# Spatiotemporal dynamics of morphological processing: an MEG/EEG investigation

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## Introduction

Human language processing relies upon several different sources of information. A primary scientific issue is to characterize how and when these features are represented and processed in the neural language system.

***Language-specific processing complexity*** - indexed here by the presence of a potential grammatical morpheme - engages primarily left lateralised processes [1].

***General processing complexity*** - indexed here by competition between lexical alternatives - engages a more bilateral network.

Previous research [1,2] has focused on the spatial distribution of these cortical activities (fMRI), leaving their temporal dynamics poorly understood. Here we use MEG and ERP methods to explore the spatio-temporal patterns of cortical activity evoked by spoken words that vary in linguistic and/or general complexity.

- Left lateralised effects due to the presence of an inflectional morpheme (the {-d} past tense) should emerge as evidence accumulates that this morpheme is present in the signal.
- Effects of increased general processing complexity should emerge bilaterally as evidence accumulates for the presence of an onset-embedded lexical competitor [2].

We combine standard univariate analyses with multivariate pattern analysis (MVPA) techniques based on Representational Similarity Analysis (RSA) [3]. These methods may give us improved access to the fine grained patterns of brain activity underpinning complex language processes.

## Methods and classical univariate analyses

### Subjects

Subjects were 17 adult, right-handed, native English speakers. They listened to lists of spoken words and occasionally performed a one back memory task.

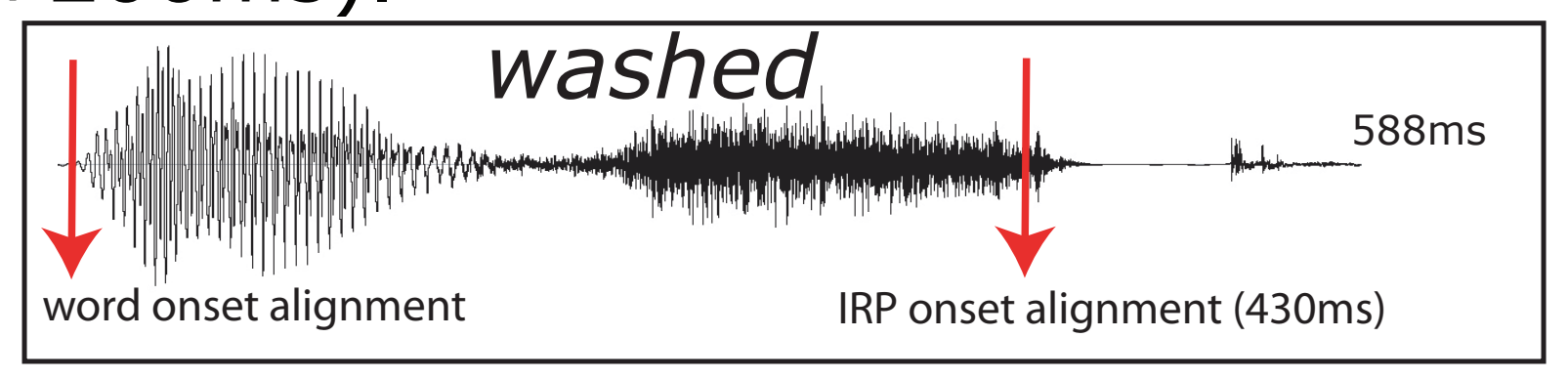
### Stimuli

40 items per condition, matched on length, lemma and word form frequency, ngram frequency, and N size.

| Condition | Example | Embedded Stem | Suffix IRP |
|---|---|---|---|
| Past Tense | played | ? (play) | Y |
| Pseudoregulars | trade | Y (tray) | Y |
| No Stem with IRP | trend | N | Y |
| Stem, no IRP | claim | Y (clay) | N |
| No Stem or IRP | cream | N | N |

### Acquisition & preprocessing

EEG-MEG (306-channel MEG, 70-channel EEG Vectorview system) and three-compartment boundary-element forward models using structural MRI scans (3T) [4]. Epochs were aligned either to **word onset** (-200 to +800ms) or **IRP onset** (-300 to +200ms).



### Analyses

***Sensor Level***

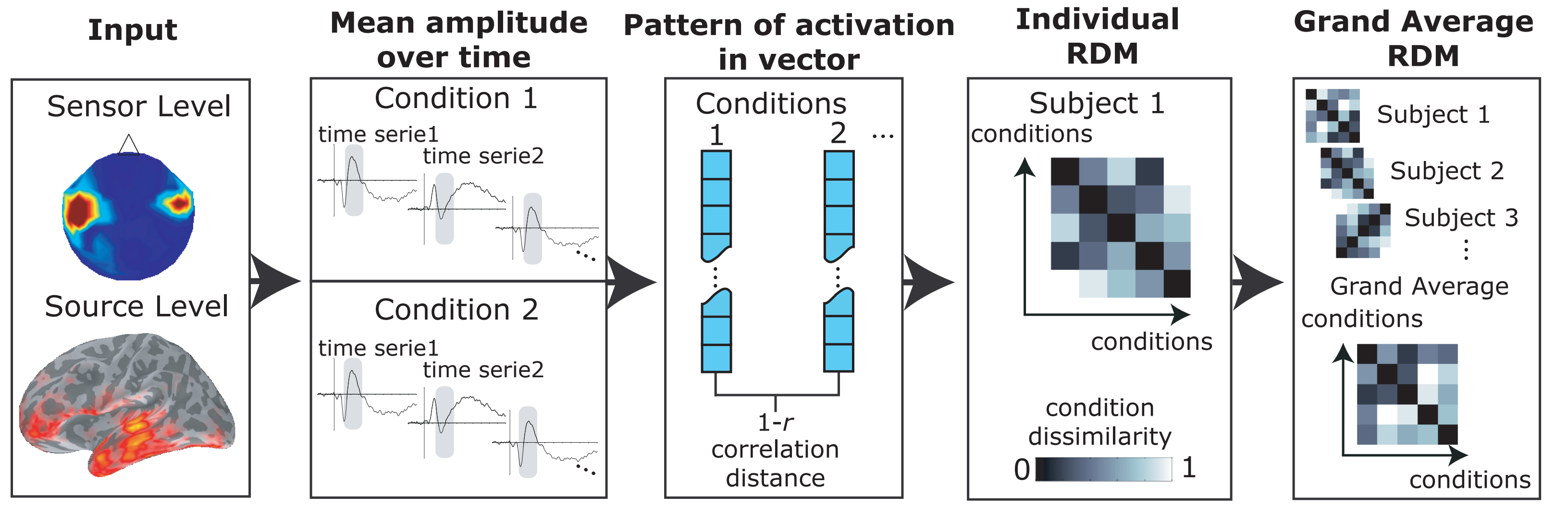
ERF transformed into a 3-Dimensional topography x time volume by projecting and interpolating the signal value at each sensor onto a 2D plane for each timepoint (SPM5). We compare entire volumes of activation patterns while correcting for multiple comparisons using Random Field Theory (height threshold $p<.01$, cluster extend $p<.05$) [5].

***Source Level***

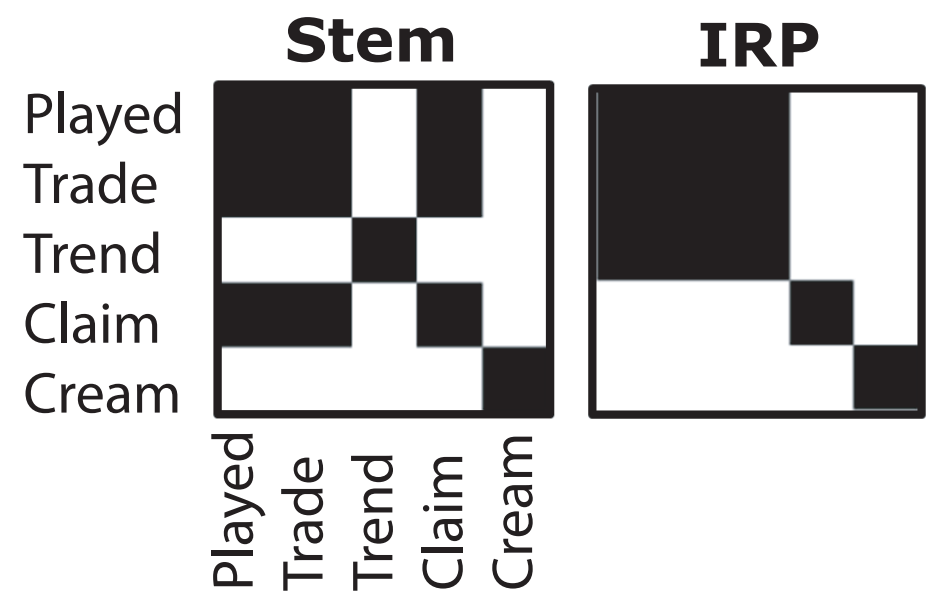
For each region of interest (FreeSurfer pre-defined) source estimations were computed for each time window identified in the SensorSPM analysis and statistically evaluated.

## Representational Similarity Analysis (RSA)

**First level analysis:** Construct the Representational Dissimilarity Matrix (RDM) for individuals



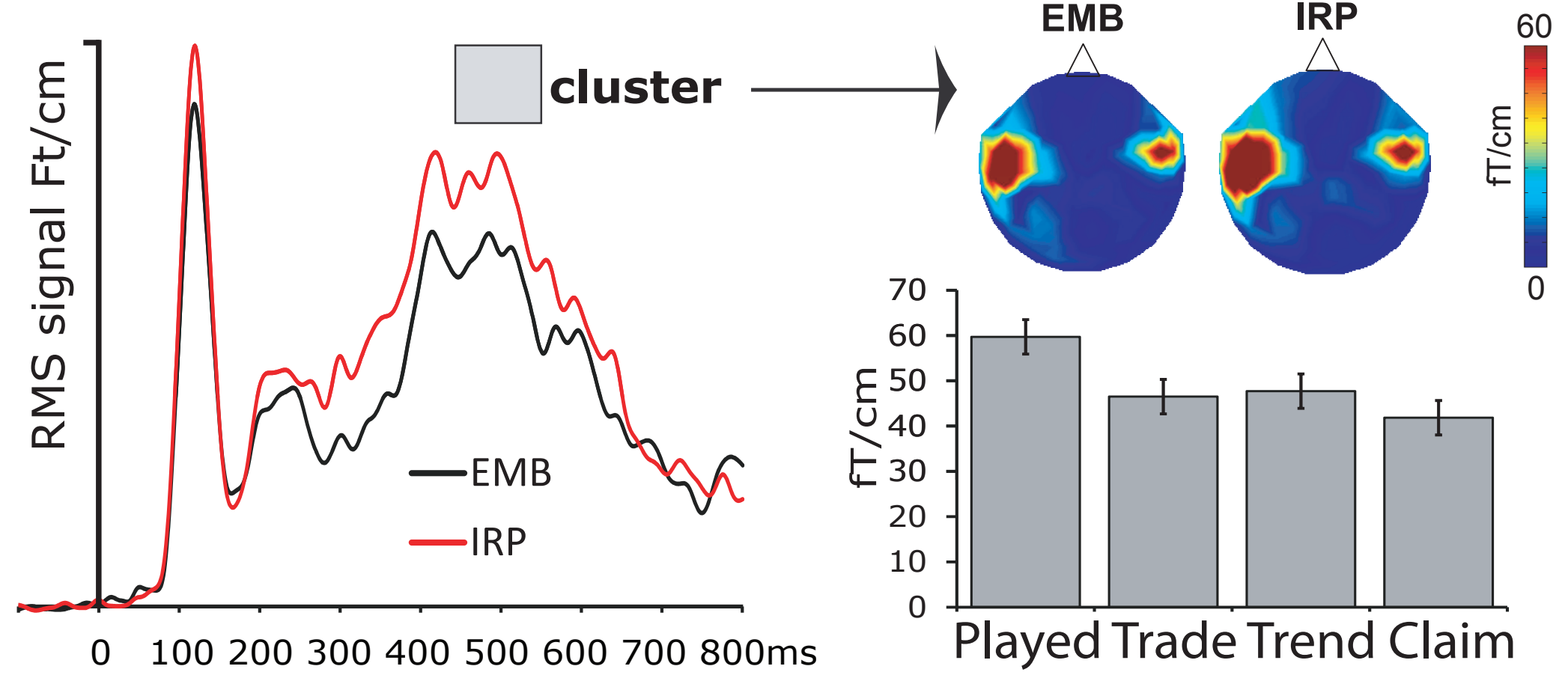
**Second Level Analysis:** Compares the brain-based RDM to contrasting functional models and applies group statistics. Each model tests whether the relevant dimension plays a significant neural processing role.



Stem model: tests for role of embedded stems
IRP model: tests for the role of IRP endings
(Black squares indicate that activation patterns correlate due to a shared property)

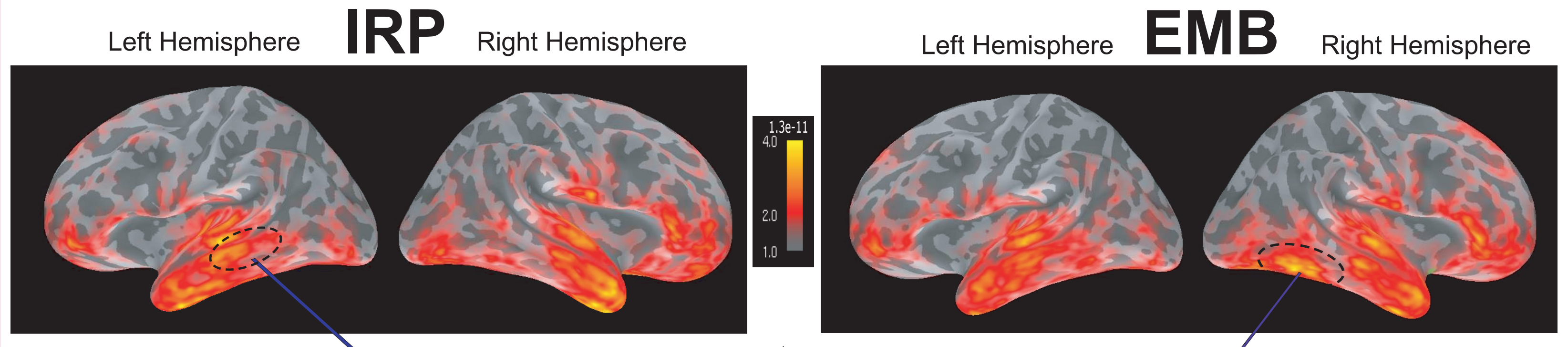
## Results: Word onset alignment

### Sensor level: SPM Gradiometers (RMS)



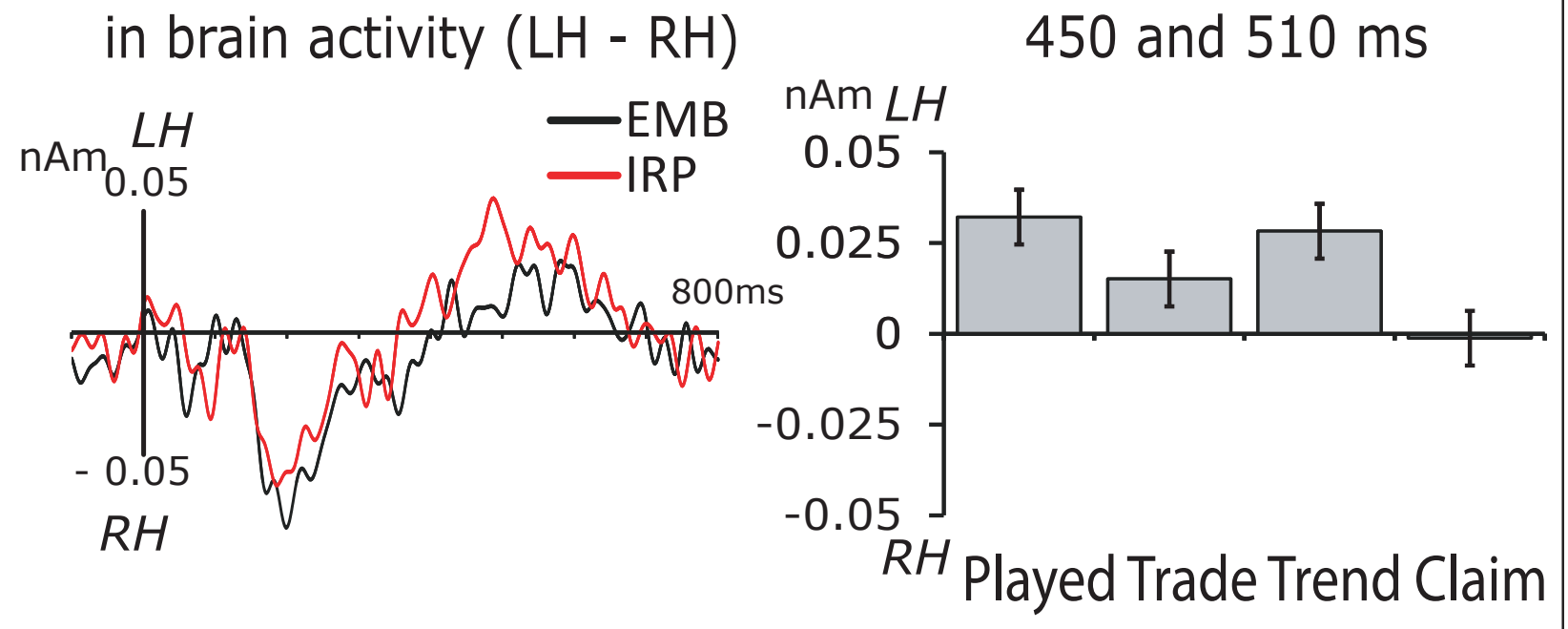
Gradiometer analyses with five experimental conditions did not show significant clusters. Analyses based on grouped conditions (IRP = *played* + *trend*; EMB = *trade* + *claim*) showed that the IRP elicited greater activity in left anterior regions of the scalp between 450 and 510 ms.

### Source level: ROI MNE (Minimum Norm Estimation)



**Middle Temporal Posterior**

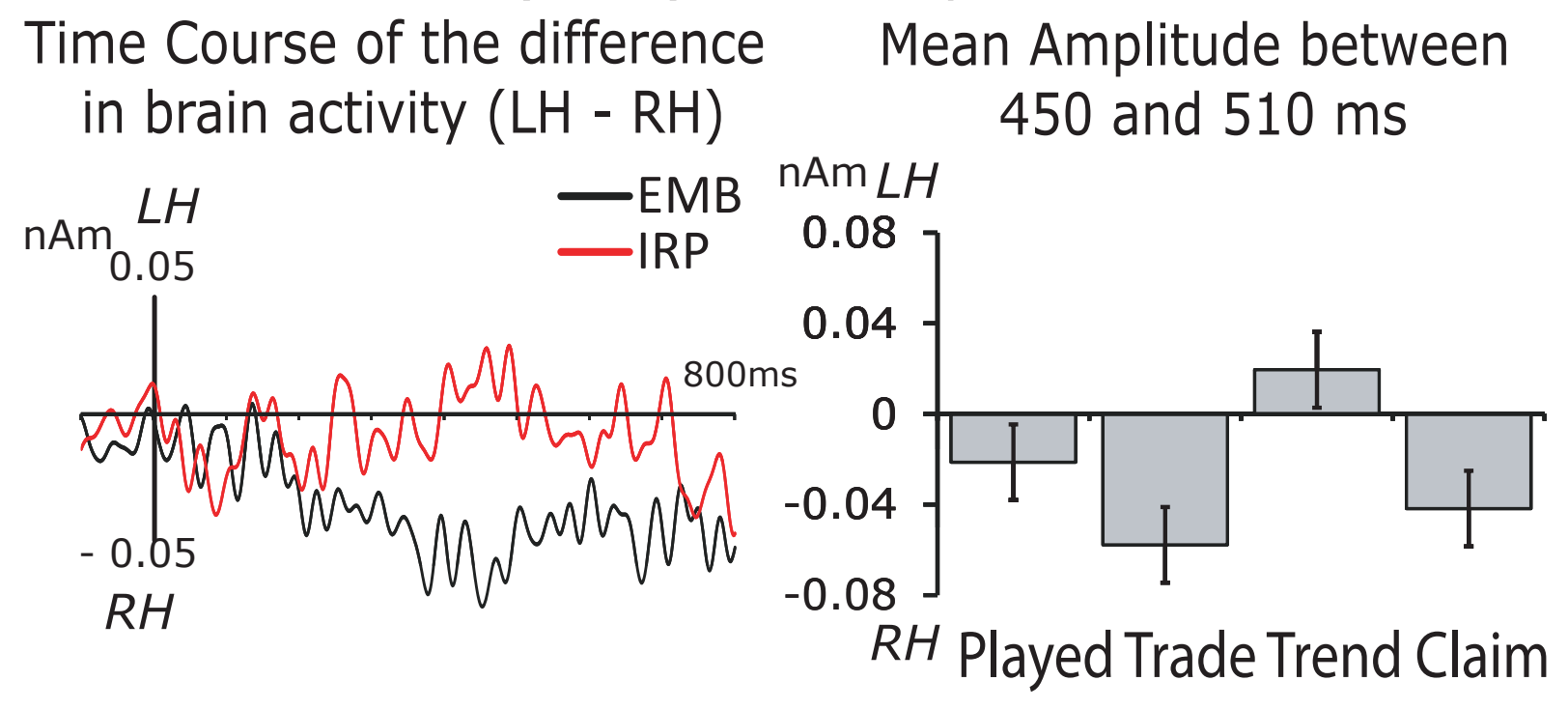
Condition x Hemisphere
$F(1,16)=6.66$, $p=.02$



The presence of the inflectional suffix (IRP) elicited greater activity on the left compared to the right hemisphere in the middle temporal posterior ROI ($p<.0001$) between 450 to 510 ms. Embedded words do not show this left lateralised effect.

**Inferior Temporal Posterior**

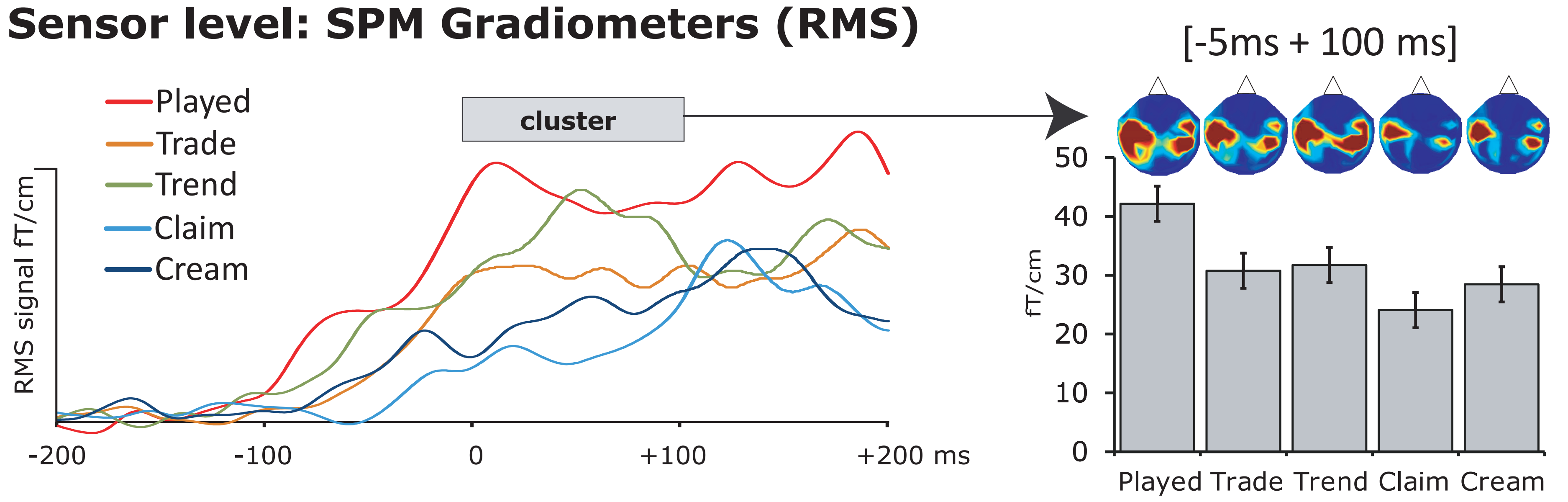
Condition x Hemisphere
$F(1,16)=10.52$, $p=.005$



The presence of embedded words (EMB) elicited greater activity on the right compared to the left hemisphere in an inferior temporal posterior ROI ($p<.003$) between 450 to 510 ms. IRP words do not show this effect, which starts as early as 350 ms.

## Results: IRP onset alignment

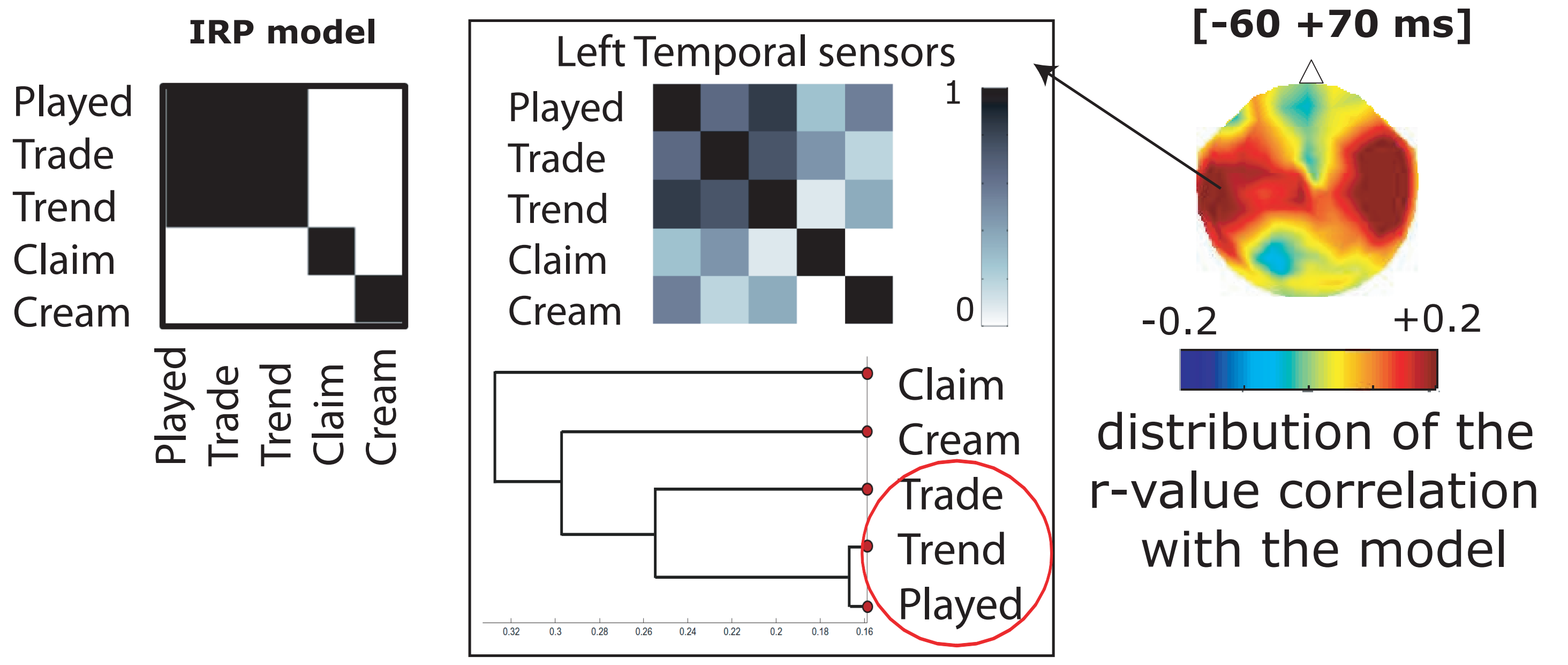
### Sensor level: SPM Gradiometers (RMS)



IRP presence (in *played, trade, trend*) elicited more activity around the IRP onset on left and right temporal sensors compared to words with no inflectional ending (*claim, cream*).

### Sensor level: RSA Gradiometers (RMS)
### Whole brain searchlight option

The searchlight computes an RDM for a predefined spatial radius (here 9 sensors) within a sliding temporal window (10 ms window applied every 5 ms). The result of the first level analysis is a set of brain-based RDMs for each participant at each spatial location and each time point. The second level analysis, comparing models and data, is run for each location and time point and entered into SPM5 for testing against zero (height threshold $p<.01$, cluster extent $p<.05$).



Only the IRP model generated significant correlations with the brain patterns observed around the IRP onset [-60 ms to +70 ms], with a bilateral temporal distribution, illustrated here for left temporal sensors (where the effects were strongest). The stem model - which does not share the same onset-alignments as the IRP-relevant effects - did not reveal any significant clustering.

## Discussion

- Overall results, for word onset and IRP onset aligned analyses, support a spatiotemporal distinction between processes corresponding to different types of lexical processing complexity [2]. IRP-sensitive processes, though eliciting bilateral activity in all analyses, consistently show stronger left hemisphere effects. Stem competition-sensitive processes, where detected, show a stronger right hemisphere distribution.
- MEG/EEG data aligned simply to word onsets may lack sensitivity to specific patterns of neural activity driven by time-varying events occurring later in the speech stream. The IRP onset-aligned data reveals a more differentiated set of results for individual conditions, and demonstrate the close temporal linkage of these effects to the gradual emergence of cues to the presence of the IRP in the vowel preceding the affixal consonant.
- Parallel effects for stem competition should emerge in future analyses based on the detailed timing with which these effects emerge in the signal.
- Multivariate analyses (such as RSA) are sensitive to linguistic processing dimensions and allow researchers to investigate more complex neuro-cognitive processing models.

## References

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[3] Kriegeskorte, N, Mur, M & Bandettini, PA (2008). Front. Syst. Neurosci, 2:4. doi: 10.3389/neuro.06.004.2008.
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## Info

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