# Rapid Presentation Rate Negatively Impacts Free Recall Performance.

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**Abstract**

A prevalent finding in memory research is that recalling a previously studied item incurs a jump back in time, such that items temporally contiguous to the recalled element have a higher probability of being subsequently remembered. While widely explored, a remaining open question concerning this contiguity effect is the extent to which the presentation rate of study lists impacts this form of temporal binding. Here, we explore the persistence of the contiguity effect at presentation rates from 2Hz to 8Hz. Our results show that temporal binding was negatively correlated with rate, and significantly diminished for a presentation rate of 8hz. This frequency matches the upper bound of neural-related theta frequency, which has been linked to temporal encoding of episodic memories. However, we also found a diminished effect of semantic relatedness, thus raising the question of whether presentation rate is directly affecting encoding, subsequent recall, or both.

**Keywords:** Words, words, words, words

## Introduction

Cognitive neuroscientists have hypothesized that the successful retrieval of an episodic memory is accompanied by a "jump back in time," a recovery of the previous memory's context. In free recall, this recovery is characterized by the contiguity effect. Following a successful recall of an item, the next item to be recalled is more likely to come from a neighboring item than a more distant one. Lags, a directed distance between two items in a study list, are used to quantify this distance. For example, in the list "absence, hollow, pupil, river, darling", the lag from absence to river is 3, and the lag from darling to pupil is -2. This effect is robust, appearing across a variety of methodological manipulations (Kahana, 2012). It is also characterized by its asymmetry; forward transitions are more likely to take place than backward transitions of the same distance. This characteristic appears in all free recall studies that have looked at output order effects (Kahana, Howard, and Poyln, 2008). While this work has confirmed the existence of this effect in free recall in most experimental manipulations, it is unknown what impact rapid presentation rates during study would have on the contiguity effect. It is conceivable that increasing the presentation rate high enough could interfere with any mechanisms that allow for the temporal binding of presented items. The contiguity effect persists at presentation rates up to at least 1 Hz. but faster rates are unexplored (Howard and Kahana, 1999). Beyond the contiguity effect, free recall contains many other well explored patterns of behavior. The potential sensitivity of these effects to subtle manipulations is fueled by previous findings. We give a short overview of these next.

### Other Phenomena in Free Recall

**Primacy and Recency Effect** Consistent with a slowly changing temporal context, individuals exhibit a strong recency effect during a standard free recall task (Sederberg, Howard, and Kahana, 2008). That is, they are more likely to recall items presented during the end of the study period. Another robust finding is that participants are more likely to recall items from the beginning of a studied list (Murdock, 1962). The relative strength of these two effects is not constant, however. Davelaar et al. (2005), found that fast presentation rates during the study period (i.e., 10 Hz.) resulted in a primacy effect that was stronger than the recency effect. This ratio was in contrast to slower presentation rates (i.e., 5, 2.5, and 1.25 Hz.) where the recency effect was stronger than the primacy effect. The recency and primacy effects also manifest at the beginning of recall. Individuals are more likely to begin recall at the beginning or end of a list, with a higher probability for more recent items (Howard and Kahana, 1999). The effect of high presentation rates on the probability of first recall has not been reported.

**Semantic Proximity Effect** In addition to building temporal associations between words, there are pre-existing associations between words? semantic meanings. For example, the words strawberry and tomato have a higher association with one another than strawberry and bridge. These associations in semantic proximity have been shown to result in words with higher semantic relations being more likely to be recalled than less semantically related words (Howard and Kahana, 2002). It is unknown how fast presentation rates impact the expression of this effect.

Across these effects, there exist outstanding questions as to the impact of fast presentation rates. Therefore, in this study we investigated the impacts of presentation rate on free recall, focusing particularly on its modulation of lag-related contiguity response probabilities (CRP). This project is driven by a number of hypotheses. First, we hypothesized that as presentation rates increase, the temporal order of items fails to be encoded. In this event, one would expect to find a flattening of the contiguity effect. Second, in relation to recency and primacy effects, we expected that there would be a shift in

the ratio between primacy and recency as presentation rate increases. While Davelaar et al. (2005) demonstrated a flip in the ratio between the primacy and recency effects for overall recall between 10 Hz and slower presentation rates, they did not report the probability of first recall (PFR). Thus, we examine this measure, expecting to also find a shift in the PFR ratio as rate increases. Finally, due to the pre-existing nature of the semantic relations between words, presentation rate is not expected to have a major impact on the semantic proximity effect.

## Methods

### Subjects

330 undergraduates from the Syracuse University participated in this study. We do not possess specific demographic information at the time. Participants were excluded if they failed to recall a correct word in at least one trial (n = 15), and if they did not perform all three conditions (n = 7). The final number of participants was 308.

### Free Recall Experiment

Each participant was exposed to 18 lists of 20 words. Six lists were presented at 2hz, six lists at 4hz, and six at 8hz. List order was randomly assigned to control for sequential effects. Following the study period, participants were asked to verbally recall as many words as possible from each list. Participant responses were recorded, and later parsed using a semi-automatic speech parsing algorithm.

### Analysis

We first computed serial position curves (SPC), which show the overall probability of a word being recalled based on its original position in the study list. For each subject, we added the number of times a word in a given position was recalled, and divided it by the total number of recalls. This probability per position was then averaged across participants for each presentation rate separately. These curves helped us identify primacy and recency effects, so that all further analyses could be focused on recall transitions that were exempt from these effects (i.e. middle of the list). To measure the PFR, we extracted the position of the first item recalled per study list, and divided the number of times each position was recalled first over the total number of first recalls per participant. We then averaged these probabilities across participants per condition. We calculated the conditional response probability for each lag by dividing the number of correct recalls for a given lag by the total number of correct recalls (contained within the adjusted window derived from the SPC). In order to test for differences in the lag-CRP across conditions, we compared all combinations of presentation rates using a chi-squared permutation analysis (3 comparisons). This approach is based on analyses performed for meta-analytic studies of fMRI data (Wager, Lindquist, and Kaplan, 2007). For each comparison, we shuffled all the number of words recalled across conditions, and randomly assigned them to lags on each iteration (5000 times). On each iteration, the proportion of recalls per lag over the total number of recalls was compared across conditions using a chi-squared test of proportions, and the maximum chi-squared statistic was stored. The final 5000 chi-squared statistics were used as a null distribution to determine the significance of the observed differences on each lag. Finally, to analyze the effect of presentation rate on semantic proximity, we quantified the latter using a latent semantic analysis (LSA). We established 100 bins of semantic similarity, and each pair of words was placed in a bin based on the LSA score, so that the higher the bin, the higher the similarity for a given pair of words. Next, we calculated the probability of recalling a word based on its bin-based semantic similarity with the previously recalled one for each presentation rate. As with the lag-CRP, this was performed only on transitions that were independent from primacy or recency effects. This procedure helped us identify the extent to which participants relied on semantic similarity as they recalled words. We compared this reliance among presentation rates by means of a generalized linear mixed model (fitted with REML), using each subject as a random effect, with semantic bin and condition as fixed effects. We also tested the interaction between bin and condition.

## Results

### Overall Performance

Before examining the effects delineated above, it was necessary to explore general differences in memory performance. Perhaps intuitively, the total number of words recalled decreased as presentation rates increased (2hz: mean = 5.13, SD = 1.72; 4hz: mean = 4.19, SD = 1.45; 8hz: mean = 3.52, SD = 1.32; ANOVA: $F(2,5530) = 532.2, p < 0.001$). On the other hand, reaction times became faster as presentation rate increased (2hz: median = 1178 ms, SD = 4210 ms; 4hz: median = 1042 ms, SD = 3940 ms; 8hz: median = 996 ms, SD = 3566 ms).

### Primacy and Recency Effects

Consistent with previous findings, participants were more likely to recall words from the beginning and end of the list rather than words at the middle (Figure 1, left). Across presentation rates, participants were also more likely to recall the last word of the list rather than the first word of the list. In agreement with the results from Davelaar et al. (2005), the ratio between the probability of remembering these the first word and the probability of remembering the last word systematically decreased as presentation rate increased. Since primacy and recency can confound CRP results, we created a window based on this data that was exempt from these effects. Specifically, our CRP and semantic relatedness findings are based on items recalled between positions 5 and 15.

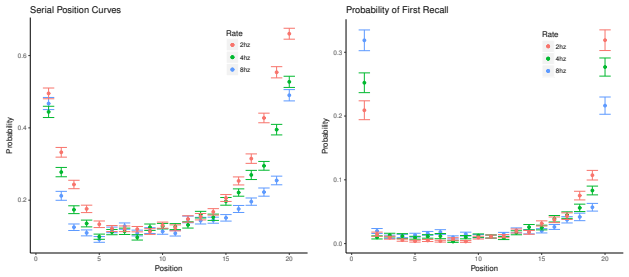


Figure 1: Left: Probability of recall as a function of position in study list. Primacy and recency effects are present for positions below 5 and over 15, respectively, and the ratio between effects gradually shifts as a function of presentation rate. Right: Probability of first recall. Primacy and recency effects are again demonstrated, with a flip in the prevalence of these effects as rate increases.

## Probability of First Recall

In general, participants were more likely to begin recall by reporting a word at the beginning or end of the list (Figure 1, right). In agreement with our hypothesis, as presentation rate increased, the probability of first recall shifted from showing a stronger recency effect to a stronger primacy effect. This shift resulted in a flip such that the probability of first recall was higher for the last item on the list than the first item for a 2 Hz. presentation rate, but lower in the 8 Hz. condition.

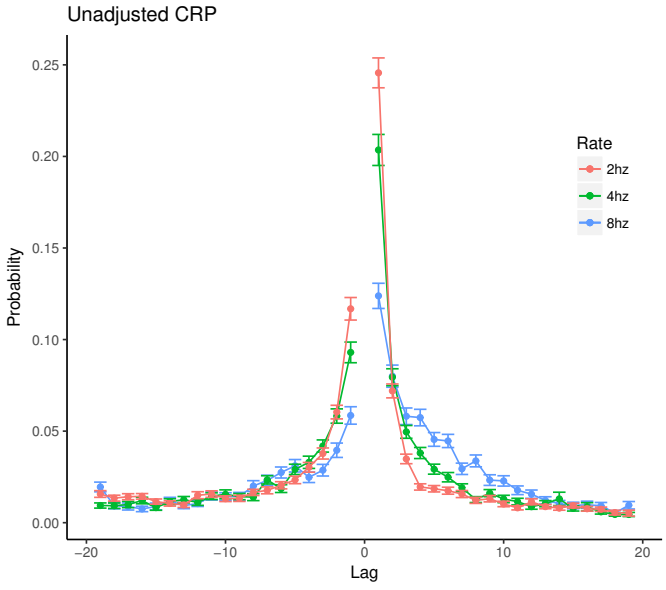


Figure 2: Lag CRP for all presentation rates. Contiguity effect visibly diminishes as presentation rate increases.

## Contiguity Effects

Figure 2 shows that after recalling a word, participants were more likely to recall a word that was presented closer in time than a word that was further away in the list. As expected, the strength of this effect decreased as presentation rate increased. There was a pronounced decrease in associations for backwards lags in the 8Hz presentation rate that was not present for 2Hz or 4Hz.

Next, we examined the lag-CRP while adjusting for primacy and recency effects. Figure 3 (left) shows that there is a reduction in temporal binding as the presentation rate increases, even when adjusting for serial position effects. While lag-wise chi-squared tests of proportions showed significant differences for all comparisons at a lag of 1, these differences were greatest for 2hz vs 8hz (Figure 3, right). Conversely, at a lag of -1 we do not see significant differences between rates of 2hz versus 4hz, thus showing the expected asymmetry between elements forward and backwards from the recalled word.

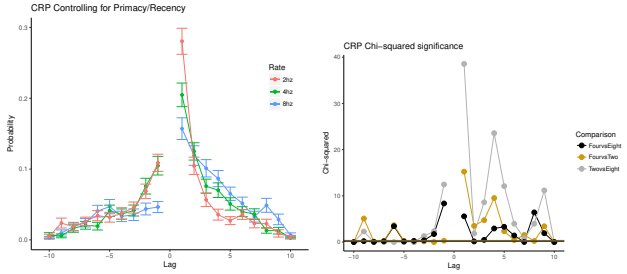


Figure 3: Left: Lag CRP adjusted for primacy and recency effects. The reduction in the effect persists. Right: Chi-squared values comparing the rate of recall at each lag among all presentation rates. Horizontal lines denote the 95th percentile from a permutation-based null distribution. There is a clear increase in the asymmetry between backwards and frontward jumps.

## Semantic Proximity

Finally, we investigated whether the rate-related effects on lag-CRP would be mirrored by semantic relatedness (Figure 4). Regardless of presentation rate, following the successful recall of a word, participants were more likely to recall a word that had similar semantic meaning (main effect of semantic bin: ? = 1.26e-04, 95 CI [0.009, 0.015], t(7674) = 8.47, p ¡ 0.001). However, the interaction between semantic bin and presentation rate showed that the effect of the former is significantly diminished when comparing 2hz to 4hz (? = -4.3e-05, 95 CI [-0.008, -0.0003], t(7674) = -2.1, p ¡ 0.05), as well as 8hz (? = -5.6e-05, 95 CI [-0.009, -0.001], t(7674) = -2.49, p ¡ 0.05). This shows that, similar to lag-CRP, the effect of semantic relatedness on contiguous recall probabilities is negatively impacted by increments in presentation rate.

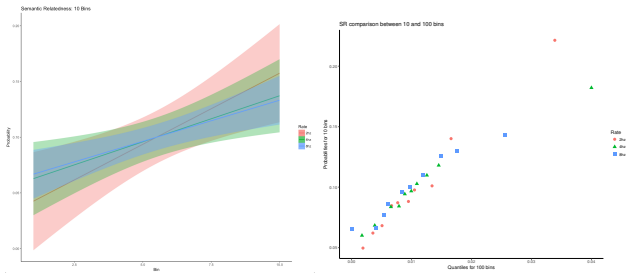

Figure 4: Left: Probability of subsequent recall as a function of semantic similarity, measured in 100 bins. Even though there is a positive relationship regardless of rate, the effect is diminished as a function of presentation rate. Right: Correspondence between 10 and 100 bins. Regardless of the number of bins used, the quantiles remain consistent.

## Discussion

It has been often observed that remembering past events is associated with a jump back in time, manifesting in a higher probability for temporally contiguous elements to be subsequently recalled. In this study, we investigated whether higher presentation rates would negatively impact our ability to engender this relationship. We found that in the 8 Hz. condition, the temporal binding of items was inhibited. This manifested as a flattening of the contiguity effect. Furthermore, there was a pronounced asymmetry between forward and backward transition probabilities. This is consistent with a failure to build temporal associations while maintaining an ability to recover a previous state of contextual drift. In addition to these findings, our results were consistent with previous free recall studies. For instance, the average number of words recalled per list decreased as presentation rate increased. In addition, as presentation rate increased, the strength of the primacy effect increased in relation to the recency effect. A novel finding was that individuals were more likely to initiate recall with the first item on the list in the 8 Hz. condition, whereas recall of the last item was more likely in the other conditions.

An interesting finding, contrary to our hypotheses, was that the semantic proximity effect was impaired as a function of presentation rate. This seems to indicate that, in addition to encoding, presentation rates can modulate the recovery of relationships. Thus, it remains to be seen whether presentation rates specifically inhibit encoding, subsequent retrieval, or both. Examination of encoding and retrieval periods using EEG could help address this issue in the future. Medial temporal lobe theta (3-8Hz) is related to successful encoding in free recall, particularly when binding elements temporally (Nyhus and Curran, 2010). In addition, Guderian and colleagues (2009) have shown that prediction of successfully-recalled items relies on theta frequency. While presentation rates of 2hz and 4hz are mostly contained within this frequency, 8hz lies at the upper bound of theta. It is possible that our presenting 8 words per second can outpace the brain?s ability to temporally associate the elements at hand, thus explaining why lag CRPs become weaker for this presentation speed.

These results suggest further experiments are necessary. Behaviorally, future studies should attempt to decouple the the lag contiguity and the semantic proximity effects. The nature of the stimuli presented is also worth exploring. Additionally, the contiguity effect manifests in some way in a variety of memory paradigms such as continuous recognition. If temporal binding does break down at high speeds, the contiguity effect should also diminish in these other paradigms. From a neural perspective, this paradigm falls naturally into EEG/MEG examinations. This would enable a fuller understanding of any links between theta oscillations in the brain, and temporal binding.