Decay versus Interference: A New Look at an Old Interaction

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A question that has been fought over for at least 80 years is whether memory traces decay with time or interfere with one another (McGeoch, 1932). The question is central to interpretations of forgetting and memory capacity and to understanding the design of the human cognitive architecture. There are two camps, which take turns declaring victory ("No Temporal Decay in Verbal Short-Term Memory" write Lewandowsky, Oberauer, & Brown, 2009; "Time Causes Forgetting from Working Memory", respond Barrouillet, De Paepe, & Langerock, 2012).

Lost in the fog of battle is evidence that decay and interference are both at work, with decay more subtle but no less common. Berman, Jonides, and Lewis (2009) made this point when they went "In Search of Decay in Verbal Working Memory" and ultimately found it, in data pooled across experiments (their Figure 7). Small but robust decay effects can be measured by focusing on controlling interference across conditions (Altmann & Gray, 2002) rather than trying to eliminate it (Reitman, 1974). There is also the theoretical argument that decay plays a functional role in cleaning up episodic detritus (Altmann & Gray, 2008), which suggests that decay effects should be pervasive.

Here we ask whether this perspective—that large interference effects and small decay effects pervasively coexist—can bring new clarity to results of a classic study that helped shape and still influences the debate. Waugh and Norman (1965) used a probe digit procedure in which a list of digits is presented for study, the last of which is the second occurrence of a probe. The target for recall is the digit that followed the first occurrence of the probe. Interference is indexed by the number of interfering items between the target and the end of the list. Decay is indexed by presentation rate.

The data appear in Figure 1 (left panel). There is a large effect of number of interfering items, but no effect of presentation rate (1 vs. 4 items/sec). The authors did not test the interaction—and although it invited comment initially (Broadbent, 1971; Massaro, 1970; Shallice, 1967, as cited in Craik, 1971), it then slipped beneath the waves. Meanwhile, the large interference effect evolved into textbook evidence for an interference-only perspective (e.g., Ashcraft & Radvansky, 2010; Galotti, 2008).

And yet, the interaction in Figure 1—which is highly reliable[1]—is exactly what one would expect if interference and decay interacted to influence recall. Early items benefit if presentation is fast because they are less decayed at test, and late items benefit if presentation is slow because early items are more decayed at test and thus generate less proactive interference.

To demonstrate this point, we developed a simple formal model based on existing memory theory (Anderson, Bothell, Lebiere, & Matessa, 1998). Decay is represented by

$$A(t) = -0.5\ln(t), \qquad (1)$$

where $A(t)$ is the activation of an item at test when it is t seconds old. The age of the last item is a free parameter, t_{last}, which together with the presentation rate binds the ages of earlier items. Interference is represented by

$$p(j) = \frac{e^{A(t_j)/s}}{\sum_i e^{A(t_i)/s}}, \qquad (2)$$

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[1] $F(8,24)=5.12$, $p=0.001$; data reconstructed from Waugh and Norman's (1965) subject-level plots are included in Supplementary Materials online. Norman's (1966) Figure 1 suggests that the interaction replicates.

where $p(j)$ is the probability of retrieving element j, A is activation from Equation 1, s is activation noise, and the summation is over all list items.

We assume two additional mechanisms. The first is priming of the target by the probe at test, in the amount of activation r. This is necessary to overcome the competition for retrieval implied by Equation 2, and is consistent with a contiguity effect in which recall of one target predicts increased recall of its successor (Kahana, 1996). Second, we assume extra-list interference. Presentation rate was blocked, so extra-list interference should have been greater in the fast condition because distractors from previous lists would have been more recent. We represented this factor with an extra distractor in the fast condition, estimating its activation E as a free parameter. With these mechanisms, the probability of recalling element j at each presentation rate is

$$p(j)_{fast} = \frac{e^{\left[r+A(t_j)\right]/s}}{e^{E/s} + \sum_i e^{A(t_i)/s}}, \tag{3a}$$

$$p(j)_{slow} = \frac{e^{\left[r+A(t_j)\right]/s}}{\sum_i e^{A(t_i)/s}}. \tag{3b}$$

We used maximum-likelihood estimation to fit these equations to the data in Figure 1, estimating four parameters (t_{last}, s, r, and E) from 18 data points. The likelihood function was the binomial distribution, with the model predicting the probability of an accurate response. The fit appears in the right panel of Figure 1 (lines with markers; ln L = -85.3). The model captures both the main effect of number of interfering items and the interaction with presentation rate.

We compared this model with one in which presentation rate has no effect and which therefore cannot capture the interaction.[2] In Figure 1, the fit of this interference-only model is the line without markers (ln L = -92.4). The Bayes factor computed from the log likelihoods for the two models is 1274:1 favoring the decay+interference model; values over 150:1 are considered "very strong" evidence (Wagenmakers, 2007).

Of course, other time-based processes could account for the interaction in Figure 1. For example, Massaro (1970) explained the interaction in terms of perceptual encoding, noting that presentation rate determines time available to process a stimulus. That said, memory is a functional system, and explaining any effect in isolation tells us little about how memory actually delivers information. A system-level focus suggests, for example, that some decay-like process is necessary to manage interference (Altmann & Gray, 2008), and detractors have yet to respond with their own account of how the system avoids grinding to a halt in the face of unmitigated buildup of interference. The prior theoretical odds for decay are therefore quite high (see also Schooler & Hertwig, 2005). The general point is that a functional, system-level focus (Newell, 1973) is an important way to drive memory theory, as well as a useful way to explore subtleties of archival data.

[2] A description of this interference-only model is included with the models themselves in Supplementary Materials online.

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Author Note

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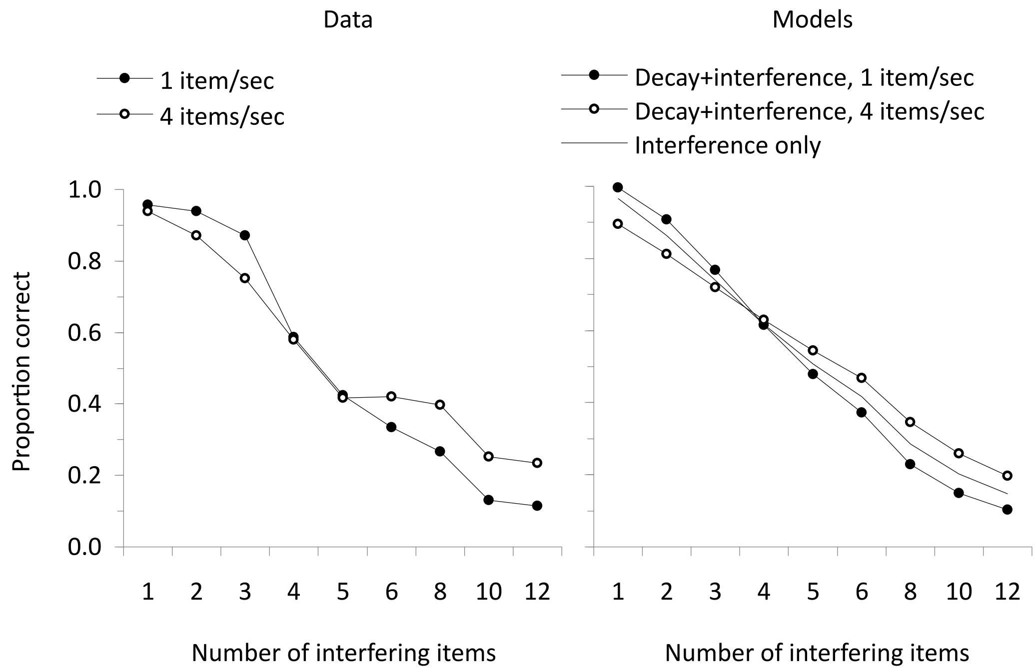

Figure 1: Left panel: Data from Waugh and Norman (1965), uncorrected for guessing. Right panel: Maximum-likelihood fits of two models, one in which decay and interference interact to influence retrieval (lines with markers) and one in which only interference influences retrieval (line without markers).