Strategic memory allocation in the dependency locality effect in comprehension

Weijie Xu (UC Irvine), Hailin Hao (USC), Richard Futrell (UC Irvine)

How is the limited capacity of working memory (WM) efficiently used to support human linguistic behaviors? We argue that WM resources are strategically allocated to prioritize novel and unexpected linguistic units, enhancing their representations to make them more robust against memory decay and interference[1-3]. We examine this hypothesis of strategic memory allocation through the lens of the dependency locality effect in comprehension, reflected in reading times.

Hypothesis and Predictions. In order to establish a syntactic dependency, an antecedent (i.e. left co-dependent) needs to be retrieved at the right co-dependent. The Dependency Locality Theory[4-5] holds that this retrieval difficulty is higher with longer dependency length *L*, due to memory decay and interference. Therefore, we first expect longer *L* to lead to higher RT at the retrieval site. Second, as hypothesized above, if novel and unexpected units are prioritized in WM and receive enhanced representation, then unexpected antecedents should tolerate longer *L* before their retrieval site, resulting in a reduced locality effect. That is, the RT at the retrieval site should increase at a slower rate as a function of *L* when the antecedent is of higher surprisal, resulting in a negative interaction between *L* and antecedent surprisal.

Corpus Analysis. We first examine our predictions with two English reading-time corpora, the *Natural Stories Corpus (NSC)*[6] (self-paced reading) and the *Dundee* corpus[7] (eye tracking). Antecedent surprisal -log $p(w_t|w_{<t})$ for each dependency is obtained from mGPT[8]. Dependency length *L* is measured as: 1) the number of intervening words; 2) the sum of surprisal over all intervening words. We run linear mixed-effect models on the log RT of right co-dependents. The critical predictor is the interaction between *L* and antecedent surprisal (Eq.1).

Result. As in Fig. 1 and 2, first, there is a significant main effect of locality, where longer *L* leads to longer RT at right co-dependents, especially for NSC corpus. Second, for both corpora, there is a significant negative interaction between *L* and antecedent surprisal, whereby antecedents of higher surprisal leads to reduced DLT effect.

Experiment. We examine our predictions in a controlled experiment (N=100) with A-Maze paradigm[9]. We focus on the subject–verb dependency, with the main verb (MV) being the retrieval site of the subject. As in (1), we manipulate subject surprisal and dependency length *L* in a 2x2 within-subject design (32 target items). Subject surprisal is manipulated through the adjective before the head noun. We run Bayesian multilevel linear models on the log RT of MV and 3 spillover words. The critical predictor is the *L* x Surprisal interaction (Eq.2).

Result. Fig. 3 shows the RT of critical MV and spillover words. In Crit, there is a *L* main effect, indicating a locality effect where longer *L* leads to longer RT at MV (b=.014, p(b>0)=.953). However, there is neither a Surprisal main effect nor an interaction effect. In Crit+1, there's no evidence for any main effect, but the data support a *L* x Surprisal interaction, where the locality effect is reversed for high surprisal subjects (b=-.009, p(b<0)=.96). In Crit+2, there is weak evidence for Surprisal main effect, where higher surprisal subjects lead to longer RT (b=.008, p(b>0)=.91). There is still weak evidence for a *L* x Surprisal interaction (b=-.008, p(b<0)=.91). In Crit+3, no effect was found.

Discussion. We find converging evidence for a reduced, even reversed locality effect for higher antecedent surprisal, suggesting that high surprisal antecedents are less susceptible to memory decay and interference. This result supports our strategic memory allocation, where unexpected linguistics units are prioritized in WM and receive enhanced memory representation[1-2].

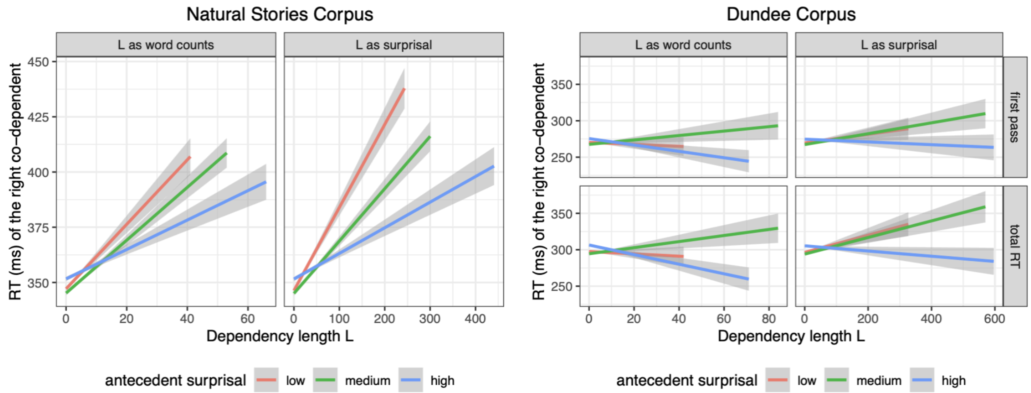

Fig 1: Interaction between dependency length and antecedent surprisal on the RT of the right codependent (with linear fits). Antecedent surprisal is a continuous variable, and is binned into tertiles.

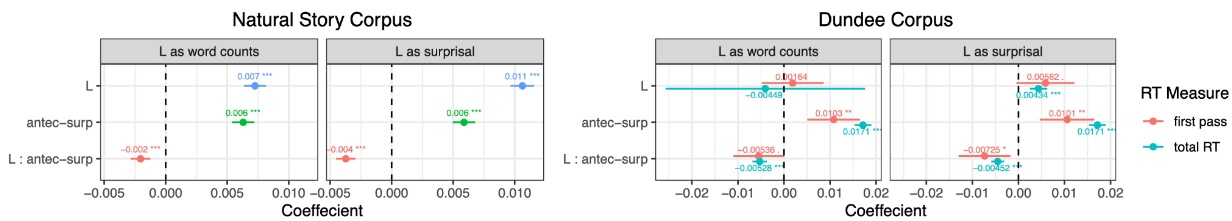

Fig 2: Statistical result on the log RT of right co-dependents (coefficient estimates with 95% CI)

Eq.1: logRT ~ *L* * antec.surp + sentence.position + antec.position + sentence.length + word.length + logfreq + logfreq.previous.word1 + logfreq.previous.word2 + (*L* * antec.surp | part) + (*L* * antec.surp | dependency.type)

(1) Sample stimuli for the A-Maze experiment. Critical region is the underlined main verb.

a. The evil *monster* $\left\{\begin{array}{c}\emptyset \\ \text{who stayed in the tower}\end{array}\right\}$ approached the princess although it only wanted a friend.

b. The cute *monster* $\left\{\begin{array}{c}\emptyset \\ \text{who stayed in the tower}\end{array}\right\}$ approached the princess although it only wanted a friend.

Eq.2: logRT ~ logRT.previous.word + *L**antec.surp + (*L**antec.surp | item) + (*L**antec.surp|part)

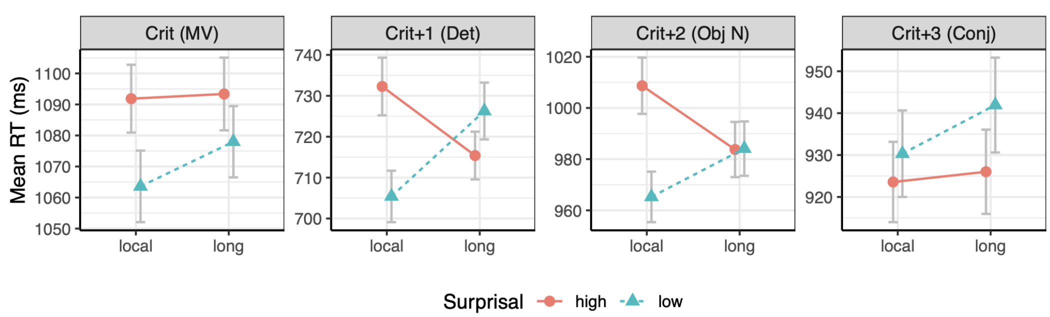

Fig 3: Interaction between antecedent surprisal and dependency length on the RT at the retrieval site.

References: [1] Xu & Futrel (2025) *JML*; [2] Xu & Futrell (2024) *SIGTYP*; [3] Hahn et al. (2022) *PNAS*; [4] Gibson (1998) *Cognition*; [5] Bartek et al. (2011) *JEP*; [6] Futrell et al. (2021) *Lang Resources and Eval*; [7] Kennedy & Pynte (2005) *Vision Research*; [8] Shliazhk et al. (2024) *TACL*; [9] Boyce et al. (2020) *JML*