

# Sensitivity to syntax in visual cortex: the role of form typicality

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## abstract

Prediction is crucial for executing complex cognitive tasks quickly and efficiently. This study provides new evidence for the mechanisms by which contextual prediction allows rapid language processing.

With magnetoencephalography, we show that a mismatch with a syntactic category prediction affects activity already in visual cortex at 130ms (the visual M100) as long as the encountered form looks typical of its category.

We propose that predictions about upcoming syntactic categories are translated into form estimates, which are made available to sensory cortices. This mechanism may be a key component for explaining the extreme rapidity of language comprehension.

## word category cues and the M100 component closed-class morphemes or form features?

Dikker, Rabagliati & Pykkänen (2009, *Cognition*) found that violations of word category predictions affect an early MEG response in visual cortex, the M100 component (below).

M100 modulation was only seen when the unexpected word contained a closed-class category-marking morpheme (CCM), such as *-ed* in participles (*reported*). This suggested that CCMs play a special role in detecting word category violations at the earliest stages of visual analysis.

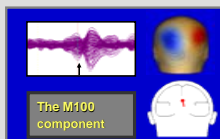
However, although CCMs are undoubtedly indicative of their word category, so are a number of other perceptual features. For example, the phonological features of words tend to cluster within categories – e.g., certain feature combinations are more typical of nouns than of verbs and vice versa. Farmer et al. (2006, *PNAS*) have shown that reading time for a noun or a verb is longer if it is atypical of its category, suggesting that form typicality is important in processing.

## Is the M100 effect only driven by closed-class morphemes or also by form typicality?

### MEG and the visual M100

The M100 component is the first prominent MEG response to visual stimulation, generated in visual cortex around ~130ms.

The M100 has previously shown sensitivity to stimulus size and noise level, but not to linguistic variables (Tarkiainen et al. 1999, *Brain*). Thus its responsiveness to syntactic factors is highly surprising.



### procedure/methods

15 subjects read sentences word-by-word (300ms on, 300ms off) containing a target word that either met or violated **word category** expectations.

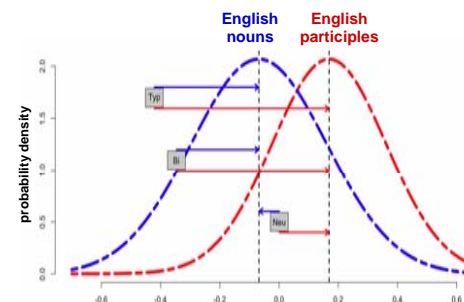
#### Dipole modeling

Multi-dipole modeling was performed to capture amplitude modulations as a result of detecting a word category violation. The main focus of analysis was the visual M100 component. Waveform analysis of the M100 dipole was performed both on **by-condition** data and on **single trials**.

## stimuli

We tested three types of nouns: **neutral**, **typical** & **bimorphemic** with a derivational morpheme, in **expected** and **unexpected** contexts (40 items/condition; N = 15). The contexts of the unexpected items set up an expectation for a participle, not a noun.

	expected	unexpected
<b>neutral nouns</b>	The thick <b>forest</b> was logged	The thickly <b>forest</b> was logged
<b>typical nouns</b>	The strong <b>garlic</b> was used	The strongly <b>garlic</b> was used
<b>bimorphemic nouns</b>	The brilliant <b>artist</b> was promoted	The brilliantly <b>artist</b> was promoted



The curves describe the estimated distribution of typicality scores for English nouns and participles (negative = more typical of nouns, positive = more typical of verbs).

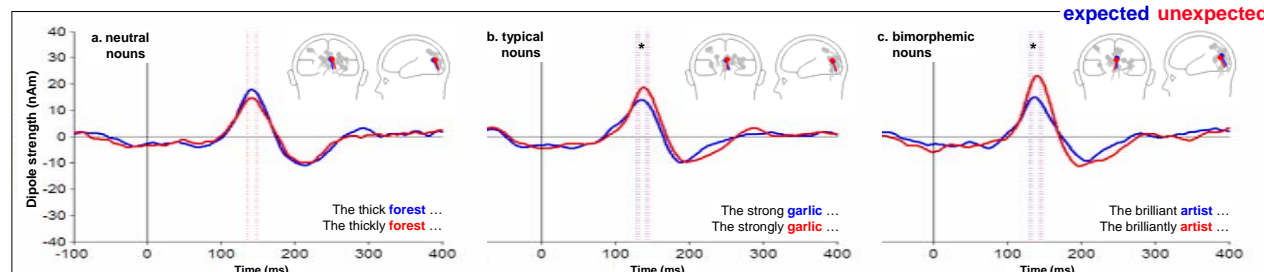
Boxes indicate mean typicality scores of the nouns in each condition. Arrows show the distance of these scores to the mean predicted typicality score.

**blue** = distance to the noun mean / **red** = distance to participle mean

The absolute distance (**predicted typicality mismatch**) to the expected/unexpected word category is largest for typical and bimorphemic nouns.

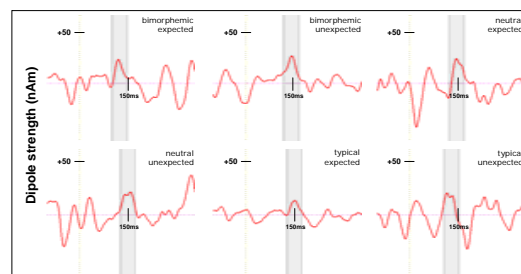
## by-condition analysis/results

**Dipole analysis on averaged data** revealed an **effect of expectedness** for both the **typical monomorphemic nouns** and the **bimorphemic nouns**, showing that closed-class morphology is not crucial for the early detection of word category violations. **No such effect was found for the neutral nouns.**



## single trial analysis/results

To test for an independent contribution of CCMs to the M100 effect, we performed a **multi-level regression analysis using single-trial data**. Controlling for a range of other lexical factors, this confirmed that M100 amplitude increases with the distance to the expected form features. There was **no additional effect of CCM presence**, nor an interaction of morpheme presence and context: controlling for typicality, the response to unexpected nouns containing a CCM was not reliably greater than the response to expected nouns.



Examples of M100 dipole waveforms on individual trials for one subject.

	Estimate	Std. Error	t statistic	pMCMC
Intercept	34.23	5.78	5.93	<0.01
Context	2.31	1.34	1.72	0.07
Morpheme Presence	-2.49	1.56	-1.60	0.08
<b>Predicted Typicality Mismatch</b>	<b>2.35</b>	<b>0.70</b>	<b>3.36</b>	<b>&lt;0.01</b>
Orthographic Length	0.80	0.62	1.27	0.18
log Frequency	0.33	0.47	0.70	0.46
No. of Syllables	-1.96	2.35	-0.84	0.37
Nearest Neighbors	-0.16	0.15	-1.03	0.27
Phonological Length	-0.40	0.74	-0.54	0.56
<b>Morpheme Presence * Context Interaction</b>	<b>0.90</b>	<b>1.95</b>	<b>0.46</b>	<b>0.64</b>

Factors entered into the regression against M100 amplitude (Deviance = 26616, Number of observations = 2913), with their estimated coefficients, the standard error of that coefficient, the associated t statistic for the coefficient and a p value simulated with Markov-Chain Monte Carlo methods.

## CONCLUSIONS

These findings suggest that predictions based on prior syntactic context include probabilistic estimates of the visual form of upcoming words. Mismatches with these predictions affect processing already at 100-130ms, during the early stages of visual form analysis in occipital cortex. Thus this finding may contribute an important piece to the puzzle of how language processing can be executed so rapidly and efficiently.