Searchlight Representational Similarity Analysis of Complex Morpholexical Processes

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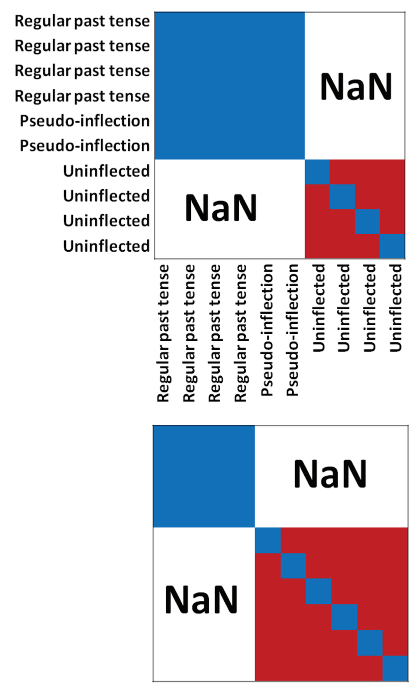
Introduction

Although the neural basis of speech comprehension has been a growing focus for neuroimaging research, detailed neural models of morpho-lexical processing are notably absent. Here we explore how the underlying properties of lexical constituents are computed in neural networks situated in bilateral fronto-temporal brain regions.

A novel method that reveals the fine grained structure of neural computation (with centimetre and millisecond precision) has been developed based on the Representational Similarity Analysis (RSA, c.f. [1,2]) of combined MEG/EEG data in source space using searchlight techniques. Specifically, we search the data in time and space for neurocomputational signatures that are correlated to theoretical models.

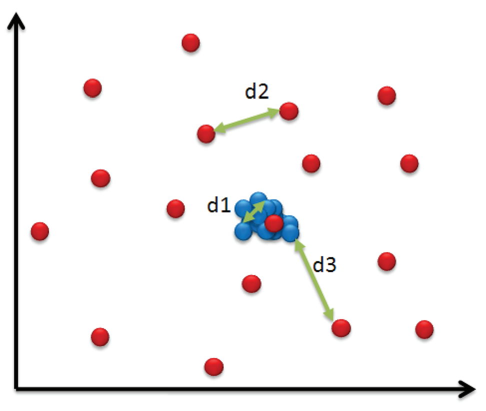
Hypothesis and Model RDMs

In RSA, experimental hypotheses are specified as model RDMs.



Phonological Model predicts that pattern of neural activation is more similar for words that shares the same phonological cue, i.e. the IRP, than for uninflected.

Morphosyntactic Model predicts that pattern of neural activation distinguishes 'real' inflected words from other ones.



Methods

Participants

17 healthy, right-handed, native English speakers

Conditions	Examples	Phonological Cues	Inflection
Regular past tense	Played	Yes	Yes
Pseudo-inflection	Trend	Yes	No
Uninflected	Cream	No	No

Experimental Conditions

80 items in regular past tense and uninflected conditions,
40 items in pseudo-inflection condition matched on length, lemma and word form frequency, ngram frequency, and N size.

Procedure

Speech comprehension tasks with one-back memory in combined MEG/EEG to test the modulation of lexical complexity

MEG/EEG Acquisition

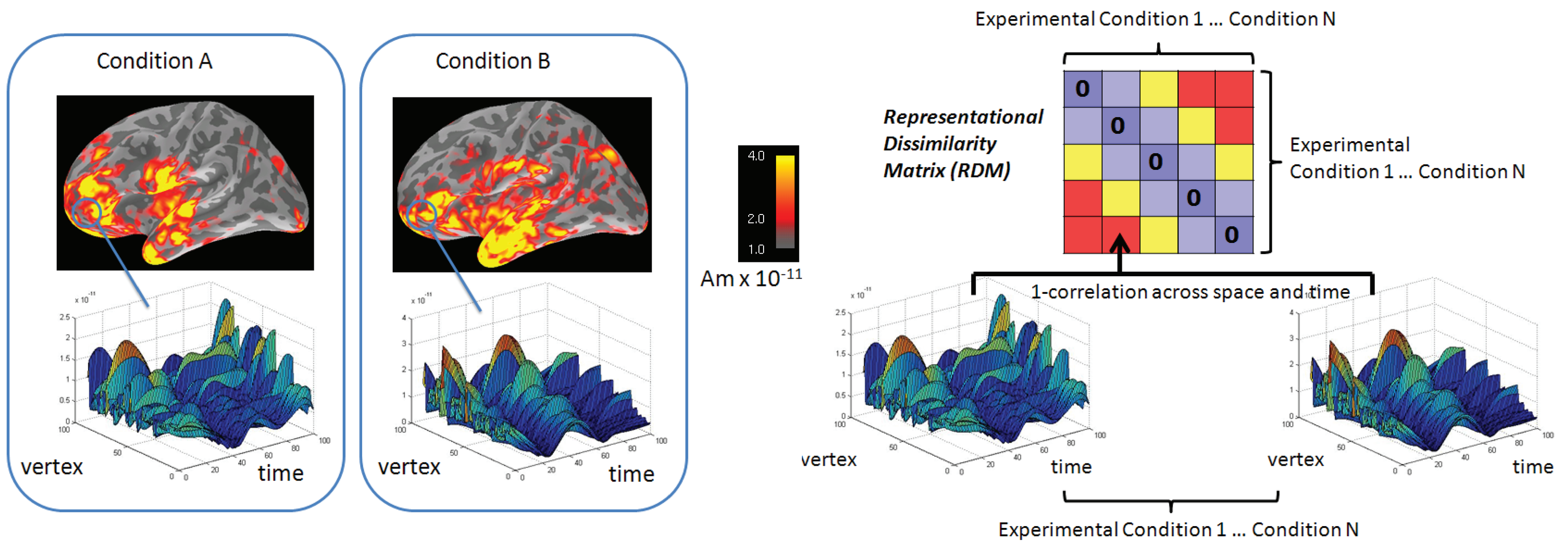
306-channel Vectorview MEG, 70-channel EEG and three-compartment boundary-element forward model using structural MRI (3T). MEG/EEG time-series are time-locked to the onset of Inflectional Rhyme Pattern (IRP) for the regular past tense and pseudo-inflection conditions, or to the onset of last phoneme in the uninflected condition. Epochs (-200 to +200ms) were taken at around IRP in order to reveal the critical process.

Searchlight Representational Similarity Analysis

First Level Analysis: Construct Representational Dissimilarity Matrix (RDM) for Individuals

The first level of RSA is the computation of similarity structures that express the dynamic patterns of neural activation over space and time. The primary data type that encodes such similarity structure is the representational dissimilarity matrix (RDM). Each entry in an RDM is the correlation-distance (e.g. one minus the correlation value) between activation patterns elicited by a pair of experimental conditions within a specific experimental setup.

For the source estimation of MEG/EEG data, we pre-processed the data with minimum-norm estimation [3], which computes a distributed-source solution combining both MEG and EEG scalp information. 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.



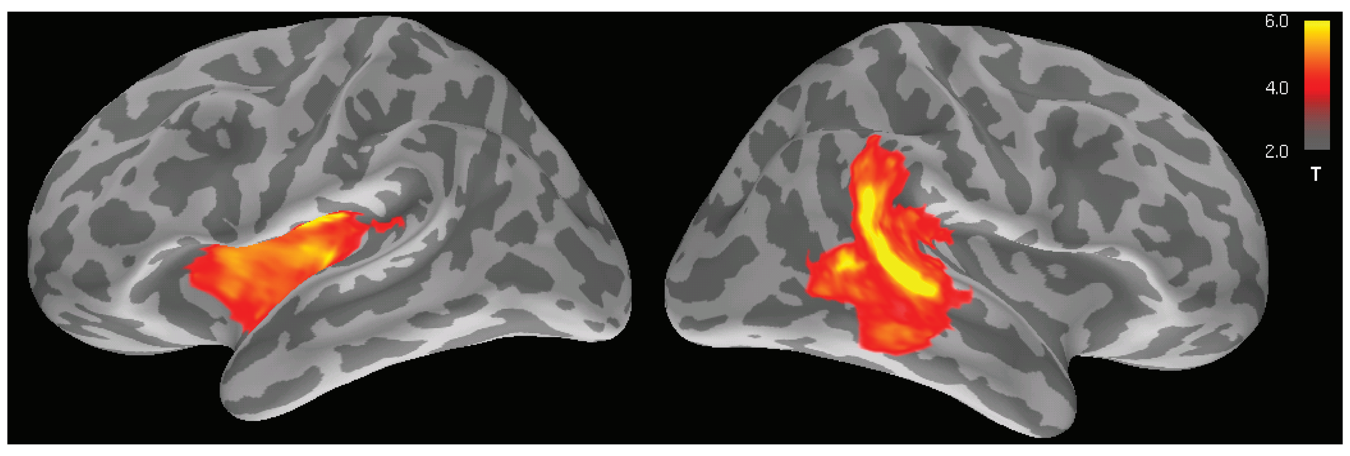
Second Level Analysis: Compare Brain-based RDMs to Theoretical Models and Group Statistics

Theoretical models can also be represented by RDMs, as shown later. So, in the second level of analysis, the resulting brain-based RDMs are compared to model RDMs.

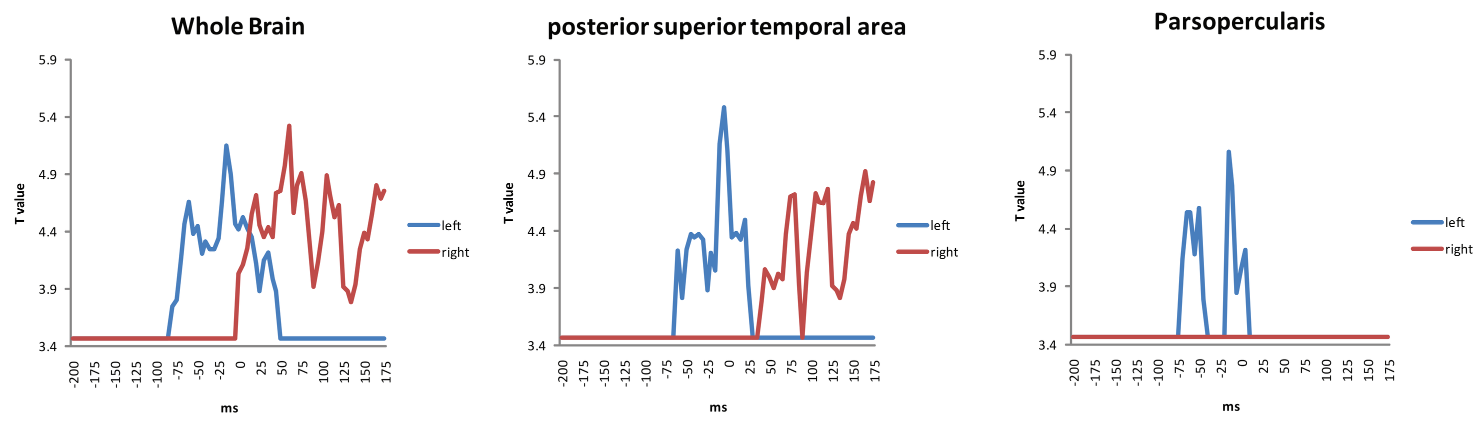
A "searchlight" algorithm [1] is used to localise pattern information by searching across the entire brain. For MEG/EEG time-series, it combines with a temporal sliding-window to separate effects in time [2]. The output indicates when and where in the brain, each model fits to the pattern of neural activities.

Group statistics is achieved using nonparametric methods, such as permutation testing, and cluster level statistics. This controls for false positive arised from multiple comparisons without making any assumptions about the distribution of the signal and noise.

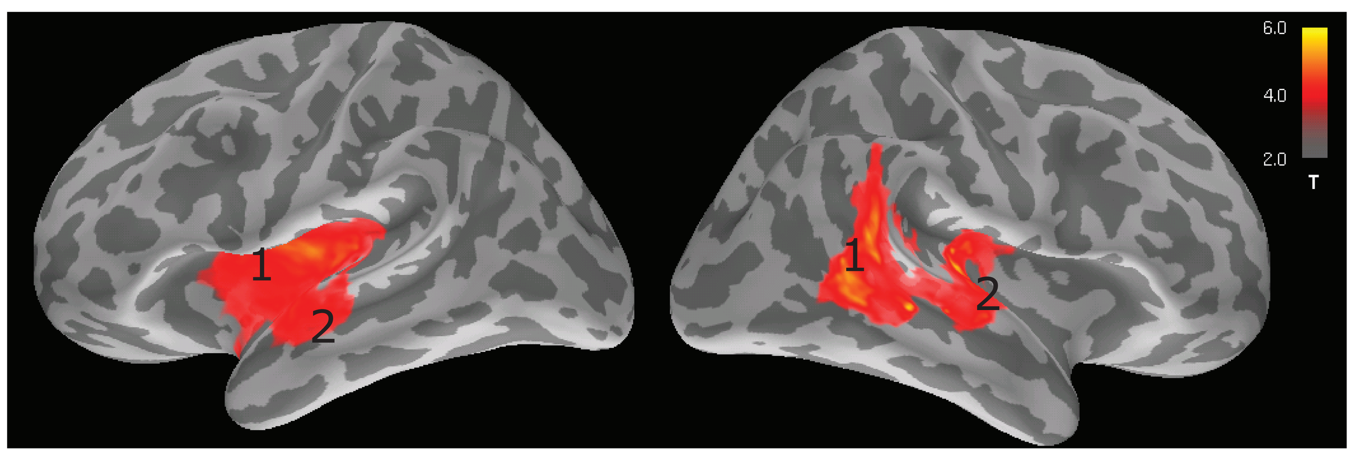
Result I Phonological Model



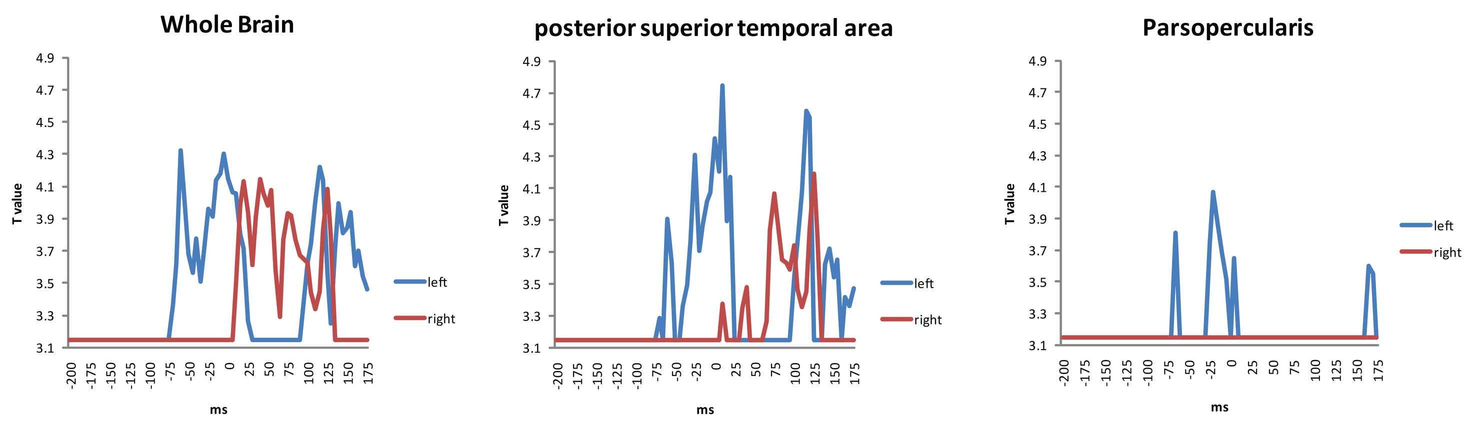
cluster	from	to	peak	p-value	Brain areas
Left	-85ms	45ms	-20ms	<0.001	Parsopercularis, superior temporal, supramarginal, transverse temporal, insula
Right	-10ms	>200ms	55ms	<0.001	inferior temporal, interior parietal, middle temporal, superior temporal, supramarginal, transverse temporal



Result II Morphosyntactic Model



cluster	from	to	peak	p-value	Brain areas
Left 1	-75ms	20ms	-65ms	0.001	parsopercularis, superior temporal, supramarginal, transverse temporal, insula
Left 2	90ms	>200ms	110ms	0.033	parsopercularis, superior temporal, middle temporal, transverse temporal, insula
Right 1	5ms	60ms	15ms	0.0052	inferior parietal, superior temporal, middle temporal, supramarginal
Right 2	55ms	125ms	75ms	0.036	superior temporal, transverse temporal, insula



Conclusions

We propose a dynamic account of morpho-lexical processing, which engages a bilateral fronto-temporal system, and potentially provide a system level account of neural processing for speech comprehension. The searchlight RSA combined with time resolved neuroimaging techniques such as combined MEG/EEG rigorously integrates multiple neuro-psychological components and may eventually result in a relatively complete picture of large-scale interactions in the brain.

References

1. Kriegeskorte, N., Goebel, R. and Bandettini, P. (2006), 'Information-based functional brain mapping,' PNAS, 103, 3863 - 3868.
2. Su, L., Wingfield, C., Bozic, M., Fonteneau, E., Marslen-Wilson, W and Kriegeskorte, N. (2010), 'A Multimodal Approach to Representational Similarity Analysis', 16th Annual Meeting of the Organization for Human Brain Mapping
3. Hämäläinen M. S. and Ilmoniemi, R. J. (1994), 'Interpreting magnetic fields of the brain: minimum norm estimates,' Med Biol Eng Comput, 32, 35 - 42.