Timing is everything: EEG and Predictive Coding simulations show that reading conditions influence whether late frontal positivities track misprediction or lexical predictability

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Introduction

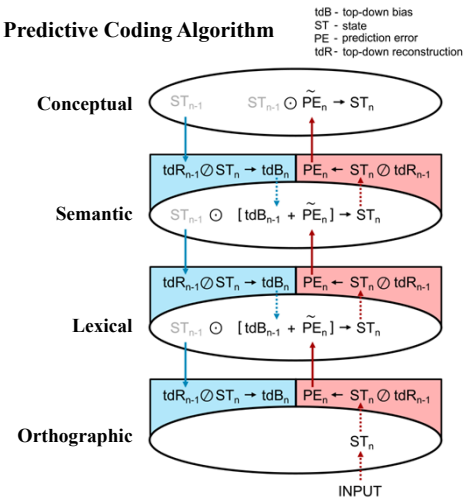
N400 (300–500 ms)

- Evoked by all content words during natural comprehension [1]
- Smaller to expected than unexpected inputs → predictions from higher-level states explain bottom-up input
- In **Predictive Coding**, **bottom-up residual error (buPE)** = information encoded in bottom-up input that was not predicted ("reconstructed") by higher-level states [2,3]

Late frontal positivity (LFP, 600–1000 ms)

- Sometimes follows N400 to unexpected but plausible words, especially when a situation model has been established [4,5]
- In **Predictive Coding**, **top-down residual error (tdB)** = information currently encoded in higher-level states that is not encoded in lower-level states [3]

Predictive Coding Algorithm



"Misprediction" LFPs

- During RSVP, LFPs selectively evoked by **unexpected but plausible words** that disconfirm strong prior predictions [4,5]

"He bought her a necklace for her **collection**/birthday."

Puzzle: LFPs in Low Constraint contexts

- During self-paced reading, LFPs produced non-selectively to unexpected words → in low constraint contexts where misprediction is unlikely [6]
- Here, LFPs (like the N400) scale with lexico-semantic prediction → less positive/more negative for predictable words

The Present Study

Question 1: Are LFPs routinely evoked by all content words during self-paced reading of short, natural stories?

Question 2: Can both LFP patterns — sensitivity to predictability vs. misprediction — be reconciled within a single Predictive Coding framework?

ERP Study

Participants (**N = 22**) self-paced through short, engaging vignettes

Cloze obtained for all content words (N = 361 raters, ~30 obs/word)

ERPs extracted for LMERs*

- **N400** = 300–500 ms (Cz/3/4, Pz/3/4, CPz/1/2)
- **LFP** = 500–1000 ms (FPz/1/2, Fz/3/4, AF3/4)

***Analysis Details:** LMER on word-level N400s or LFPs • Only analyzed words with higher probability alternatives • **Fixed effects:** Predictability (cloze of target); Mispredction (cloze of most common alternative); **Nuisance variables:** ONSize, Frequency, Concreteness. All z-scored.

Predictive Coding Simulations

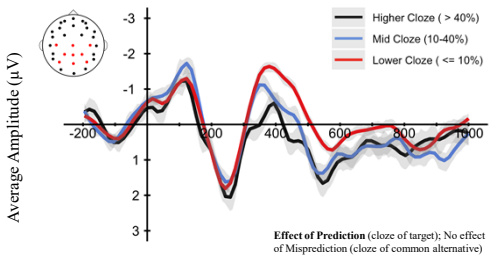
Implemented a Predictive Coding model of lexico-semantic processing

Simulated ERPs:

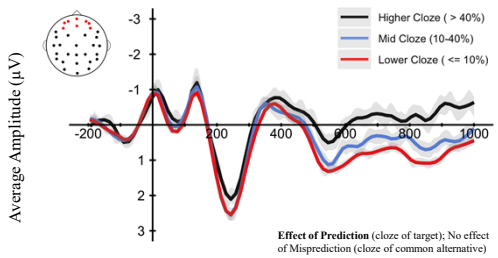
- **Simulated N400 = Bottom-up residual lexico-semantic error (PE)** at each iteration as the model converged
- **Simulated LFP = Top-down residual lexico-semantic error (tdB)** at each iteration as the model converged

Varied **degree of overlap** between top-down and bottom-up activation phases—the phase timings are depicted in simulation figures below

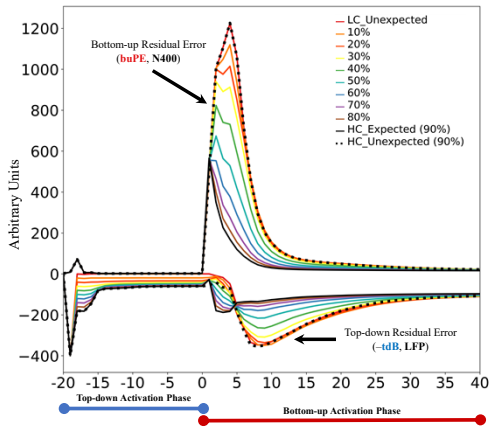
N400 Results (300–500 ms)



LFP Results (500–1000 ms)



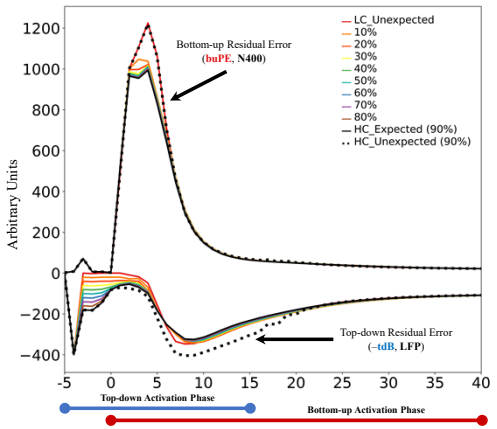
Simulation 1: Present bottom-up input *after* top-down activation phase; **cf. Self-paced reading**



Why LC Unexpected > HC Expected and HC Unexpected > HC Expected?
- Unexpected words activate orthographic neighbors & their semantic features → representational misalignment → more tdB
- The more pre-activation, the more suppression of neighbors & their features → less tdB

Why HC Unexpected = LC Unexpected?
- Top-down error from misprediction doesn't overlap with bottom-up phase → no tdB for misprediction → non-selective LFPs

Simulation 2: Present bottom-up input *during* top-down activation phase; **cf. fast RSVP**



Why LC Unexpected = HC Expected?
- Less top-down *pre*-activation → unable to suppress activation of orthographic neighbors and their semantic features → similar tdBs

Why HC Unexpected > LC Unexpected?
- Overlap in top-down and bottom-up activation → continued misprediction = prolonged misalignment → more tdB for misprediction

Discussion

Answer 1: Yes, LFPs evoked by all content words during self-paced reading of short, natural stories

- Highly **sensitive to lexico-semantic predictability**; not sensitive to misprediction
- **Predictive Coding Mechanism:** Residual misalignment between levels → information encoded in higher-level states not encoded in lower lexical states → continued propagation down of top-down residual error (**tdB**)

Answer 2: Yes, two sources of lingering misalignment (top-down residual error) across generative hierarchy

- **Misprediction LFP:** Reconstructions = ***outdated incorrect*** top-down predictions inconsistent with current bottom-up lexical input
- **Probability-sensitive LFP**: Reconstructions = ***residual semantic features*** activated during bottom-up processing
  - These features are irrelevant to input (e.g., semantic features of orthographic neighbors, not of the target)
  - Activation of these features is **reduced** by top-down lexical-level pre-activation of expected inputs → *sensitivity to lexico-semantic probability* (**cloze**)

Timing of bottom-up and top-down activation

- May explain why LFPs can be *selective* to mispredictions (RSVP), but otherwise *non-selective* in a graded way to unpredicted words (self-paced reading, longer SOAs)
- Longer *pre*-activation → more top-down cycles → default LFP to unexpected words is attenuated, regardless of misprediction
- Bottom-up activation coincides with top-down activation → fewer top-down cycles & overlapping phase of active misprediction → *selective* LFPs to misprediction

Limitations of present study

- In model, top-down activation externally provided → In brain, we assume it originates from higher-level situation model
- Model only likely to capture *initial phase* of LFP (the trigger)
- Extended phase of LFP may be linked to the active retrieval of new event schemas from long-term memory
- Retroactive propagation of new information down the hierarchy → prolonged top-down error until lower-level representations are fully aligned with higher-level updates

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References: [1] Kutas & Federmeier, 2011; [2] Nour Eddine et al., 2024; [3] Rao & Ballard, 1999; [4] Federmeier et al., 2007; [5] Brothers et al., 2020; [6] Payne & Federmeier, 2017.