A Probabilistic Framework for Understanding the Neurobiology of Language Comprehension

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Introduction

The Challenge of Language Comprehension

- We must decode a sequence of letters or sounds that unfold rapidly in real time...
- ...in a noisy environment
- ...in the face of ambiguity at all levels of the language code.

To overcome this challenge, we draw upon stored linguistic and real-world knowledge, which we can mobilize very quickly as language unfolds in real time.

Do we use this stored information to *predict* upcoming information prior to bottom-up input?

Well, what do *you* mean by prediction?
Are you assuming

- an all-or-nothing phenomenon (we either predict or we don't)?
- that prediction = lexical prediction (we predict either a specific lexical item, or group of lexical items)?

What *I* mean by prediction

- Occurs at multiple levels of representation: semantic features (1), coarse semantic features (2), syntax (3), phonology (4), orthography (5)
- Graded (6)
- Probabilistic (7)

Two Questions

1. Can the *level of representation* at which we predict determine what neurocognitive mechanisms we engage to integrate an incoming word into its context?

In a probabilistic Bayesian framework of neurocognition, integration = prediction error = difference between what we predict and what we get.

Predictions of specific event(s): predictions of mapping(s) between wordform (phonology, orthography), semantic features and syntactic properties of a specific incoming word.

So if incoming word matches on syntax but mismatches semantic features and/or wordform, then integration is at the semantic-wordform interface.

Predictions of event structure(s): predictions of mapping(s) between coarse semantic features (e.g. animacy) and syntactic properties of an incoming word.

So if incoming word mismatches on coarse semantic features and/or syntax, then integration is at the semantic-syntactic interface.

2. Can the *strength/certainty* of our predictions determine what neurocognitive mechanisms we engage to integrate an incoming word into its context?

In a probabilistic Bayesian framework, prediction error is weighted by the *certainty* of our beliefs/predictions (in information theory, formalized as entropy).

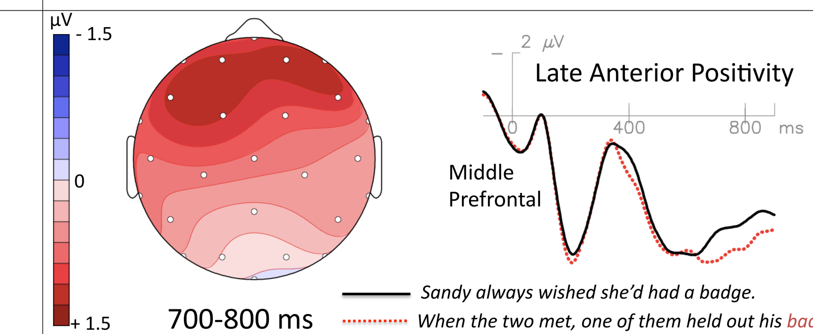
So if incoming word violates a strong, high certainty prediction, this triggers a shift outside existing hypothesis space: its integration into context is through (delayed) bottom-up processing.

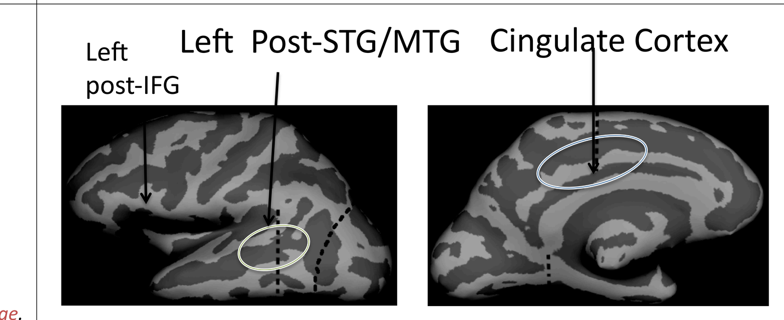
And if an incoming word is consistent with one of a few medium certainty predictions, it cannot be integrated until its competitor predictions are suppressed: its integration into context is through (delayed) top-down selection.

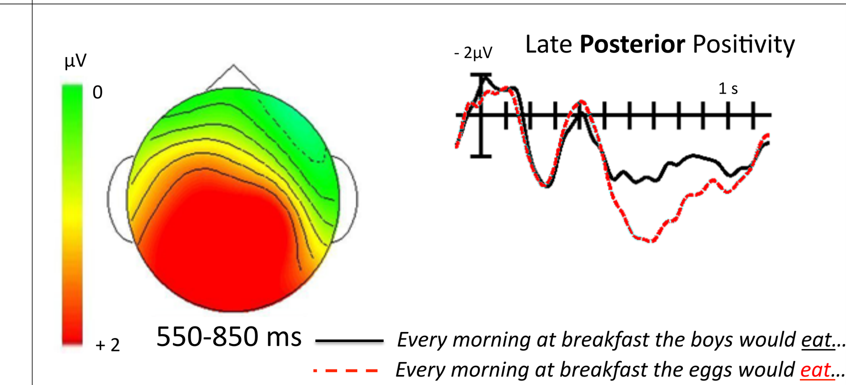
Some Tentative Answers

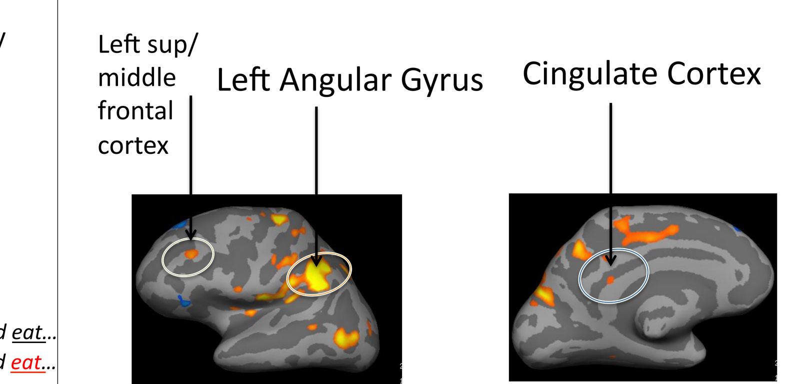
<table>
<tr><th>Certainty & Strength of prediction(s)</th><th>Representational level of prediction(s)</th><th>Encountering mismatching input..</th><th>Mechanism of integration</th><th>ERP signature</th><th>Neuroanatomy</th></tr>
<tr><td rowspan="2">High certainty prediction for one specific mapping between...</td><td>...wordform + semantic features
i.e.
Specific lexical item
Specific event</td><td rowspan="2">Detection of conflict

Suppression of predicted representation

Input is integrated with context through...</td><td>...bottom-up lexico-semantic processing</td><td>

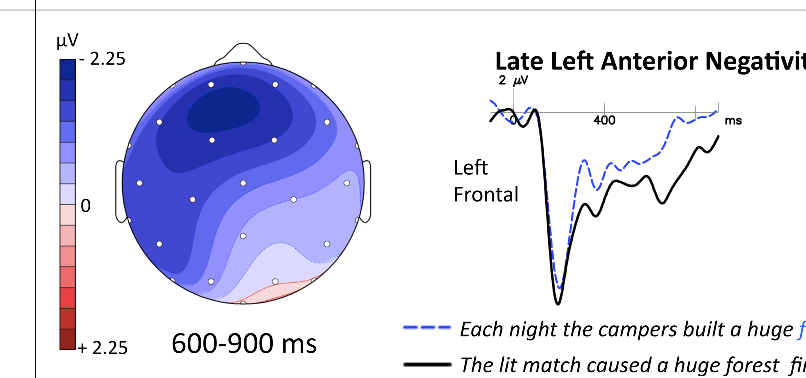
From: (8) Federmeier et al. (2007)
See also: (9,10). For review: (11).</td><td>

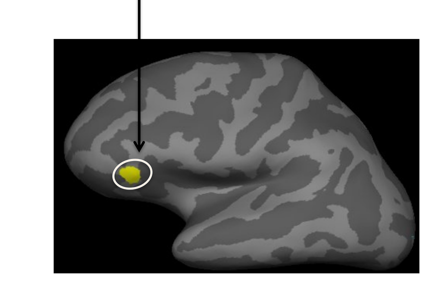
Hypotheses
Motivated by: (24) (25) (26)
Motivated by: (27)</td></tr>
<tr><td>...syntax + (coarse) semantic features (e.g. animacy)
i.e.
Specific semantic role
Specific event structure</td><td>...bottom-up semantic-syntactic processing</td><td>

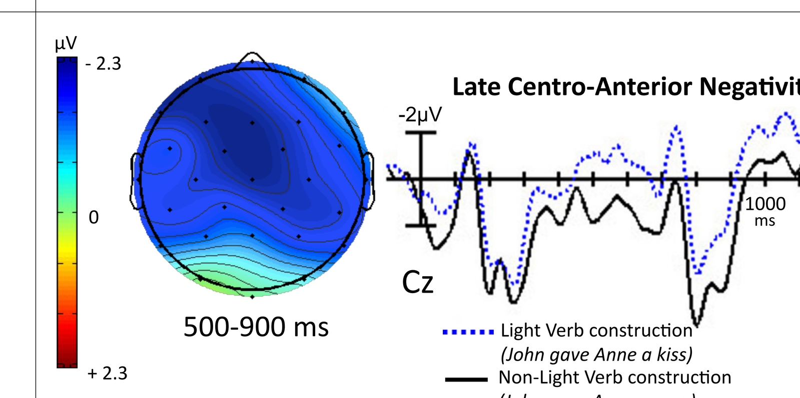
From: (12) Kuperberg et al. (2003)
See also: (2, 13-16). For review: (17).</td><td>

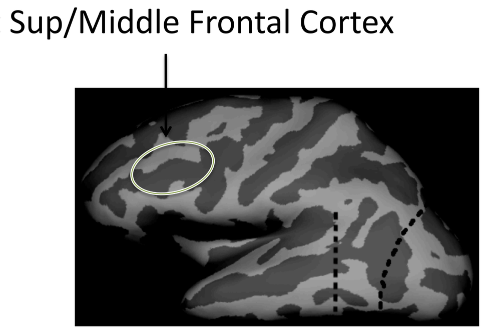
From: (28) Kuperberg et al. (2008)
See also: (29, 30)
See also: (27)</td></tr>
<tr><td rowspan="2">Medium certainty prediction for 2 or 3 alternative mappings between...</td><td>...wordform + semantic features
i.e.
2 or 3 lexical items
2 or 3 events</td><td rowspan="2">Correctly prediction maintained in working memory

Incorrect predictions suppressed

Input is integrated with context through...</td><td>...top-down lexico-semantic (event) selection</td><td>

From: (18) Wlotko & Federmeier (2012)
See also: (19)</td><td>

From: (28) Kuperberg et al. (2008)
See also: (31-33)</td></tr>
<tr><td>...syntax + (coarse) semantic features (e.g. animacy)
i.e.
>1 semantic role
>1 event structure</td><td>...top-down semantic-syntactic (event structure) selection</td><td>

From: (20) Wittenberg, Jackendoff & Kuperberg (Under review)
See also: (21-23)</td><td>

Hypotheses
Motivated by: (34, 35, 36)</td></tr>
</table>

Conclusions

The cognitive mechanisms and the neural networks we recruit to integrate a word into its context depend not only on the representations (form, semantic, syntactic) encoded in the lexical entry of the incoming word, but also on *the representational level* of our predictions, and the *strength/certainty* of these predictions.

Therefore, the cognitive mechanisms and neural networks we recruit to integrate a word into its context will depend not only on the nature of the linguistic input (the context and the incoming word), but also on the reliability of the input and the speed with which it unfolds, the wider statistical structure of the environment, the task at hand and on individual differences in predictive processing.

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