Dynamic Duo: Insights from a Dual-Unit Predictive Coding Model of Lexico-semantic Processing

Samer Nour Eddine[1], Trevor Brothers[3], Thomas Hansen[1], Gina R. Kuperberg[1,2]

[1] Tufts University, [2] Massachusetts General Hospital, [3] North Carolina Agricultural and Technical State University

Introduction

Many behavioral and neural experiments show that **accessing the meaning of linguistic input** is facilitated in supportive contexts

For example, supportive linguistic contexts can be:

- Prime-target pairs (e.g., salt–PEPPER)
- Sentence or discourse contexts (e.g., "I baked a birthday…***cake***")

In these contexts, facilitation often manifests as **faster behavioral responses** and **reduced neural activity** to predictable words [1]

Easy to interpret faster behavior as facilitation, but it is less clear for reduced neural activity

Thus, we would benefit from a model with explicit constructs that can explain these behavioral and neural patterns

Predictive coding (PC) [2] implemented in Nour Eddine et al. (2024) [3] is an ideal model for this task:

- Dual-unit architecture captures both patterns (*state* vs. *error* units)
- Theoretical framework used in neuroscience
- Brain **predicts** sensory inputs, **observes** the actual input, and then **updates** its predictions based on the discrepancies between them
- Cortical dynamics aim to minimize discrepancies (*prediction errors*); these errors represent the information flowing through the system.

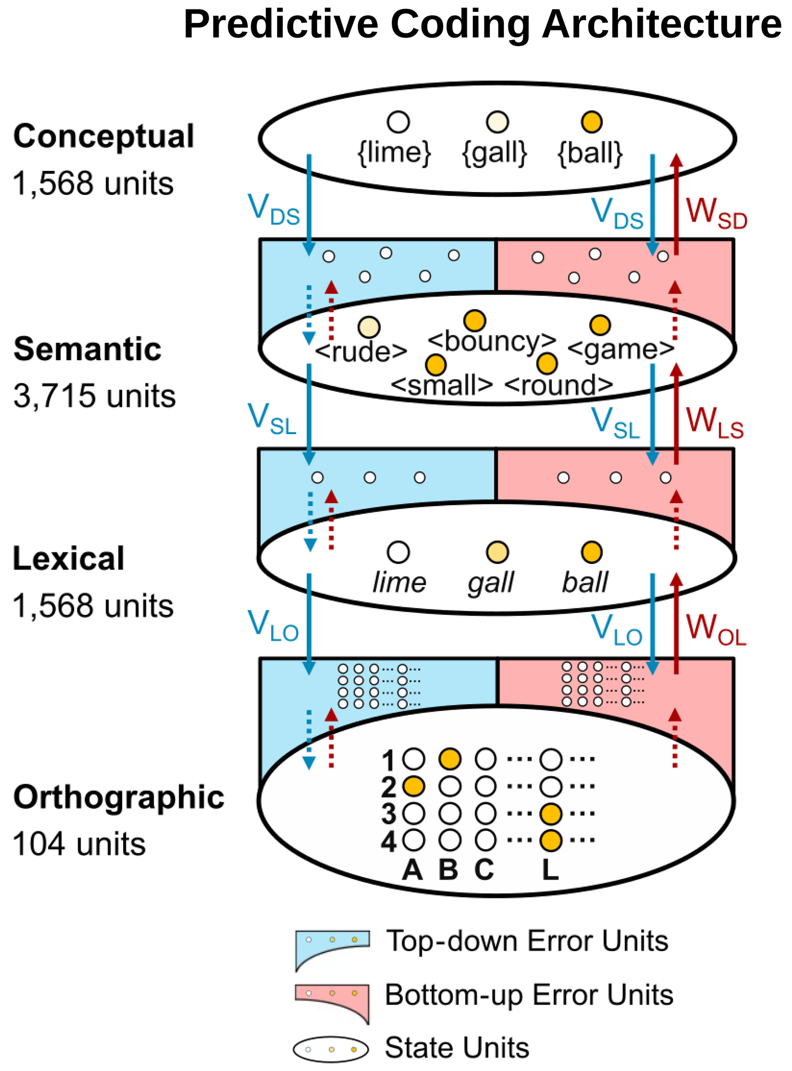
Method: Architecture & Algorithm

PC for language: Hierarchical, each level has two kinds of units:

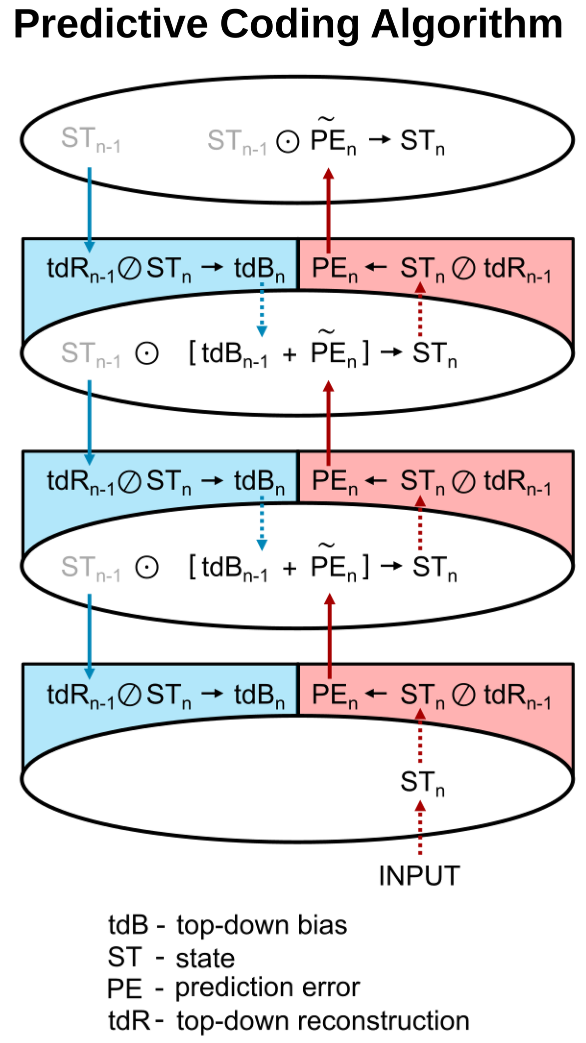
- **State units** encode internal representations inferred by model
- **Error units** encode the difference in information encoded in state units at that level and predictions generated by the level above

At each iteration *n*, (1) state units get updated; (2) prediction error computed; (3) top-down predictions generated

Predictive Coding Architecture



Predictive Coding Algorithm



Present Study

Our model captures most behavioral (reaction time data) and neural (centroparietal N400 response amplitudes) from the prior literature

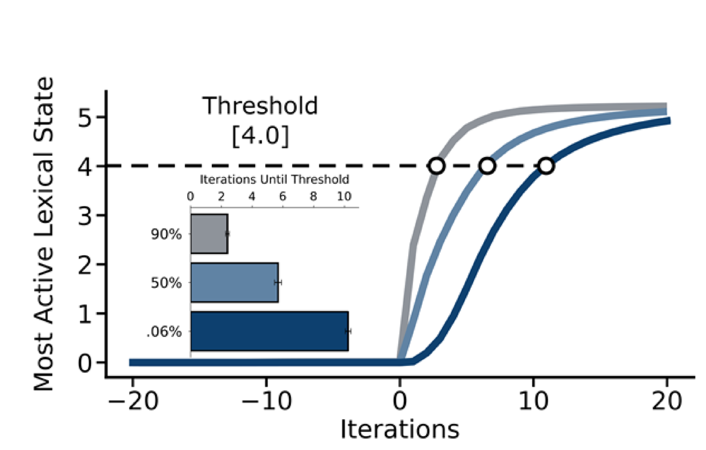
We explore a novel prediction: Input that *superficially* matches an expected input should (i) **attenuate the neural activity** (N400) but (ii) **slow down comprehension behavior** (reaction times, RTs).

To test this, we conducted both simulated and empirical research.

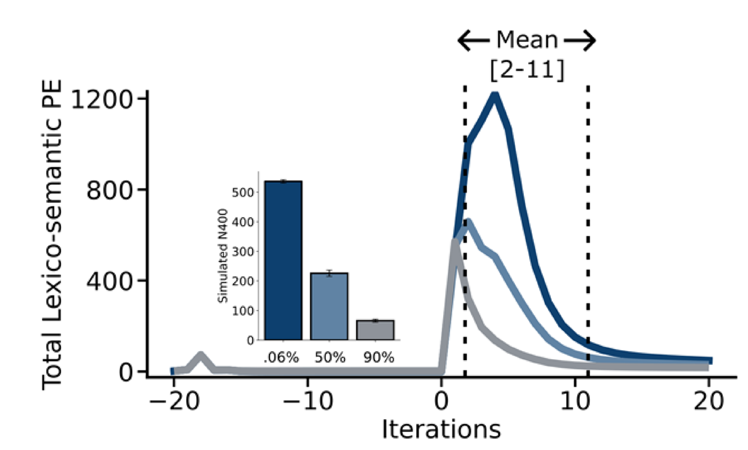
Study 1: RT and N400 Simulated Effects

Contextual predictability simulations: *Pre*-activate dummy layer for 20 iterations; then provide target input for 20 iterations**.**

Simulated RTs (State Units)

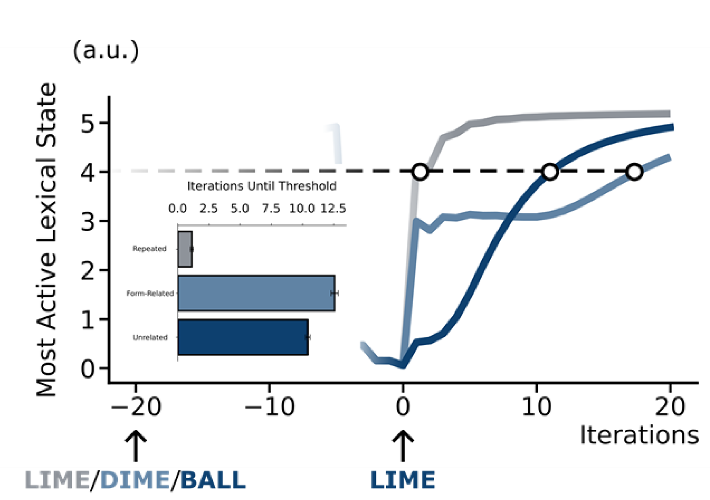


Simulated N400 (Error Units)

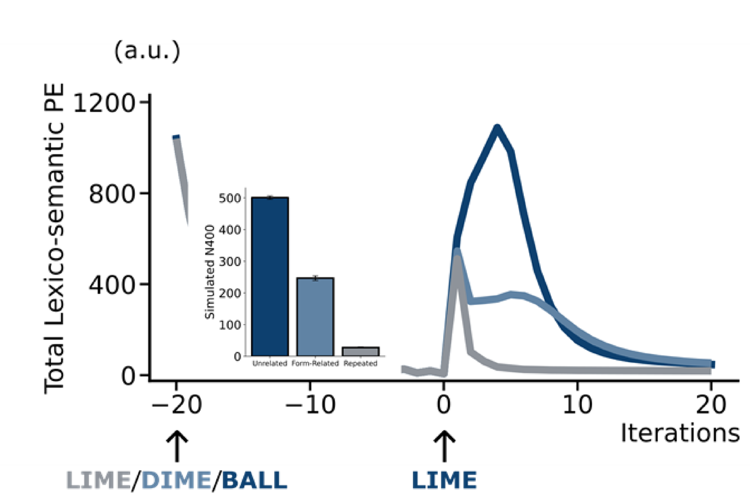


Priming effect simulations: Present the prime for 20 iterations; then blanks for 20 iterations; and then the target for 20 iterations.

Simulated RTs (State Units)



Simulated N400 (Error Units)



***For statistics:** RTs = Number of iterations after target for any state to cross threshold; N400s = Summed prediction error from lexical and semantic levels from iterations 2–11.

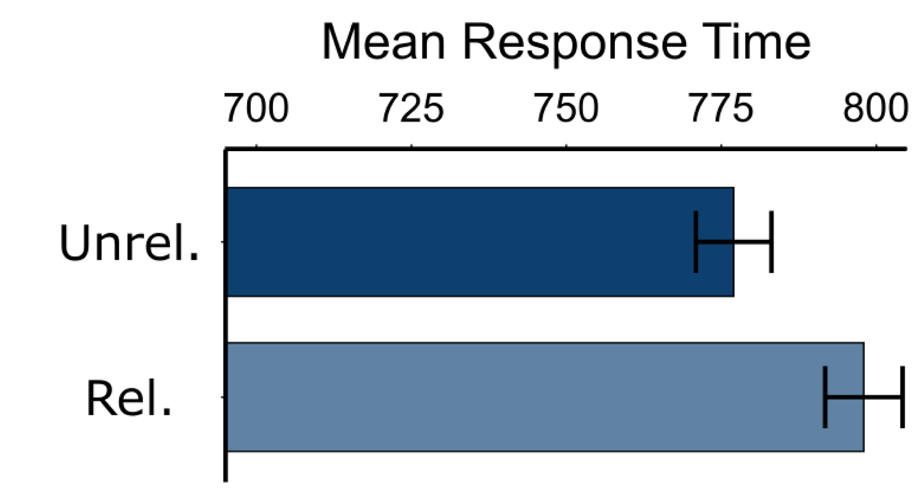
Study 2: RT and N400 Empirical Effects

Design. Present Form-Related (dime-LIME) or Form-Unrelated (ball-LIME) pairs to English-speaking adults.

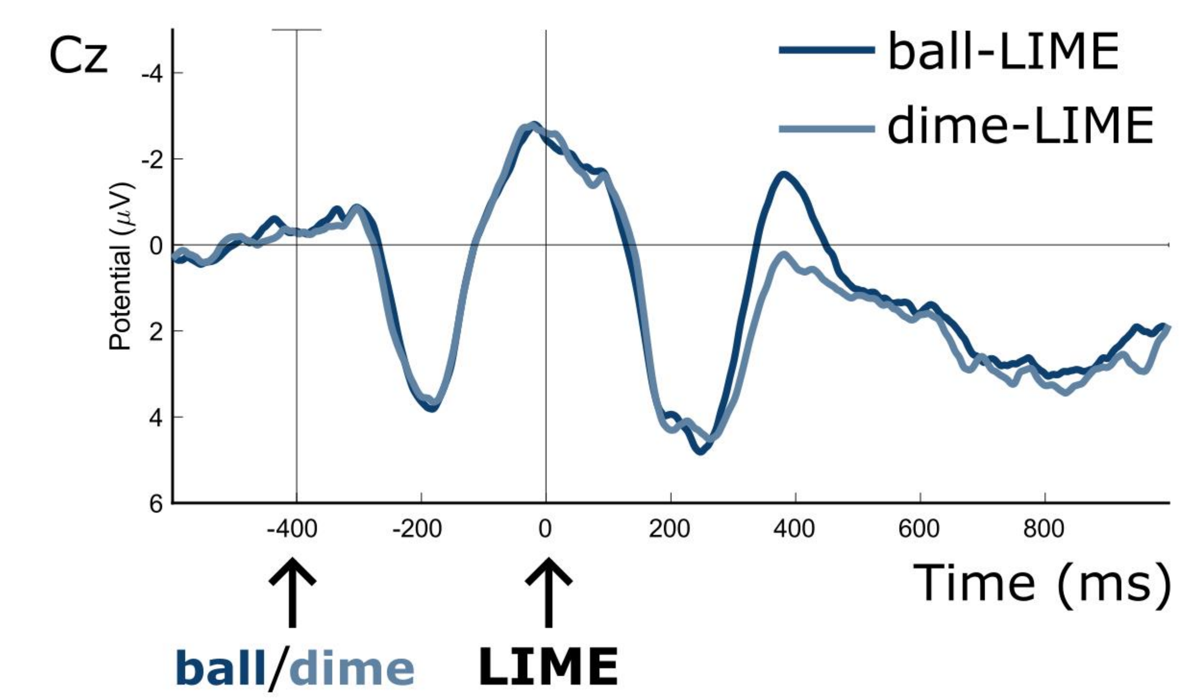
Tasks. (*Online*, **N = 64**) Categorize target words as being abstract or concrete. (ERP study, **N = 22**) Monitor prime-target pairs for animal words, which occurred on 56 filter trials. Presented at SOA of 400ms.

Prime-target stimuli. 320 four-letter target words, half abstract, half concrete; Related primes created by changing one letter; unrelated primes by shuffling; across subjects, target words occurred in both conditions

Study 2: Empirical results



Behavioral and neural constructs dissociate!



Discussion

In PC, **RTs** reflect the accumulating activity for a target (*state units*), whereas **N400s** reflect the *mismatch* between our expectations and the target (*error units*).

PC replicates the patterns found when expectations match the input:

- Target State units are activated *before* the target input appears
- Model settles on correct target state units faster → **Faster RTs**
- Active target states then suppress prediction errors → **Reduced N400s**

We also explored **novel predictions** from PC:

- When the input *superficially* matches expectations (form priming; dime-LIME), non-target state units inappropriately suppress prediction errors
- This results in **reduced N400s** but **longer RTs**, suggesting that N400s carry information about bottom-up input and is critical to comprehension

Future work seeks to (i) **reproduce this dissociation in sentences** and (ii) **assess how *semantic* overlaps influence task performance** when needing access to the non-overlapping semantic features.

Acknowledgments

We thank Anthony Yacovone for his comments. This work was funded by the NICHD (R01MHD082527) to G.R.K

[1] Kutas & Federmeier (2011). *Annual review of psychology*, 62: 621-647; [2] Rao & Ballard (1999). *Nature neuroscience*, 2(1), 79-87; [3] Nour Eddine, Brothers, Wang, Spratling & Kuperberg (2024) *Cognition, 246, 105755.* [4]