Proportional semantic pre-activation during sentence comprehension: Evidence from ERPs

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While, anticipatory processing mechanisms are a central to many theories of sentence comprehension, it has been difficult to experimentally disentangle effects of contextual predictability and other forms of processing difficulty. Indeed, to date, there is little *direct* neural evidence that readers probabilistically predict upcoming semantic information during everyday sentence comprehension. Three pieces of evidence in particular would provide strong support for semantic pre-activation during reading: 1) the anticipatory responses of interest should appear *prior* to the onset of the predicted stimulus, 2) these neural responses should be "representational" in nature, carrying information that co-varies with relevant linguistic properties of the anticipated word, and 3) the strength of this anticipatory response should increase as the subjective probability of encountering the stimulus increases.

During sentence processing, concrete words (e.g. *farm*) are known to elicit larger neural responses than abstract words (e.g. *truth*). Here, we used this abstract/concrete distinction to probe the time-course of semantic activation during the processing of sentences with different levels of lexical constraint. Specifically, we tested whether the semantic features of a predicted word would be encoded in reader's patterns of neural activity *prior* to word onset. By using a continuous manipulation of contextual constraint, we also tested whether the magnitude of these anticipatory neural responses would increase proportionally with lexical predictability.

Methods: We developed a set of 216 sentence triplets, which parametrically manipulated the lexical predictability of individual critical words (cloze: HC=90%, MC=20%, or LC=1%, based on offline norms). These critical words also varied continuously in concreteness (range: 1.6 - 5.0). Participants in the main ERP experiment (N = 32) read one sentence from each triplet, presented using self-paced rapid serial visual presentation (mean RT = 282ms per word). The participants' only task was to answer True/False comprehension questions following 25% of sentences. Neural activity was recorded continuously from the scalp, and measures of contextual constraint and lexical concreteness were used to predict the magnitude of single-trial ERP responses both before (-200 to 0ms) and after (+300 to +500ms) the onset of each critical word.

ERP Results: In the post-stimulus N400 time-window we observed significant interactions between contextual constraint and concreteness (t =2.73, p = .006). A robust concreteness effect was observed for unpredictable words, and the magnitude of this concreteness effect decreased in more predictive sentence contexts (LC: -1.3μV ± *0.5*, MC: -1.2μV ± *0.5*, HC: -0.4μV ± *0.5*). Critically, in the anticipatory window before critical word onset, ERP responses also co-varied with the concreteness of the *upcoming* word (t = -3.28, p =.001), and the magnitude of this anticipatory concreteness effect was also modulated by sentence constraint (t = -2.40, p =.017). As predictability increased, neural signals in this anticipatory window began to more strongly reflect the upcoming word's abstract/concrete semantic properties (LC: -0.01μV ± *0.4*, MC: -0.32μV ± *0.3*, HC: -0.62μV ± *0.4*). The scalp distribution of these concreteness effects in the anticipatory and post-stimulus time-windows were highly similar (r = 0.81, p = 0.003, *permutation test)*, suggesting they may represent reciprocal activation of same underlying neural process (i.e. the activation/pre-activation of concrete semantic features).

Discussion: These findings provide clear evidence for the probabilistic pre-activation of semantic information during word-by-word sentence comprehension. These results are consistent with specific predictive processing accounts, in which pre-activation strength scales proportionally with lexical expectancy, and pre-activation can directly influence the difficulty of lexico-semantic retrieval. The design of the current experiment allows us to rule out a number of alternative explanations for these findings, including low-level lexical confounds, artificial task demands, and unnaturally slow presentation rates.

Examples of sentences with concrete and abstract critical words:

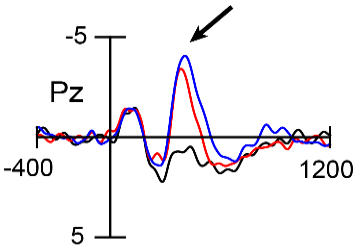
HC: Her vision is terrible and she has to wear **glasses** in class.
MC: She looks very different when she has to wear **glasses** in class.
LC: Her mother was adamant that she has to wear **glasses** in class.

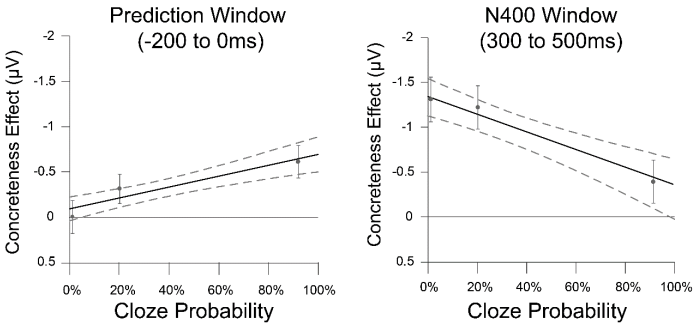
HC: Old McDonald had plenty of animals on his **farm** in Pennsylvania.
MC: My uncle planted lots of trees on his **farm** in Pennsylvania.
LC: My uncle is installing solar panels on his **farm** in Pennsylvania.

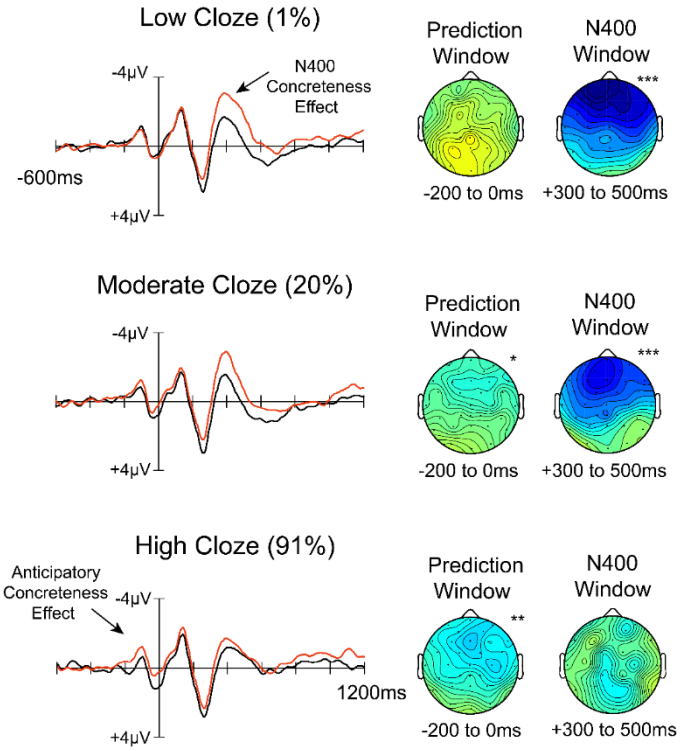
HC: There's no need to lie, you can tell me the **truth** about Sarah.
MC: My friend at the office refused to tell me the **truth** about Sarah.
LC: The police officer was unsure if he could find the **truth** about Sarah.

HC: The disease is fatal and there is no known **cure** for it.
MC: This danger is real and there is no known **cure** for it.
LC: We heard that the remote island has no known **cure** for it.

Main effects of Cloze on the N400







(*Figure Above*) E*ffects of semantic concreteness on ERP amplitudes over frontal-central electrode sites, plotted at different levels of cloze probability in the prediction window (left) and N400 time window (right). Errors bars are ±1 SEM.*

(*Figure to the Right*) *The left panel shows the average magnitude of the semantic concreteness effect over frontal-central electrode sites, for low, moderate, or high cloze critical words. Continuous effects of concreteness at each level of cloze probability are superimposed on the grand-average ERP waveform in each condition. The vertical line represents critical word onset. The right panel shows the topographic distribution of the concreteness effect at each level of cloze probability, in both the "prediction window" (-200 to 0ms) and in the N400 time-window (300-500ms).* p* < .05, ***p* <. 01, *** *p* < .001

References:

Luke & Christianson, (2016). Limits on lexical prediction during reading. *Cognitive Psychology*

Nieuwland, et al., (2018) Large-scale replication study reveals a limit on probabilistic prediction in language comprehension. *eLife*

Holcomb, Kounios, Anderson & West, (1999), Dual-coding, context-availability, and concreteness effects in sentence comprehension: An electrophysiological investigation. *JEP:LMC*

Wang, Kuperberg & Jensen, (2018) Specific lexico-semantic predictions are associated with unique spatial and temporal patterns of neural activity *eLife*