

# From brief gaps to very long pauses: Temporal isolation does not benefit serial recall

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Theoretical explanations of short-term memory for serial order can be classified on the basis of whether or not they invoke time as a causal variable. According to time-based accounts, such as temporal distinctiveness theories, there is an intimate link between time and memory. Event-based theories, by contrast, postulate processes such as interference or rehearsal to account for seemingly temporal phenomena in short-term memory. We report an experiment that examined whether extended temporal isolation benefits serial recall performance. Regardless of whether the participants were quiet or performed articulatory suppression during list presentation, temporal isolation did not benefit memory even if items were separated from their neighbors by up to 7 sec. These findings challenge time-based theories of short-term memory.

The ability to sequentially order behavior underlies many everyday cognitive activities, including the ability to converse with others (e.g., Brown, Preece, & Hulme, 2000). Given the obvious importance of human language, much research has focused on memory for serial order, and numerous theories have been designed to explain performance in the primary manifestation of short-term order memory—namely, serial recall. One important distinction between the various theories concerns whether or not they invoke time as a causal variable.

One class of theories (e.g., Brown, Neath, & Chater, 2002; Burgess & Hitch, 1999) is built around the premise that time and memory are intimately linked. According to these time-based theories, the fact that items are recalled better if they are widely separated in time rather than temporally crowded (e.g., Glenberg & Swanson, 1986; Neath & Crowder, 1990, 1996; Welte & Laughery, 1971) is interpreted as reflecting the unique role of time as a cue during encoding and retrieval. Two particularly clear demonstrations of the beneficial effects of temporal isolation were reported by Welte and Laughery (1971) and Neath and Crowder (1996). In both studies, participants were presented with lists in which the interitem intervals (ITIs) either sequentially increased (e.g., A•B••C•••D) or sequentially decreased (e.g., A•••B••C•D) across serial positions. Both studies found a memory advantage for items that were temporally isolated from their neighbors, such that the decreasing lists led to better performance

than the increasing lists at early serial positions, and vice versa for the last serial positions.

Event-based theories (e.g., Farrell & Lewandowsky, 2002; Murdock, 1993; Nairne, 1990), by contrast, explain memory without reference to time. Accordingly, event-based theories ascribe the beneficial effects of temporal isolation as observed by Welte and Laughery (1971) and Neath and Crowder (1996) to nontemporal processes. For example, in the study by Welte and Laughery, intervals between items were up to 1,900 msec long, thus arguably providing ample opportunity for rehearsal or some other consolidation process to boost memory for the preceding, temporally isolated item. Similarly, although rehearsal was precluded in the study by Neath and Crowder because the intervals were far shorter (the entire five-item list was presented in little over 1 sec), the fact that each trial's ITIs were predictable from the gap between the first two items may have encouraged a selective encoding strategy, with participants memorizing only those items that they knew to be widely separated.

Better theoretical adjudication between time-based and event-based theories has been provided by several recent studies that reexamined the role of temporal isolation with unpredictable ITIs, thus preventing selective encoding strategies (Lewandowsky & Brown, 2005; Lewandowsky, Brown, Wright, & Nimmo, in press; Nimmo & Lewandowsky, in press). Because event-based theories can explain isolation effects by invoking postpresentation consolidation processes such as rehearsal, Lewandowsky and colleagues differentiated between the contribution of the interval that preceded a particular item (called *preitem interval* from here on) and the effect of the interval that followed the item (*postitem interval*). Time-based theories would expect memory to benefit as the duration of both intervals increases, whereas event-based theories could accommodate an effect of the postitem interval but not of the preitem interval. Across four experiments with

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unpredictable ITIs, Lewandowsky et al. and Lewandowsky and Nimmo found no evidence that temporal isolation necessarily improves memory, regardless of whether temporal isolation arose from intervals that preceded or followed an item.

However, this general outcome was accompanied by one exception: Lewandowsky and Brown (2005) also found that the preitem interval had no effect on recall, but they additionally found that memory benefited from longer postitem intervals, provided that people did not engage in articulatory suppression (AS) during encoding. The presence of a postitem effect during quiet study and its simultaneous absence during AS is fully compatible with an event-based view that ascribes isolation effects to a consolidation process (e.g., rehearsal) that is disrupted by articulation.

The studies by Lewandowsky and colleagues thus provide evidence against a causal link between time and memory, although the results leave open the possibility that time may indirectly help create isolation effects if people can engage some form of consolidation process during the interitem intervals. Given that this beneficial effect of consolidation was confined to only one of the studies (Lewandowsky & Brown, 2005), its generality may however be questionable. One possible reason for this limited generality is that in the studies by Lewandowsky and colleagues to date, none of the ITIs exceeded 1,200 msec, with total list presentation not exceeding 6.55 sec. In consequence, one could argue that these ITIs were usually too brief to permit any event-based consolidation processes to occur and that longer intervals may yet give rise to pervasive isolation effects.

In the present experiment, we therefore examined the effect of temporal isolation when the range of ITIs was spread over a wider temporal band (ranging from 50 to 4,000 msec) with list presentation extending to 14.35 sec. We compared the effects of temporal isolation between a standard quiet condition, in which participants studied the visually presented lists without articulation, and an AS condition, in which participants repeated an irrelevant item during study.

## Method

**Participants.** Twenty-four members of the University of Western Australia campus community participated voluntarily. The participants were either remunerated at a rate of Au\$10 per hour or received course credit. An equal number of participants were randomly allocated into either the AS condition or the quiet condition.

**Design and Materials.** A set of 19 letters (all consonants except *Q* and *Y*) were used to construct seven-item lists by random sampling without replacement. Lists contained six ITIs, of 50, 400, 900, 2,000, 3,000, and 4,000 msec. All possible permutations of these intervals resulted in 720 unique trials, each representing one possible ordering of intervals. The 720 unique permutations were divided into six sets of 120 trials, subject to the constraint that, within each set, each ITI was presented the same number of times (i.e., 20) in each possible position. The participants were randomly assigned to sets, and each condition included two replications of each set of trials.

**Procedure.** The participants were tested in groups of three and were seated in front of computers that were separated by privacy screens. Regardless of condition, all participants wore headphones

to minimize noise interference. The participants in the AS condition repeated the word *thou* aloud during list presentation, whereas the participants in the quiet condition silently watched the lists. Each participant was presented with four practice trials before the experimental session.

A computer running a MATLAB program, designed using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997), was used to display the stimuli and record responses. Each list took a constant 15,350 msec to present, with the time divided as follows: First, in the center of the screen, a 1,200 msec fixation symbol (“+”) was displayed to signal the beginning of the trial. Each item was visually displayed in the center of the computer screen for 400 msec, with the gap between items determined by the ITI for that trial and position. A 1,000-msec pause separated the final list item from the response cue “All”: A participant’s task was to recall the list items in the order in which they were visually presented.

All responses were entered on the keyboard, with the space bar used to indicate an omission, and the participants could not correct a response once it was entered. The last response remained visible for 300 msec before the screen was cleared, and the next trial commenced 2,000 msec later. A self-paced break was provided after every 30 trials. Instructions emphasized both accuracy and latency. The experiment lasted approximately 60 min.

## Results

**Serial position analysis.** Correct-in-position performance (averaged across serial positions) ranged from .26 to .76 across participants in the AS condition and from .65 to .90 in the quiet condition. Analysis of the distribution of individual differences identified 2 participants in the AS condition whose performance (.26 and .27) was around .25 below the group mean and some .13 below that of the next-lowest participant. Those 2 participants were therefore eliminated from the analysis. Figure 1 shows the serial position curves for both conditions using correct-in-position scoring.

A  $2 \times 7$  (condition  $\times$  serial position) between-/within-subjects ANOVA confirmed the obvious effects of condition [ $F(1,20) = 33.91$ ,  $MS_e = 0.069$ ,  $p < .0001$ ] and serial position [ $F(6,120) = 38.32$ ,  $MS_e = 0.008$ ,  $p < .0001$ ] and an interaction of both variables [ $F(6,120) = 3.53$ ,  $MS_e = 0.008$ ,  $p < .003$ ]. These results confirm that the articulation manipulation had the expected effect of depressing performance.

**Temporal isolation effects.** An overall visual impression of the effects of temporal isolation can be provided by summing the preitem and postitem intervals at each serial position to form the combined temporal isolation (ranging from 450 msec to 7 sec). Figure 2 shows the effects of combined temporal isolation and serial position (excluding end items because they have only one list neighbor) for both conditions. The figure provides no evidence that temporal isolation affected recall performance.

To explore the apparent absence of a temporal separation effect further, the remaining analysis considered the effects of preitem and postitem intervals separately by focusing on three critical items in Serial Positions 2, 4, and 6. Focus on those items ensures that the effects of preitem and postitem intervals can be observed independently, since any given interval contributes to performance on one item only.

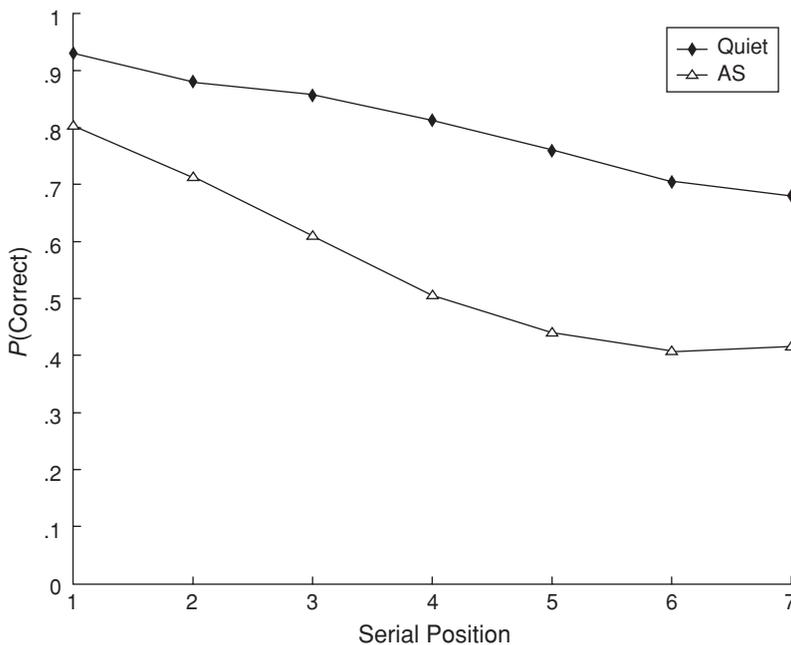


Figure 1. Serial position curves for the articulatory suppression (AS) and quiet conditions.

Figure 3 shows performance on the critical items as a function of preitem intervals (left-hand panels) and postitem intervals (right-hand panels). The figure reveals a very strong overall serial position effect, as indicated by the vertical separation between the parameters in each panel, which represent the three critical positions. The figure also shows that there is no clear beneficial effect of either interval in any condition and at any of the critical positions.

Statistical confirmation of the pattern in the figure was provided by a hierarchical linear regression analysis (e.g., Busing, Meijer, & van der Leeden, 1994). Hierarchical regression permits an aggregate analysis of data from all participants without confounding within- and between-subjects variability and was also used by Lewandowsky and Brown (2005) and Lewandowsky et al. (in press). In a hierarchical regression, estimates of the parameters—in the present case, the intercept and the duration of the preitem and postitem intervals—vary across participants, and the statistical significance of those parameter estimates is assessed across all participants. A separate model was fit for each critical item within each condition, using the proportion correct for each conjunction of preitem and postitem intervals as the dependent measure. The obtained parameter estimates are shown in Table 1.

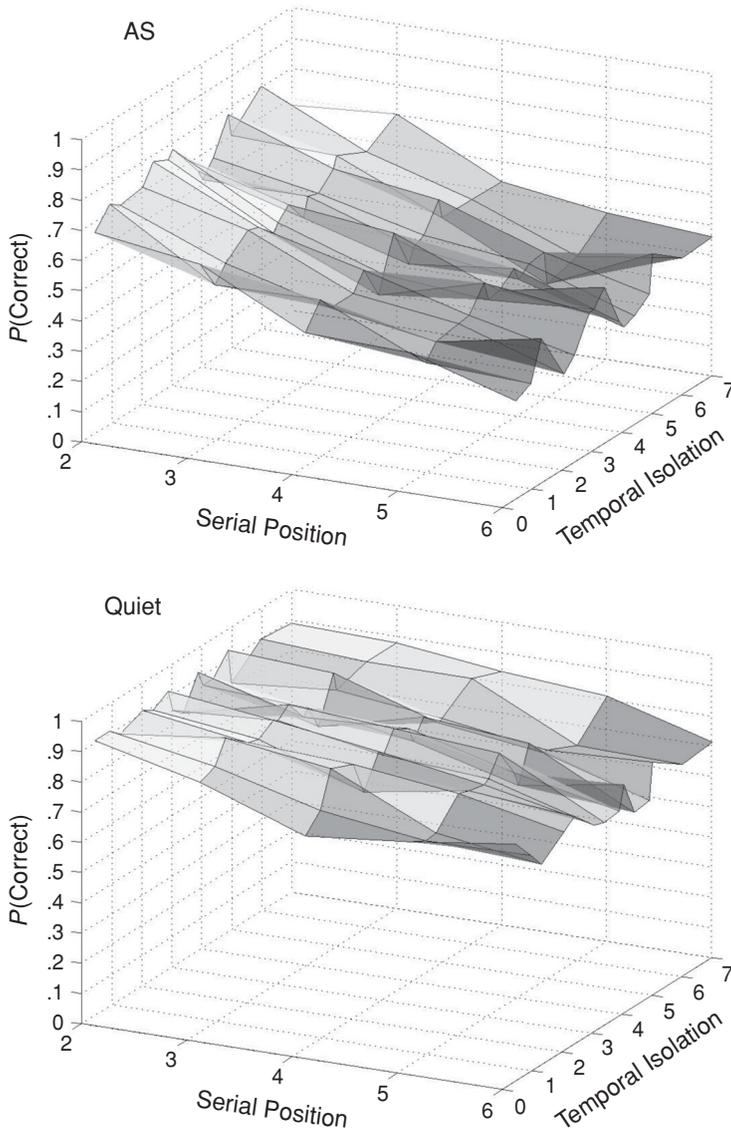
To facilitate interpretation, note that the intercept captures performance at each critical position before the effects of preitem and postitem intervals are included. The decline of the intercept estimates with the position of the critical item captures the extensive primacy in the data. Similarly, the difference in estimates between conditions captures the overall effect of AS on performance. Concerning temporal separation, it is noteworthy that neither postitem nor preitem intervals had any effect in any of the conditions at any critical position. This further sup-

ports what was suggested visually in Figures 2 and 3 and demonstrates that, even when an item is separated from its neighbors by a total of 7 sec, it is recalled no better than when its neighbors are less than half a second away.

To reconcile the present findings with previous research that has found large isolation effects with predictably increasing or decreasing presentation schedules (e.g., Neath & Crowder, 1996), we extracted those responses at each serial position whose preitem and postitem interval pairs were consistent with an increasing or decreasing presentation schedule. For example, any responses at Serial Position 2 with preitem and postitem intervals of 50 and 400 msec, respectively, were used for the increasing schedule, whereas preitem and postitem intervals of 4 and 3 sec at the same serial position contributed to the decreasing presentation schedule. This process yielded composite serial position curves for both an increasing and a decreasing presentation schedule for each participant, which were entered into a  $2 \times 7$  (presentation schedule  $\times$  serial position) within-subjects ANOVA. In contrast to situations involving predictably increasing or decreasing presentation schedules (i.e., Neath & Crowder, 1996; Welte & Laughery, 1971), the critical interaction between presentation schedule and serial position did not materialize in the present study involving unpredictable intervals [ $F(6,126) = 0.572$ ,  $MS_e = 0.059$ ,  $p > .10$ ]. The absence of the interaction confirms that, when participants are unable to use the predictability of item presentation rate as a cue for recall, temporal isolation does not benefit memory.

## Discussion

The results of the present study enhance the generality of other recent findings that, when the ITIs are temporally unpredictable, temporal isolation has no beneficial effect



**Figure 2.** The effects of combined temporal isolation (in seconds) and serial position on performance in both conditions. End items are not included because they have only one neighbor. AS, articulatory suppression.

on serial recall (cf. Lewandowsky & Brown, 2005; Lewandowsky et al., in press). By extending the average ITIs from around half a second (cf. Lewandowsky et al., in press; Nimmo & Lewandowsky, in press) to nearly 2 sec, the present study was designed to encourage the use of memory consolidation processes such as rehearsal during list presentation. Notwithstanding combined separations of up to 7 sec, and irrespective of whether the participants were quiet or engaged in articulatory suppression during study, memory was unaffected by temporal isolation at any serial position. Hence, the present data suggest that, when the ITIs are of an unpredictable duration, temporal isolation does not benefit memory, even when memory consolidation processes are given the best possible chance to operate.

Before discussing the implications of our results, we note a potential limitation of this study in the form of output interference (we use the theoretically neutral term *output effects* from here on). It is well known that the act of recalling any list item diminishes a participant's ability to recall the remaining items (e.g., Anderson & Neely, 1996), either by interfering with yet-to-be-recalled items (an event-based interpretation) or by delaying recall of subsequent list items (a time-based interpretation). It follows that, if the effect of temporal isolation was small to begin with, output effects may have masked any isolation advantage on memory. This potential criticism was addressed in a parallel set of experiments by Nimmo and Lewandowsky (in press), who showed that memory was still unaffected by temporal distinctiveness, even when

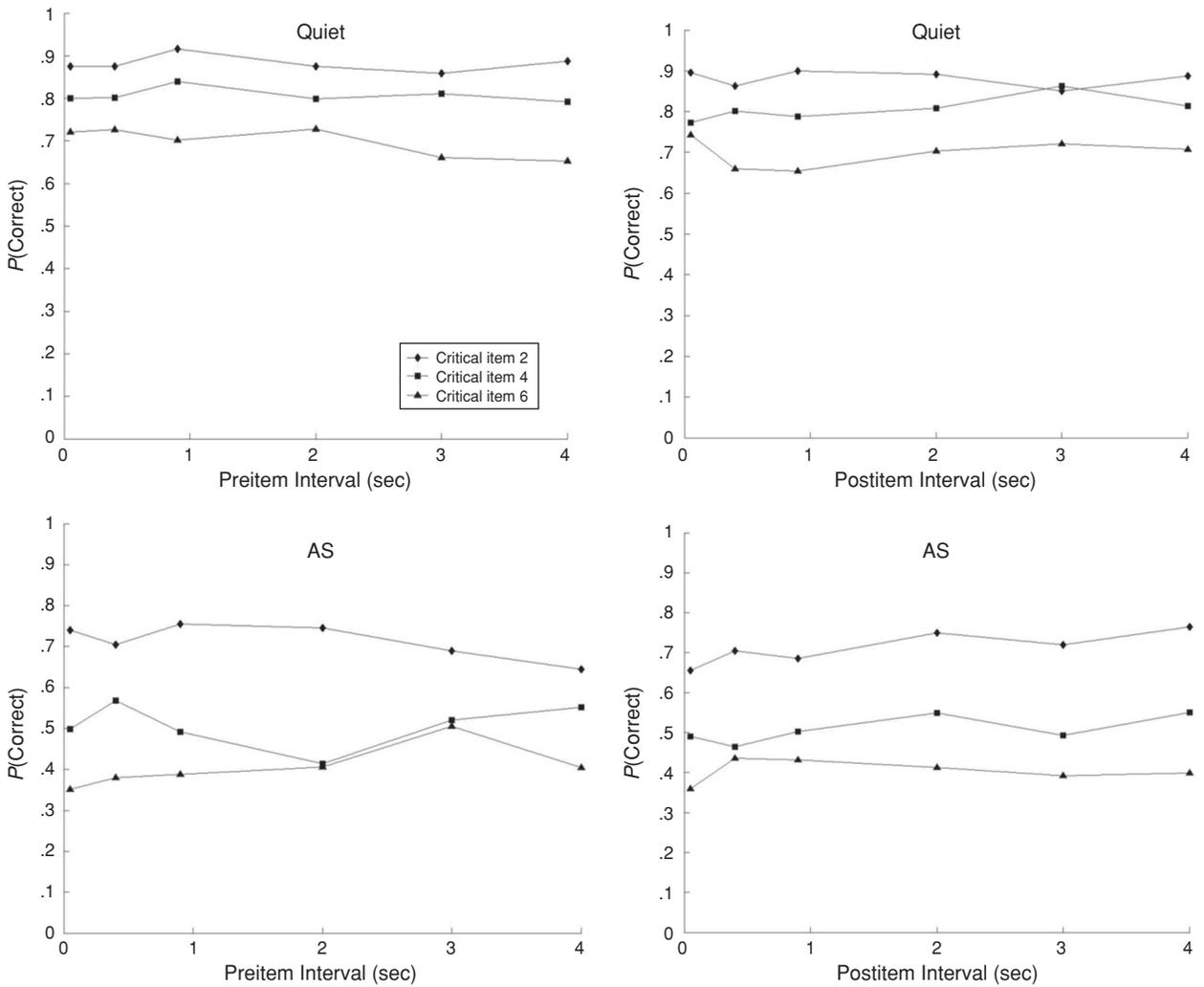


Figure 3. Mean proportion of correct recall for each critical item as a function of preitem (left panels) and postitem (right panels) intervals for the quiet and articulatory suppression (AS) conditions.

output effects were eliminated because people were cued to recall a single item on each trial.

The theoretical implications of our data are quite clear: The results argue against time-based theories (e.g., Brown et al., 2002; Burgess & Hitch, 1999), which assume that there is a causal link between time and memory and which cannot handle the absence of temporal isolation effects (see Lewandowsky et al., in press, for a computational demonstration of this prediction). Instead, the results support event-based theories (e.g., Farrell & Lewandowsky, 2002; Murdock, 1993), which do not expect temporal isolation to have any effect unless other, nontemporal consolidation processes are invoked. In the present study, the convincing absence of isolation effects suggests that those nontemporal consolidation processes were inactive.

Why, then, did the postitem effect obtained by Lewandowsky and Brown (2005) fail to materialize in the present study? Its absence is readily explained for the AS condition, where the articulation would be expected to disrupt consolidation processes (the overall lower performance

under AS relative to quiet attests to the fact that encoding was in fact disrupted). The absence of a postitem effect in the quiet condition can be explained by assuming that the ITIs were sufficiently large to permit rehearsal of all previously presented list items "online," adding each item to the rehearsal sequence as it was presented. Hence, an effect of the postitem interval on performance on the preceding item did not occur because, as the length of that interval increased, the participants used it for cumulative list-wide rehearsal rather than extended rehearsal of the immediately preceding item. The idea that the participants were using a list-wide progressive rehearsal strategy is consistent with the finding that overall performance was higher in the present study (.80) than in the related studies by Lewandowsky et al. (in press), where performance was at .69 on average when the task was serial recall and .68 when memory was positionally probed.

Irrespective of what rehearsal strategy was used to aid memory, the primary contribution of this study was to show that, even when list items are—unpredictably—

**Table 1**  
**Hierarchical Regression Parameters and Associated *t* Values**  
**(*df* = 11 for the Quiet Condition and 9 for the AS Condition)**  
**for All Critical Items in Both Conditions**

Critical Item	Intercept	<i>t</i>	Preitem		Postitem	
			Parameter	<i>t</i>	Parameter	<i>t</i>
Quiet Condition						
2	.89	43.41***	-.003	-0.48	-.004	-0.62
4	.78	18.25***	-.000	-0.02	.013	1.40
6	.73	14.49***	-.017	-1.64	.002	0.24
AS Condition						
2	.71	14.72***	-.016	-1.65	.019	2.01
4	.47	8.11***	.005	0.42	.019	1.58
6	.36	4.90**	.022	1.91	.004	0.34

\*\**p* < .001. \*\*\**p* < .0001.

separated by up to 7 sec, temporal isolation still does not facilitate memory. Therefore, the data provide a further challenge to temporal distinctiveness models (e.g., Brown et al., 2000; Glenberg & Swanson, 1986; Neath, 1993) and add to the growing body of research demonstrating that, as with long-term memory, for temporally unpredictable events, temporal distinctiveness does not benefit memory over the short term (e.g., Lewandowsky & Brown, 2005; Lewandowsky et al., in press; Nimmo & Lewandowsky, in press).

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