nature of stimuli, and proactive interference from previous lists (see Brown et al., 2002, for details). Our concern here is with the qualitative behaviour of the model, and with the effects of encoding strength. We therefore implemented a basic two-parameter version of SIMPLE within which to explore the role of post-presentation consolidation. This facilitates understanding of the model's behaviour, albeit at the expense of detailed data fitting.

The probability R_i of recalling item i of n given the temporal distance of item j (TD_j) from the point of retrieval as a cue is:

$$P(R_i \mid TD_j) = \frac{S_{i,j}}{\sum_{k=1}^{n} S_{i,k}}$$

where, as described earlier, the confusability between any two memory items, $S_{i,j}$, is the ratio of their temporal distances (shorter/longer) raised to the power c. This means that the probability of recalling a given item in its correct serial position is simply inversely proportional to its summed confusability with all other list items. The parameter c is central to the behaviour of the model. As c becomes larger, the confusability between items decreases more quickly as a function of their temporal separation, and memory performance increases.

In understanding the model's behaviour, it is important to note that the temporal distance of an item, TD_j, is measured from the time that that particular item is retrieved. In serial recall experiments such as those reported here, recall may be slower than presentation, and hence extended primacy may result as the temporal distance at the time of retrieval is greater for late-presented items than for early-presented items. In the present simulations we assumed a 100 ms retrieval time for the first item recalled, and an additional 750 ms for each subsequent item. This approximates the observed recall latencies for correct recalls. In all other respects the temporal protocol in the model mirrored the experimental conditions precisely.

We implemented in SIMPLE the new assumption that rehearsal or consolidation of a briefly presented item in memory can occur in the interval following an item's offset. The potential for such rehearsal is assumed to be reduced under articulatory suppression. Such an assumption, although post-hoc in the present context, has some plausibility. Indeed, in the limit, when items are presented very briefly or even tachistoscopically, it would be highly unlikely if processing and consolidation did not continue to occur after item offset.

It is straightforward to model encoding strength in terms of variations in the c parameter for a given item. Additional encoding is assumed to increase the distinctiveness of an item, and this is implemented in the model by increasing c just for that item. It was assumed that additional encoding could (in the absence of articulatory suppression) occur during the post-item gap. Thus the encoding strength (= c) for a given item was made up of two components. One component reflected encoding during item presentation; that amount of encoding depends on the presentation duration but in the current simulation this was the same for every item. The second component reflected consolidation during the post-item gap; this encoding increased with post-item gap duration but could only occur in the absence of articulatory suppression. Regarding this second component, the c parameter for a given item was increased as an exponential function of the post-item gap, such that c increased monotonically with post-item gap but gradually reached asymptote.

More specifically, the value of c for item i was:

$$c_i = C \times (1 - e^{(-p_i/2)}) + K \times C \times (1 - e^{(-g_i/2)})$$

where p_i is set to a constant 0.3 (the item presentation duration throughout) and g_i is the duration of the gap following item i (assumed to be a constant .15 s for the final item). The first part of the equation represents encoding strength achieved during item presentation; the second part of the equation represents consolidation achieved during the post-item gap. The parameter K governs the extent of consolidation such that when $K = 0$ (simulating articulatory suppression), no consolidation occurs and c_i is constant (being determined solely by the item presentation duration). As K increases to 1 (simulating decreasing amounts of articulatory suppression), more and more consolidation (= incrementation of c_i) is assumed to occur during the post-item gap.

The resulting pre and post correlations in the model, with C set to 40, are illustrated in Figure 4. The pattern is exactly as expected. Under simulated articulatory suppression, there is little effect of post because no rehearsal occurs during and in proportion to the post gap. As simulated articulatory suppression is reduced, additional encoding occurs during the post-item gap, and the extent of this consolidation increased monotonically with gap duration.

We did not attempt detailed model fitting as additional parameters are required to do so. However, the model generated appropriate serial position curves (extended primacy and very limited recency) and reasonable overall levels of performance. Better fits could be obtained with a more highly parameterised model, but the inclusion of additional parameters would obscure the point at issue.

We note that the account we have given is not the only possible model. Response suppression, an important factor in many models (e.g., Brown et al., 2000; Burgess & Hitch, 1999; Farrell & Lewandowsky, 2002; Henson, 1998; Lewandowsky, 1999; Lewandowsky & Murdock, 1989; Nairne, 1990; Page & Norris, 1998; Vousden & Brown, 1998) could play a role in explaining these results. If recalled items are removed from a retrieval set after output, or their strength is reduced, they will not be strong competitors during recall of subsequent targets and hence their temporal proximity to targets will be less relevant. Thus it would be expected that the pre correlations would be reduced as response suppression increases in the model. This expectation was confirmed by simulations (not reported here due to space limitations) although those simulations also revealed a suppression-induced increase in recency at odds with the data.

GENERAL DISCUSSION

The empirical contribution of this article is readily summarised: Experiment 1 showed that when factors such as serial position and output position are controlled, memory for an item benefits from

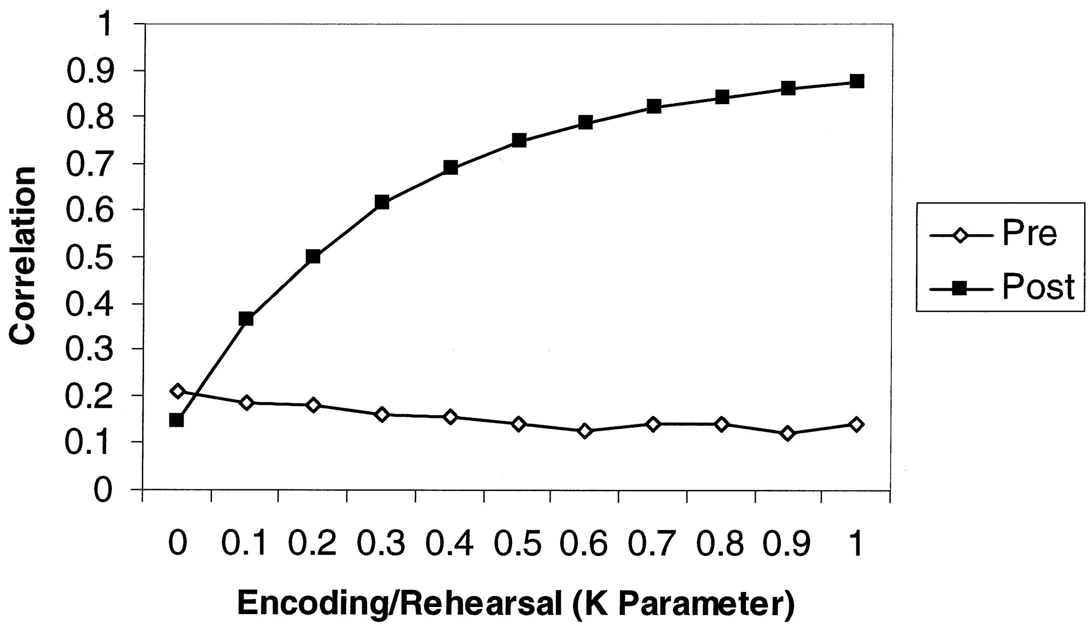

Figure 4. Correlation between pre or post with item recall probability as a function of amount of simulated articulatory suppression in SIMPLE.

brief temporal pauses after its presentation (an effect of post) whereas memory is unaffected by pauses preceding presentation (no effect of pre). Experiment 2 showed that articulatory suppression during presentation eliminates the effect of post.

The results of both experiments are compatible with event-based accounts that postulate rehearsal or consolidation during unfilled intervals following an item. Unless disrupted by articulatory suppression, this rehearsal is a regular component of encoding. To date, it has not been observed because our studies are the first to disentangle pre and post intervals and to manipulate inter-item intervals independently of input and output position.

By the same token, the results are at odds with symmetrical temporal distinctiveness, as embodied in SIMPLE (Brown et al., 2002), which would predict an effect of both pre and post irrespective of articulatory suppression—a prediction that was clearly disconfirmed by both experiments. Nonetheless, SIMPLE can be augmented to accommodate the present findings. The absence of a pre effect in Experiment 1, and the additional absence of a post effect in Experiment 2 under articulatory suppression, can be handled by assuming that rehearsal is disrupted by articulation. Within SIMPLE, the disruption of rehearsal was modelled by reducing the amount by which item distinctiveness increased during the post-item gap.

Finally, the fact that neither experiment revealed an effect of pre must be contrasted with the large and universal effect of temporal grouping (e.g., Henson, 1999; Hitch et al., 1996; Ryan, 1969). Indeed, grouping can be considered a ‘‘pre effect’’ *par excellence*: The first item in each group benefits from the temporal pause that precedes it, as revealed by the ‘‘mini’’ within-group primacy. How, then, can the absence of a pre effect in the present studies be reconciled with grouping?

Our preferred explanation suggests the involvement of a top-down component in the encoding of temporally grouped lists that is absent in the present studies. There is considerable support for this assumption. First, at a theoretical level, encoding of grouped lists in SIMPLE requires a second dimension of distinctiveness that is orthogonal to time and represents position-within-group. This additional dimension proved necessary to account for transposition errors that preserve within-group position (e.g., Ryan, 1969). Second, evidence from the first author’s laboratory shows that people’s grouping of a list can be completely at odds with its physical characteristics: In an unpublished experiment, people received numerous trials on which nine-item lists were temporally grouped in threes, before the physical grouping slowly changed, in small increments, to a 2-2-2-2-l structure. Even after numerous trials on this new structure, people continued to group the list in threes, as evidence by the transposition gradients and serial position curves. Third, on balance, articulatory suppression does not abolish grouping for visually presented lists. Although Hitch et al. (1996) reported a much-abated grouping effect with articulation, Klapp et al. (1983) and Frick (1989) reported its persistence under similar circumstances. Finally, Ryan (1969) found that the magnitude of the grouping effect did not differ with the duration of the pauses (0.9 s vs 3.4 s). If grouping reflected simple local distinctiveness, the duration of the pauses should have made a difference.

In conclusion, if an item benefits from a preceding pause, this likely reflects a top-down processing strategy that is engaged when the physical list structure is regular and predictable or when people are highly practised in chunking. When this top-down process cannot be applied because the list structure is random, pauses preceding an item have no beneficial effects. By contrast, irrespective of predictability, people can use pauses that follow an item to rehearse or consolidate already encoded information, unless this is prevented by articulatory suppression.

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