Long Term Recency Is Nothing More Than Ordinary Forgetting

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Long Term Recency Is Nothing More Than Ordinary Forgetting

When tested on a list of items, individuals show a recency effect: the more recently a list item was presented, the more likely it is to be recalled. For short interpresentation intervals (IPIs) and retention intervals (RIs), this effect may be attributable to working memory. However, recency effects also occur over long timescales where IPIs and RIs stretch into the weeks and months. These *long-term recency* (LTR) effects have intrigued researchers because of their scale-invariant properties and the sense that understanding the mechanisms of LTR will provide insights into the fundamental nature of memory. An early explanation of LTR posited that it is a consequence of memory trace decay, but this *decay hypothesis* was discarded in part because LTR was not observed in continuous distractor recognition memory tasks (Glenberg & Kraus, 1981; Bjork & Whitten, 1974; Poltrock & MacLeod, 1977). Since then, a diverse collection of elaborate mechanistic accounts of LTR have been proposed. In this article, we revive the decay hypothesis. Based on the uncontroversial assumption that forgetting occurs according to a power-law function of time, we argue that not only is the decay hypothesis a sufficient qualitative explanation of LTR, but also that it yields excellent quantitative predictions of LTR strength as a function of list size, test type, IPI, and RI. Through fits to a simple model, this article aims to bring resolution to the subject of LTR by arguing that LTR is nothing more than ordinary forgetting.

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Introduction

When subjects are studying a list of to-be-remembered items over a period of time, their recall accuracy at a subsequent test is greater for items at the end of the list than those in the middle. Studies of this phenomenon, the *recency effect*, date back to the time of Ebbinghaus, and in the past 125 years many experimental and theoretical papers have been published on the topic. Recency effects were initially attributed to residual information in working memory (Atkinson & Shiffrin, 1968). However, recency effects can occur when working memory is disrupted via a distractor task during the retention period (e.g., Nairne, Neath, Serra, & Byun, 1997). Surprisingly, recency effects also occur when list items are presented days or weeks apart (Baddeley & Hitch, 1977; Glenberg, Bradley, Kraus, & Renzaglia, 1983). For example, Glenberg et al. (1983) found a large recency effect for items spaced a full week apart, as shown in Figure 1a. They observed an astonishing 65% difference in the level of recall between items at the end of the list and items in the middle of the list.

Studies of such *long term* recency (LTR) effects (Baddeley & Hitch, 1977; Bjork & Whitten, 1974; Glenberg et al., 1980; Glenberg & Kraus, 1981; Glenberg et al., 1983; Greene, 1986; Nairne, 1991; Neath, 1993; Neath & Crowder, 1990, 1996) reveal a form of scale invariance. When recall is tested following a retention interval (*RI*) on the order of seconds, LTR will be observed if the time between items (the interpresentation interval or *IPI*) is on the order of seconds. When the RI is on the order of days, LTR will be observed only if the IPI is on that scale as well. This scale invariance leads one to wonder whether LTR might serve as a window into the operation of memory systems at many different timescales, and therefore might be a phenomenon whose mechanistic understanding will reveal deep insights into the nature of memory. Nonetheless, no consensus on the nature of the phenomenon has been reached.

This article argues that an obvious and parsimonious — but long discarded —

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account of LTR effects is fully consistent with the literature. This hypothesis, the *decay hypothesis*, posits that recency effects are due to the decay of memory trace (Glenberg et al., 1983). Simply put, people gradually forget things. Typically, when little time has elapsed since study, relatively little forgetting will have occurred; thus, items studied toward the end of a list are most easily recalled because they were studied most recently. Hence, long term recency (LTR) is a direct consequence of ordinary forgetting. This explanation was abandoned in favor of alternative theories because, in several key early studies, long-term recency effects were not observed in recognition tasks (in particular, see Glenberg & Kraus, 1981; Bjork & Whitten, 1974; Poltrock & MacLeod, 1977). This finding appeared to be decisive evidence against the decay hypothesis: if the decay of memory strength is solely responsible for LTR, the manner in which subjects respond should be irrelevant and there should be LTR in recognition tasks just as there is in free recall tasks.

We show that the phenomenon of LTR, including the lack of statistically significant LTR effects in recognition memory, can be fully predicted by what is independently believed about forgetting: that memories decay according to a power-law function of time.

Formalization of the Decay Hypothesis

Our model rests on the relatively uncontroversial assumption that recall probability of an item following a single study presentation decays according to a power-law function (Anderson & Schooler, 1991; Wickelgren, 1974; Wixted & Carpenter, 2007; Wixted & Ebbesen, 1991). The recall probability following an elapsed time t since study, $p(t)$, is defined as $p(t) = (1 + \alpha t)^{-\beta}$, where α is a time-scaling parameter ($\alpha > 0$) and β is the decay rate ($\beta > 0$).[1] This equation is an instance of the Wickelgren power-law forgetting curve $\gamma(1 + \alpha t)^{-\beta}$ (Wickelgren, 1974), where γ represents initial recall probability or the effectiveness of study. Without loss of explanatory power, in this article we assume that initial encoding is certain ($\gamma = 1$).

In free recall, subjects determine the order of report. Consequently, the *effective* retention interval of an item depends not only on its serial position in the initial list, but also on its recall output position. If forgetting follows a power law, slight variability in retention interval should not matter for material held in memory for hours or days, but due to the steepness of the forgetting curve shortly after study, variability in retention interval can have noticeable effects on recall accuracy for material held in memory just seconds or minutes. Studies of long-term recency do not necessarily involve long retention intervals; for instance, in Nairne et al. (1997), IPIs and RIs were as short as 1s and responses extended over a 12s recall window.

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Because small variability in the RI can have a large effect on recall probability in such a situation, we found it necessary to make an additional assumption about free report in order to determine the effective retention interval. We assume that items presented late in a list are more likely to be recalled first because their memory traces are strongest among the list items and they will out-compete older items in the list. Empirical support for this assumption comes from Nilsson, Wright, and Murdock (1975), who found that in a free recall test given immediately after a sequence of visually presented stimuli, later items in the list tend to be recalled before earlier items. (While this assumption may be incorrect for the initial items in a list due to primacy, those items are irrelevant for the purpose of determining LTR effects.) The consequence of this assumption is that the last items will have shorter effective RIs than earlier items, and increasing the effective retention interval of the earlier items by a measurable percentage will amplify recency effects. This amplification is noticeable only when RIs and IPIs are brief.

We characterize recall output order in terms of a probabilistic generative process having the property that if items in serial positions i and j are both reported, item i will be reported after j if and only if $i < j$. In the generative process, the time at which a memory retrieval attempt for serial position i occurs depends on which later items j, i.e., $j > i$, were correctly recalled. Let $R_i \in \{0, 1\}$ denote whether the ith serial position is recalled during the test and let T_i be the time at which the memory retrieval was attempted. We assume that $T_{i-1} = T_i + R_i \; \mathcal{L}(p(T_i))$, where $\mathcal{L}$ is the response latency (described in the next paragraph) and p is the power-law function already described. Whether or not an item is recalled is determined by a biased coin flip: $R_i \sim \text{Bernoulli}(p(T_i))$. Recall does not necessarily begin at the last serial position or proceed consecutively, but it does always proceed from high to low serial positions. The model's recall probability for serial position i is the expectation $\mathbb{E}[R_i]$.

To estimate response latencies, we leverage ACT-R (Anderson et al., 2004) which is perhaps the best accepted model of long-term memory. Based on ACT-R's declarative memory module, we adopt the assumption that when successful recall of an item occurs, the time to recall it depends on its memory strength. In ACT-R, this strength also determines recall probability. Response latency $\mathcal{L}$ in ACT-R can, under simplifying assumptions, be solved algebraically in terms of recall probability and written as $\mathcal{L}(p) = \psi \frac{1-p}{p}$, where ψ scales how much response latency increases with decreasing odds of successful recall.[2]

In summary, our model embodies well-accepted characteristics of memory recall and includes a simple generative process to describe free recall. It has three parameters: α, β, and ψ. The parameters are constrained post hoc to describe the material, population, and testing procedure of a study.

Empirical Phenomena Associated with LTR

Recency is evident in serial position curves by a characteristic upward bend for the final serial positions (e.g., Figure 2a). The *strength* of LTR can be characterized by the steepness of the upward bend, which Glenberg et al. (1983) and subsequent authors

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quantified in terms of the slope of the line fit by least-squares to the last three serial positions.[3] In this section, we present evidence that the decay hypothesis explains the key phenomena associated with LTR and obtains excellent quantitative fits to various experimental outcomes as demonstrated by serial position curves and the associated LTR strength.

Absence of LTR in Recognition Tasks

A study by Glenberg and Kraus (1981), titled *Long-term recency is not found on a recognition test*, contributed to the abandonment of the decay hypothesis. LTR was assessed in two testing formats: free recall and recognition. The dotted lines in Figure 2a represent the serial position curves for recognition (squares) and recall (diamonds). Glenberg and Kraus performed several analyses, including an ANOVA testing for a main effect of serial position across the final 3 positions of each curve. Finding a reliable effect in recall but not recognition performance, the authors rejected the decay hypothesis. Their reasoning was that if LTR was a consequence of memory trace decay over time, testing format should not matter. Because testing format matters, the decay hypothesis seemed implausible. In other early studies, LTR was not detected in recognition either (Bjork & Whitten, 1974; Poltrock & MacLeod, 1977).

In our model, the power-law forgetting curves do not directly represent the strength of memory; rather, they indicate memory strength *as reflected in a particular read-out task*. The same memory state may yield poor performance in a challenging task like free recall, where veridical recall requires reconstruction of the specific items studied, but good performance in an easy task like recognition, where the memory trace must merely be strong enough to support a reliable old vs. new discrimination. Thus, distinct forgetting curves are warranted for recall and recognition.

The solid lines in Figure 2a show independent least-squares fits of the

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two-parameter forgetting curve $p(t)$ to the two serial position curves. The forgetting curve, reflecting proportion correct as a function of time, are obtained by flipping the solid lines from right to left. (For the recognition condition, the ψ parameter—determining free recall order—was not used, because testing was cued and randomized.) The model's forgetting curves are good matches to the serial position curves. Forgetting, as reflected in the drop in performance from serial position 9 to position 3, is shallower for recognition. Consequently, if the model predictions are correct, the experiment may not have had sufficient power to detect a difference in recognition accuracy across serial positions.

With the model's forgetting curve in the recognition condition, we can perform a power analysis to determine how likely an LTR effect is to be detected by Glenberg and Kraus (1981) at the 95% significance level. The experiment included 54 subjects, and each was tested on 3 lists in each testing condition. Assuming (a) model estimates of recall and recognition probability are accurate for serial positions 7-9, (b) probability is the same across subjects and lists tested, and (c) items within a list are independent of one another, we used the model to simulate experimental outcomes and tested for a main effect of serial position. Although according to the model there is a true LTR effect for both recognition and recall, the simulated experiment had only a 14% chance of detecting the effect in recognition, but a 98% chance in recall. To meet the convention of 80% statistical power (Cohen, 1992), Glenberg and Kraus would have needed to run approximately 400 subjects.

Talmi and Goshen-Gottstein (2006) critiqued the multi-probe testing procedure used in earlier recognition experiments, noting that the procedure likely attenuated or eliminated LTR. Instead, they probed only one serial position per trial in recognition testing. Their study included two presentation conditions: in one condition, subjects performed a distracting task during the IPI and RI; in the other, subjects performed a distracting task only during the RI. (We omit a third condition in the experiment because it did not test LTR.) The serial position curves obtained in the study, along with the

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model fits, are shown in Figure 2b.[4] Talmi and Goshen-Gottstein (2006) reported reliable LTR in the condition with a distractor in the IPI and RI but not in the condition with a distractor only in the RI. These findings are consistent with a statistical power analysis we performed based on the model, which reveals a 93% chance of observing an extant LTR effect in the former condition, but only an 8% chance of observing extant LTR in the latter condition.

In summary, the failure to detect LTR in some recognition studies does not disconfirm the decay hypothesis because those studies lacked the statistical power necessary to reach this conclusion: forgetting rates in recognition are slow, and consequently differences across serial positions are so small that experimental noise can mask them. Previous studies had no reasonable expectation of observing an extant LTR effect given their inadequate power. Although the power could be increased by running more subjects, Talmi and Goshen-Gottstein (2006) employed experimental manipulations that helped increase the power by increasing the magnitude of forgetting (though they did so for reasons unrelated to power).

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Effect of List Length

Increasing the length of the list of to-be-remembered items has little effect on the recall accuracy of the last few serial positions but lowers recall accuracy for earlier serial positions (Greene, 1986; Murdock, 1962). For example, Greene (1986) performed an LTR study in which list length was manipulated within-subject so that the lists were either 6 or 10 items long. With IPIs and RIs of 20s filled with a distracting task, list length did not affect recall accuracy for any serial position relative to the end of the list (dotted lines in Figure 3).

Our simple model makes the strong assumption that each list item decays independently. Because there are no interactions among items, the number of items preceding a serial position is irrelevant and consequently the model predicts that the recall accuracies of the final serial positions are unaffected by an increase in list length. The model predicts that recall accuracies for early serial positions are lowered because these items' effective RIs increase when list length is increased. A model fit to the data is shown as the solid lines in Figure 3 and describes the empirical data well.

Ratio Rule

Various authors have noted what appears to be a form of scale invariance of LTR wherein the strength of LTR depends only on the ratio of IPI to RI (Baddeley & Hitch, 1977; Bjork & Whitten, 1974; Glenberg et al., 1983, 1980; Nairne et al., 1997). Further, as the IPI:RI ratio increases, so does the strength of LTR. Thus, LTR is stronger if the IPI is increased for a fixed RI or if the RI is decreased for a fixed IPI. This dependence of LTR solely on the IPI:RI ratio has been dubbed the *ratio rule*.

Glenberg et al. (1983) conducted a series of experiments exploring the ratio rule, two of which examined scale invariance of the ratio rule by varying the IPI and RI over several orders of magnitude in a free recall task: In Experiment 5, each subject participated in 7 study sessions separated by an IPI of 1 or 7 days and was then tested following an RI of 1 or 14 days. In Experiment 6, IPIs were 5 or 20 minutes, the RI was 40 minutes, and the IPI and RI were filled with a distracting task (television) to prevent rehearsal. The serial position curves reported from these two experiments are shown in Figures 1a,b. Figure 4a shows the LTR strength, the slope measure defined earlier, across a variety of IPIs and RIs combined from the two experiments. The abscissa expresses the IPI:RI ratio on a logarithmic scale. The dashed regression line suggests a log-linear trend: the LTR strength is proportional to the logarithm of the IPI:RI ratio. The figure also offers some direct support for the ratio rule via two points, the star and upward-facing triangle, with the same IPI:RI ratio having roughly the same LTR strength.

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Figures 1c,d show least-squares fits of the model to the empirical serial position curves (Figures 1a,b). Figure 4b shows the fitted model's prediction of the empirical LTR strengths (Figure 4a). The model's predicted LTR strength shows a close qualitative correspondence to the empirical LTR strengths and provides further support for the decay hypothesis.

Nairne et al. (1997) includes a single session LTR experiment that, like Glenberg et al. (1983), explores the scale invariance of the ratio rule over a wide range of IPIs and RIs. Subjects were presented with 6-item lists of letters, and the test session's format was free recall. During the IPI and RI, subjects were presented with a randomly selected digit every 500ms to disrupt short term memory. The serial position curves reported from this experiment are shown in Figures 5a,b. (They are divided into two figures for visual clarity.) The dotted line in Figure 6 shows LTR strength as a function of the log IPI:RI ratio. As with Glenberg et al. (1983), the observed LTR strength exhibits a log-linear trend and is supportive of the ratio rule.

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Figures 5c,d show a single least-squares fit of the model to all of the empirical serial position curves (Figures 5a,b). The solid line in Figure 6 shows the fitted model's prediction of the empirical LTR strengths. The model's predicted LTR strength shows a close quantitative correspondence to the empirical LTR strength.

Systematic Deviations from the Ratio Rule

Nairne et al. (1997) conducted an experiment in which they kept the IPI:RI ratio constant while varying the IPI and RI. They used a multiple choice test format in which subjects were presented with 16 letters and were asked to click on the six that appeared in the list. Figure 7a shows serial position curves from this experiment. The dotted line shows the variation in LTR strength as a functon of the IPI and RI. If the ratio rule is strictly correct, then LTR strength should be constant along the abscissa. In actuality, LTR systematically decreased as the duration of the IPI and RI increased. Thus, the ratio rule does not always hold: as the timescale of an experiment increases, LTR effects decrease.

Figure 7b shows a least-squares fit of the model to the serial position curves (Figure 7a). The solid line in Figure 8 shows the fitted model's LTR strength as a function of the IPI and RI. It demonstrates that the decay hypothesis can account for the observed deviations from the ratio rule. When the IPI increases, the effective RI of individual items also increases, which shifts items toward the relatively flat portion of the power-law forgetting curve. The plateauing of forgetting as the timescale increases reduces LTR strength by reducing the differences in recall probabilities among different serial positions.

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Conclusion

LTR and its associated phenomena have long appeared enigmatic. Why does LTR have an apparent scale invariance? Why is it more readily observed in free recall than in recognition? Why is it invariant to list length? Why does LTR strength have a systematic relationship with the IPI:RI ratio, yet sometimes it changes even when the ratio is held constant? Our simple model, based on the notion that LTR is nothing more than ordinary forgetting, answers all of these questions and provides quantitative fits to experimental data. Though separate qualitative arguments about how the decay hypothesis accounts for each of these could be made, the single quantitative account embodied in our model represents the most rigorous and unified treatment of the decay hypothesis to date. On grounds of parsimony, an explanation of LTR distinct from ordinary forgetting does not seem to be warranted. Further, future LTR research should be directed toward directly evaluating the one key assumption of our model: that forgetting and LTR curves are indeed the same.

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Author Note

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Footnotes

[1] This account is noncommittal as to whether t refers to the mere passage of time, to a measure of the number of intervening events, or to a combination thereof. LTR appears to be due to both passage of time and interference (da Costa Pinto & Baddeley, 1991).

[2] Recall probability p in ACT-R as given in terms of memory strength m and free parameters τ and θ is $p(m) = (1 + \exp(\frac{\tau - m}{\theta}))^{-1}$. Response latency $\mathcal{L}$ is given in terms of m and free parameters ω and ϕ by $\mathcal{L}(m) = \omega \exp(-m) + \phi$. Assuming ϕ, a fixed time cost associated with perceptual motor encoding, is negligible, $\mathcal{L}(p) \approx \psi(\frac{1-p}{p})$ where $\psi \equiv \theta\omega e^{-\tau}$.

[3] With straightforward algebra, the slope of the least-squares fit can be shown to be half the difference between the score at the last and third-to-last serial positions, $\frac{1}{2}(\mathbb{E}[R_n] - \mathbb{E}[R_{n-2}])$.

[4] Because Talmi and Goshen-Gottstein tested only one serial position per list, there was no uncertainty in the effective retention interval, and we again fit a two-parameter model which did not make use of the read-out order assumptions or parameter ψ.

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Figure Captions

Figure 1. Glenberg et al. (1983) Experiment 5 (a) and 6 (b) empirical data, and Experiment 5 (c) and 6 (d) simulation. Here and throughout the article, we have excluded the first few serial positions because they evidence primacy, a separate phenomenon from recency which is not our focus.

Figure (a).

Figure (b).

Figure (c).

Figure (d).

Figure 2. Serial position curves and model fits for (a) Glenberg & Kraus (1981) and (b) Talmi & Goshen-Gottstein (2006). Because of the design of both experiments, the model fits shown are simply the two-parameter power law forgetting curve; no adjustments for response times or recall order were made.

Figure (a).

Figure (b).

Figure 3. Serial position curves from Greene (1986) and a single model parameterization obtained by a least-squares fit to both serial position curves. The strength of LTR, the steepness of the upward bend in the curves on the last few serial positions, is invariant to list size. For early serial positions, recall accuracy is decreased by an increase in list length.

Figure 4. (a) Empirical and (b) simulated LTR strength for Glenberg et al. (1983). The simulation used the model fits shown in Figures 1c and 1d.

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Figure (a).

Figure (b).

Figure 5. (a,b) Serial position curves for Nairne et al. (1997) Experiment 1 and (c,d) the model fit, a model parameterization obtained by least-squares.

Figure (a).

Figure (b).

Figure (c).

Figure (d).

Figure 6. Empirical and simulated LTR strength for Nairne et al. (1997) Experiment 1. The simulation used the fit shown in Figures 5c,d.

Figure 7. (a) Serial position curves for Nairne et al. (1997) Experiment 3 and (b) the least-squares model fit.

Figure (a).

Figure (b).

Figure 8. Empirical and simulated LTR strength for Nairne et al. (1997) Experiment 3. The simulation used the model fit shown in Figure 7b.

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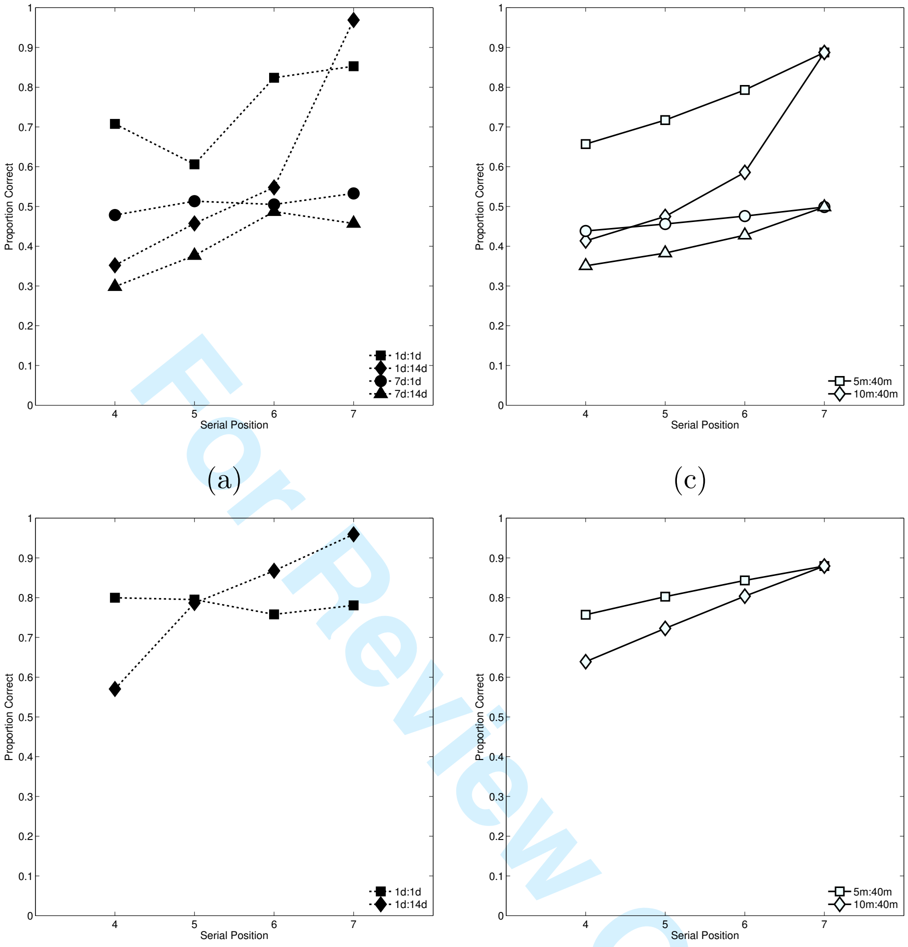

(a)

(c)

(b)

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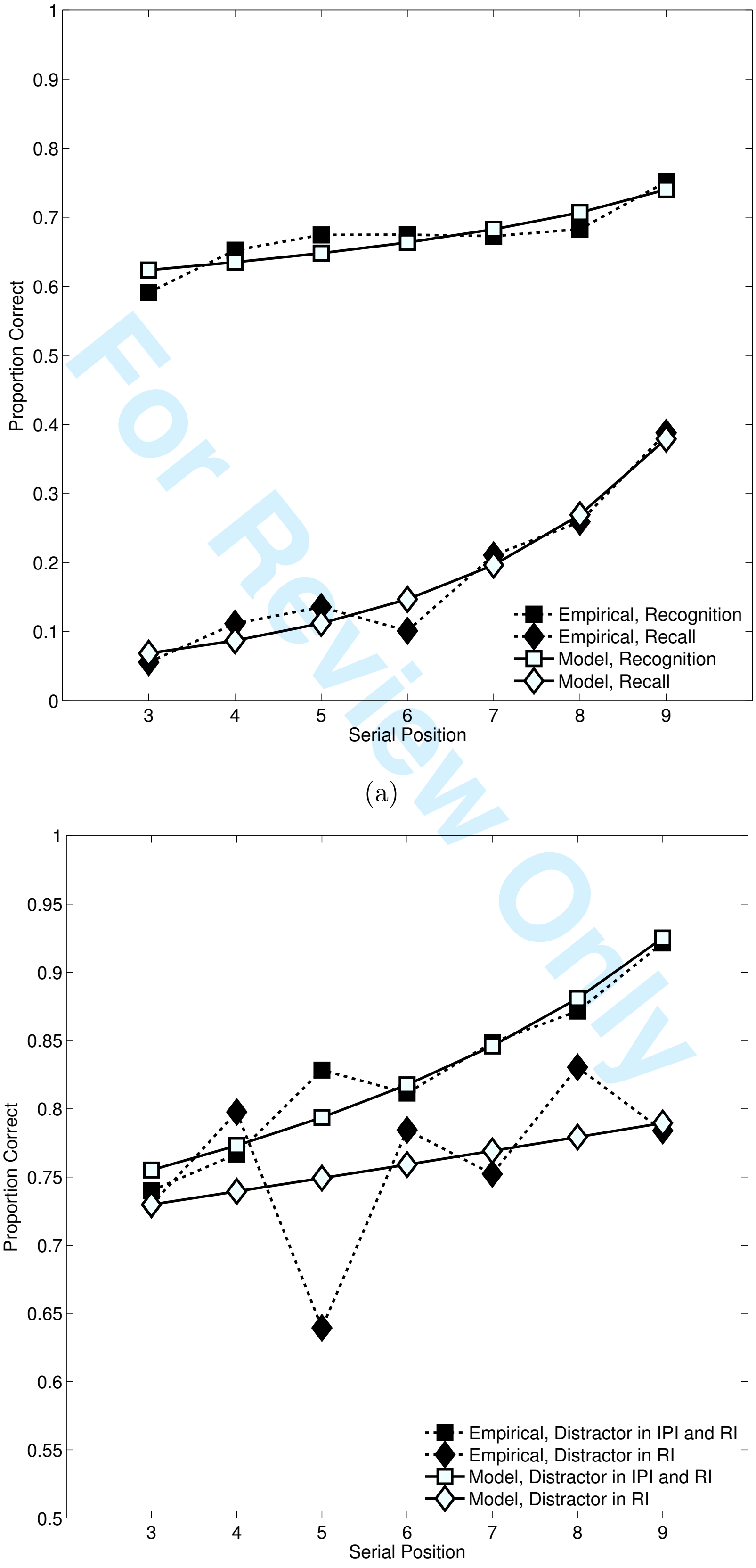

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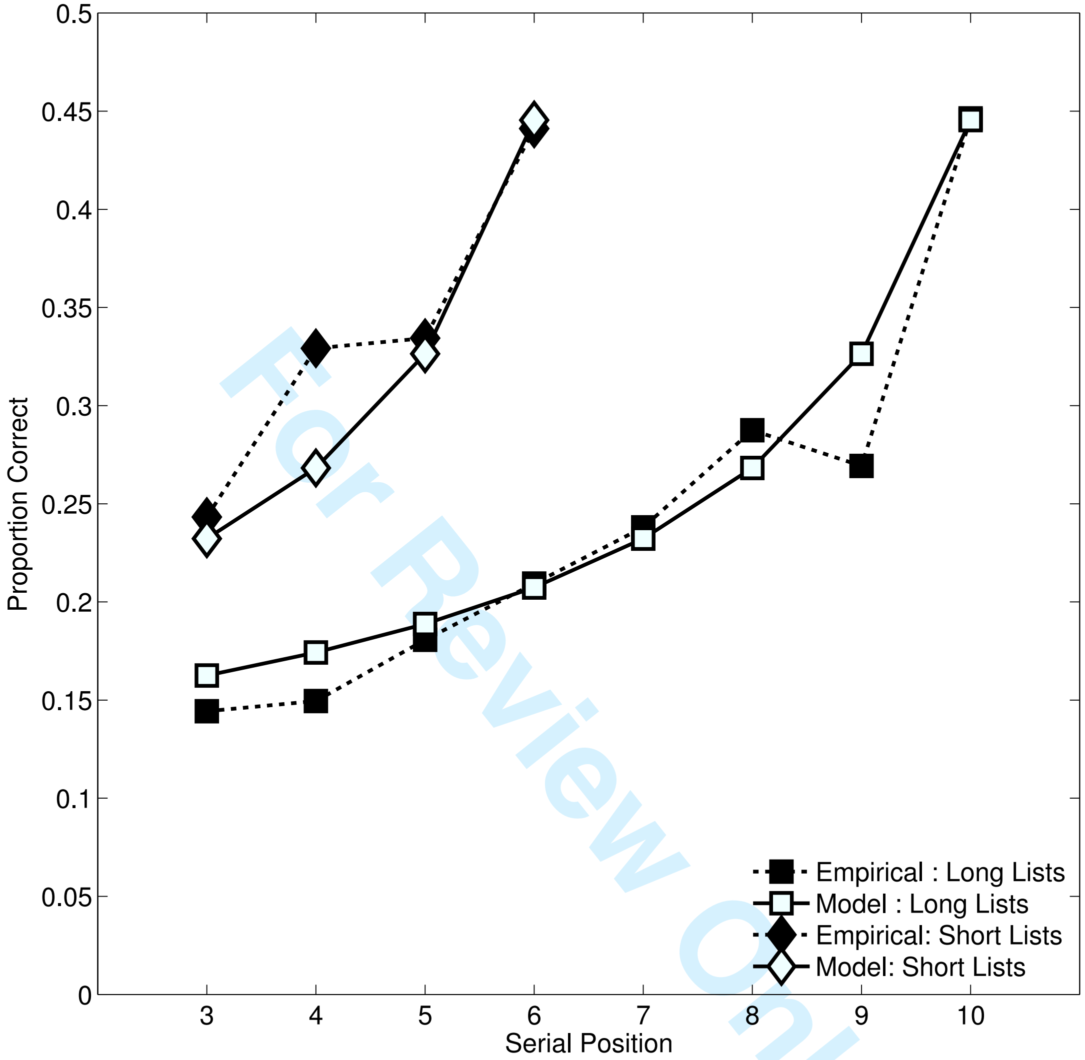

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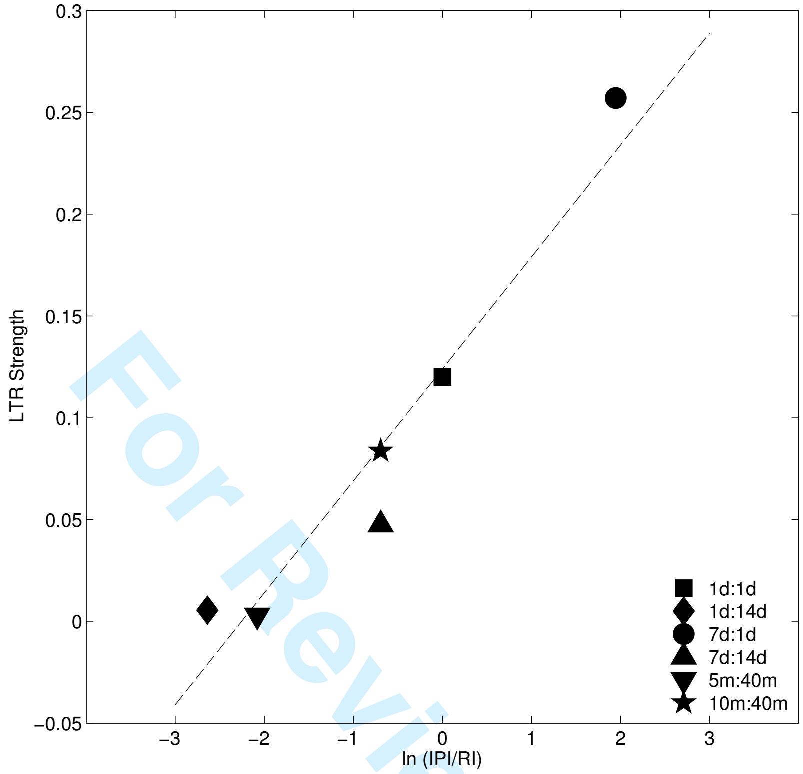

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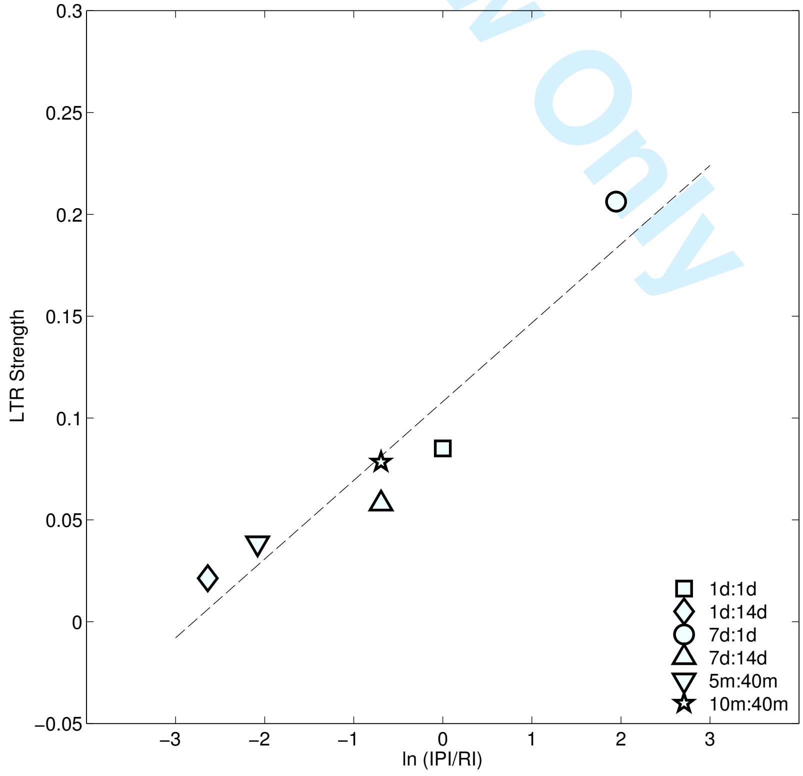

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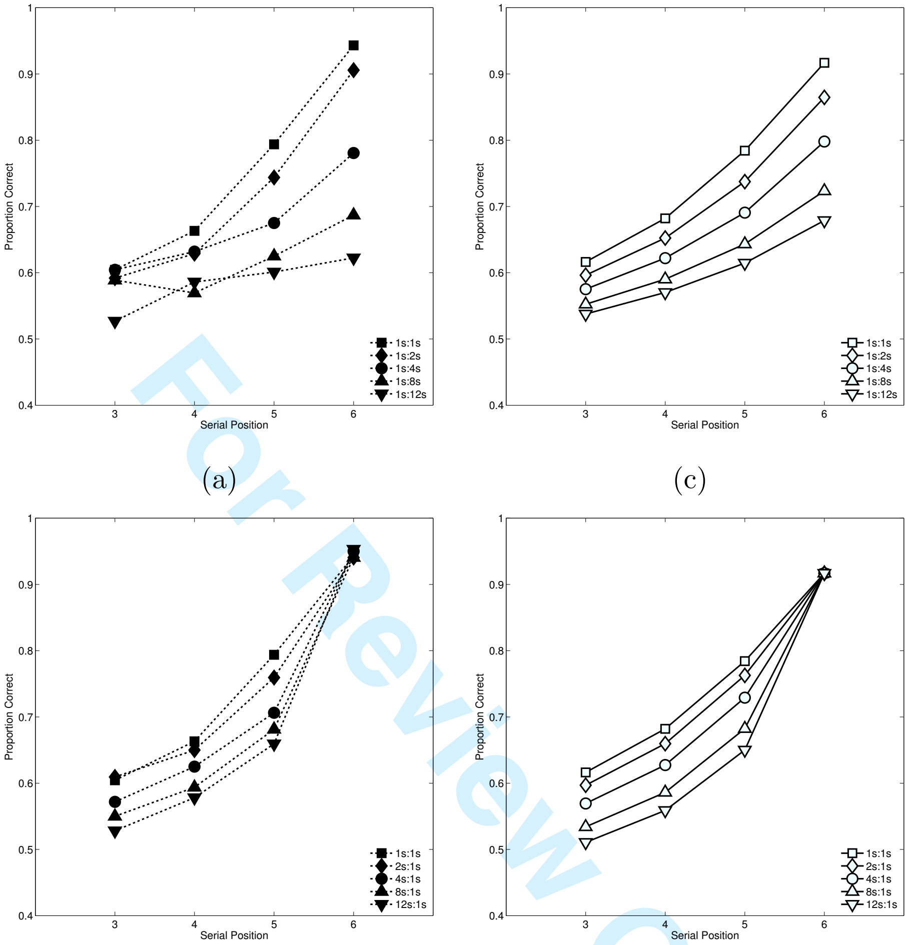

(a) (c)

(b) (d)

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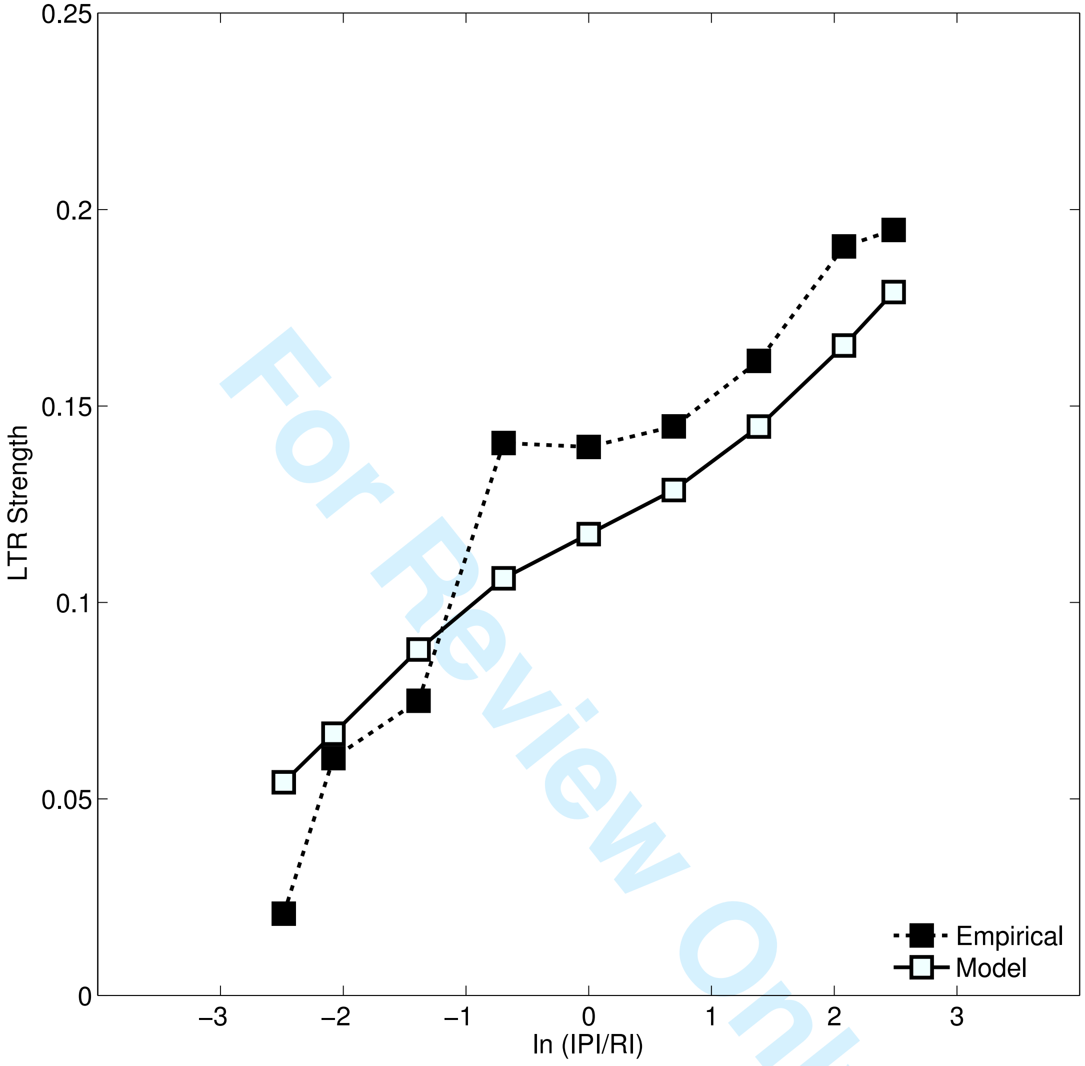

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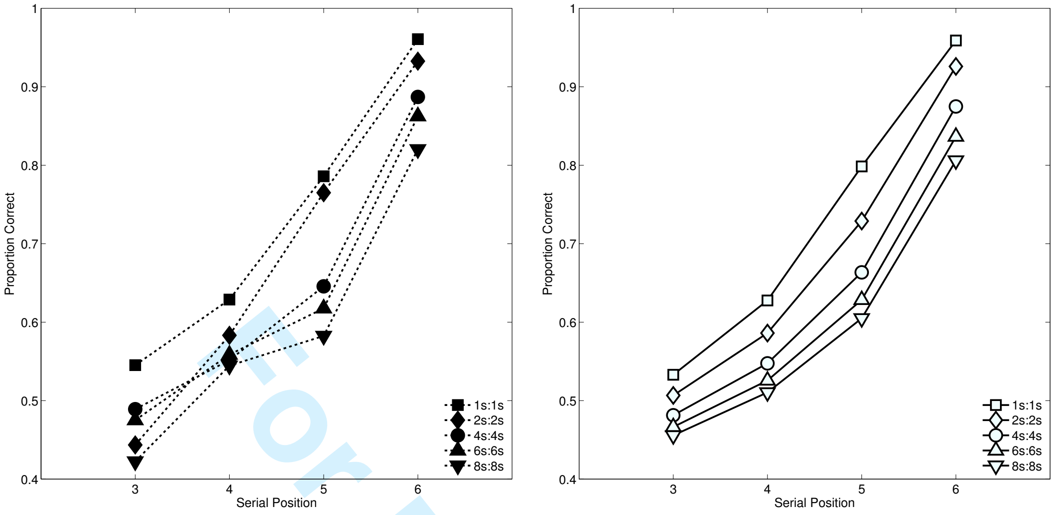

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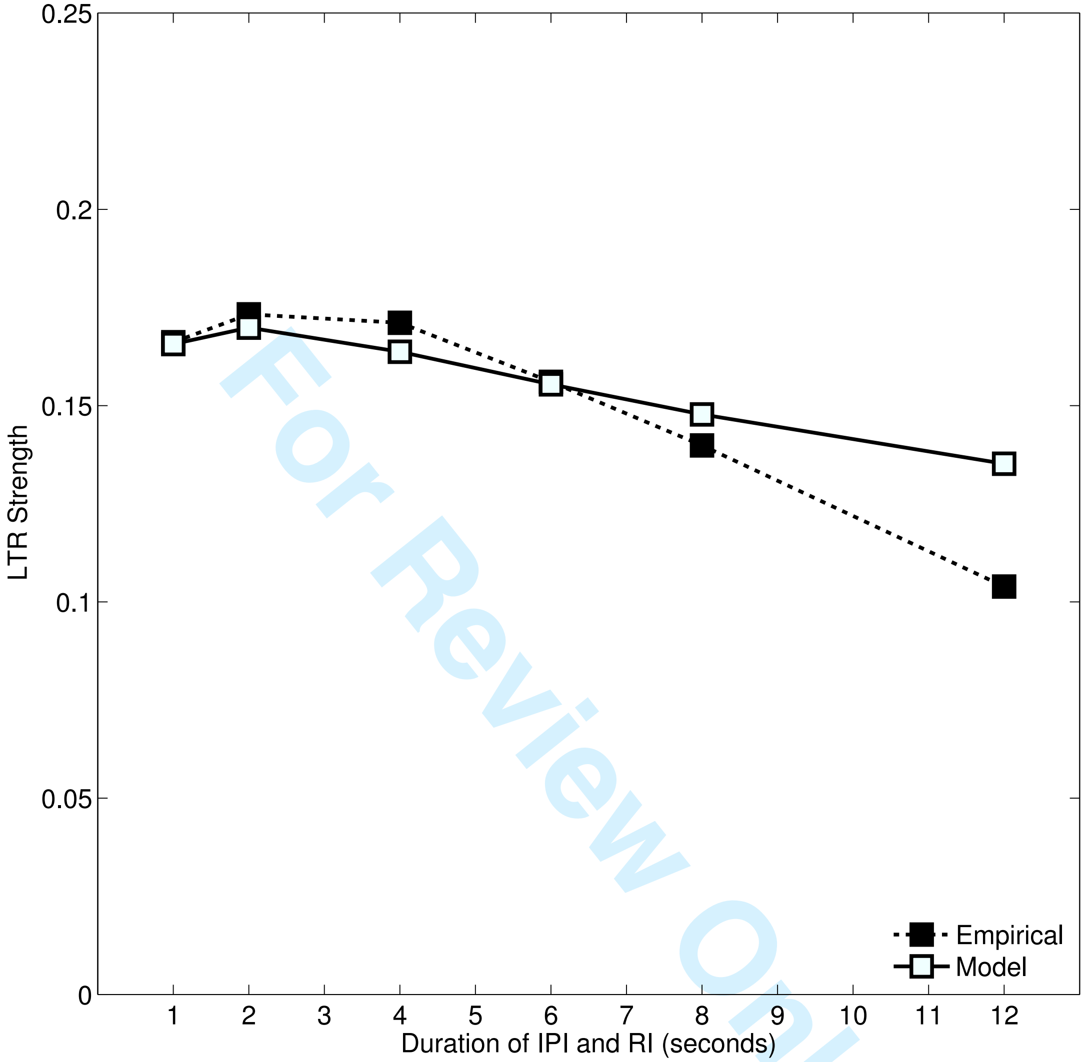

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