Inflectional and phrasal interactions with lexical processes: an MEG/EEG study

Elisabeth Fonteneau, Mirjana Bozic, Li Su, Cai Wingfield & William D. Marslen-Wilson

MRC Cognition and Brain Sciences Unit, Cambridge, UK

Introduction

The comprehension of spoken language requires the rapid access and integration of lexical information in order to create dynamic interpretations of the incoming utterance.

What is the role of grammatical category information in these processes?

• **lexical** accounts claim that different word types (nouns and verbs) have distinct neural substrates.

• **process** accounts claim that noun-verb differences only emerge in the appropriate combinatorial/grammatical context, triggered both by inflectional and phrasal markers [1].

Here we use combined MEG and EEG to track the spatiotemporal dynamics of these different combinatorial processes, examined in spoken words and without a response task.

Verb category dominance (relative frequency of use as a verb) should modulate brain activity only if combined with a functional phrasal marker and/or in the presence of an inflectional morpheme (the {-d} past tense).

We combine standard univariate analyses with multivariate pattern analysis (MVPA) techniques based on Representational Similarity Analysis (RSA) [2]. 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 20 adult, right-handed, native English speakers. They heard single words or phrases and occasionally performed a one back memory task.

Stimuli

120 verbs divided into 3 groups (N=40) based on their verb category dominance [1], matched on length, lemma and word form frequency, ngram frequency, and N size. Each verb is heard in 4 different contexts: in isolation 'argue' (stem); with an inflectional suffix 'argued' (past: p); with a phrasal context 'we argue' (cont: c); with both suffix and context 'we argued' (comb: pc).

Verb dominance	*Example*	*Verb dominance*
Unique (u)	argue	1
Dominant (d)	clasp	0.8
Less dominant (l)	probe	0.6

Acquisition & preprocessing

EEG-MEG (306-channel MEG, 70-channel EEG Vectorview system). Epochs were aligned to the verb onset (-100 to +800ms).

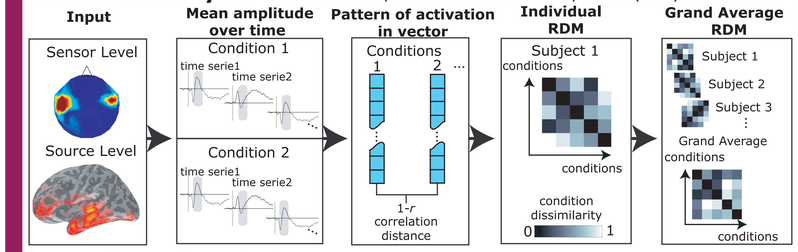
Analyses

Sensor Level

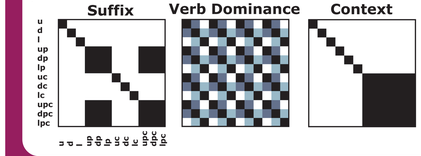
Analyses were performed on gradiometers only. ERF are transformed into a 3-Dimensional topography x time volume by projecting and interpolating the signal value at each sensor onto a 2D plane for each timepoint (SPM5). We compare entire volumes of activation patterns while correcting for multiple comparisons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

Representational Similarity Analysis (RSA)

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

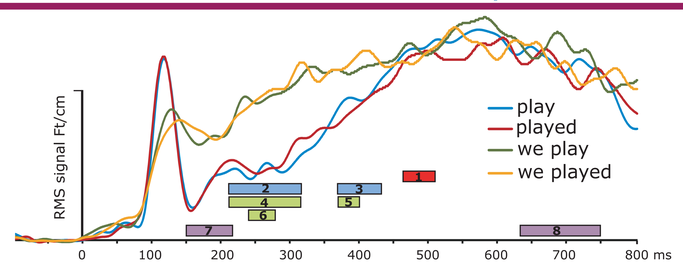


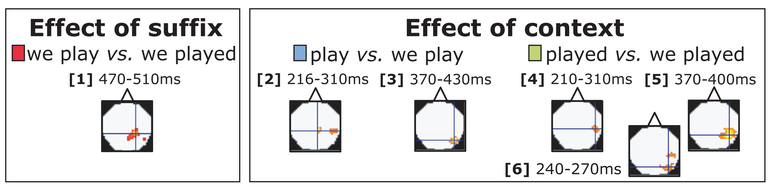
Second Level Analysis: Compares the brain-based RDM to contrasting functional models and applies group statistics. Each model tests whether the relevant dimension plays a significant neural processing role.



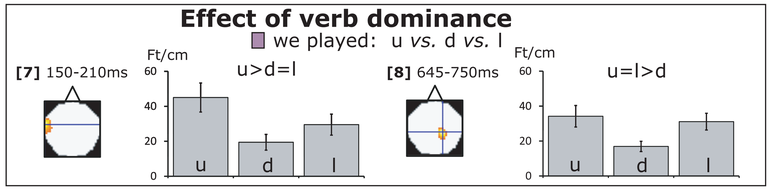
Suffix model: tests for effects of the inflectional morpheme.
Verb dominance model: tests for effects of verb dominance.
Context model: tests for effects of the phrasal marker.
Black squares indicate that activation patterns correlate due to a shared property.

Results: Univariate analyses





Inflectional morphemes induced topographical differences only when combined with a phrasal context (*we play vs. we played*). A suffix in isolation did not trigger detectable differences to an uninflected stem (*play vs. played*). In contrast the phrasal context triggered large topographical differences from 210 ms to 400 ms post verb onset.

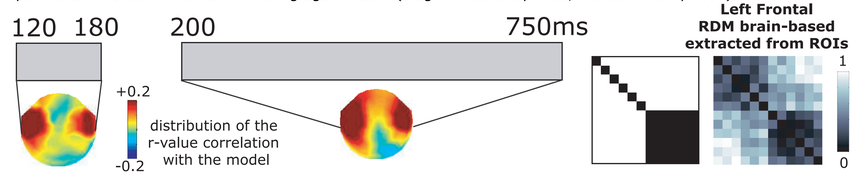


Verb dominance modified brain patterns in two different time windows. (a) Starting from 150 ms, unique verbs (u) elicited more left lateralised activity compared to less dominant verbs (d and l). (b) From 645 ms the dominant verb group (d) elicited less activity on central right sensors compared to the unique verb group and the less dominant group.

Results: RSA analyses

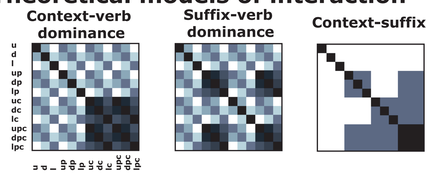
RSA whole brain searchlight option

The searchlight computes an RDM for a predefined spatial radius (here 9 sensors) within a sliding temporal window (10ms 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 $p<.05$).



RSA confirms the robust effect of the phrasal context but reveals more fine grained detail compared to the univariate analysis. The context model significantly correlates with the patterns of activation observed as early as 120 ms and until 750ms. The distribution of the first cluster is left lateralised whereas the second cluster is more bilateral. Verb dominance and suffix models alone do not significantly correlate with the patterns of activation observed.

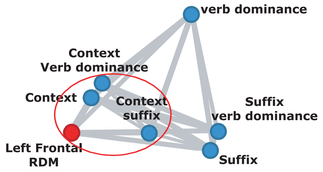
Theoretical models of interaction

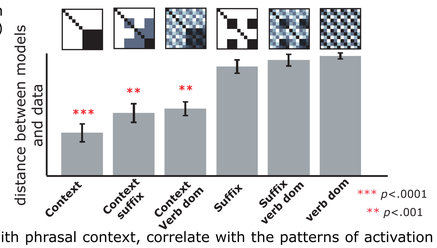


Context-verb dominance model: tests for interactions between phrasal context and verb dominance.
Suffix-verb dominance model: tests for interactions between inflectional morphemes and verb dominance.
Context-suffix model: tests for phrasal context-suffix interactions.
Black squares indicate that activation patterns correlate due to a shared property.

Fit of models to data in the left frontal ROI between 200-750ms

Comparing RDMs using Multi-Dimensional Scaling: Diagram shows Euclidean distances between the RDMs and models in a multidimensional space. Line area (length * thickness) specifies the distance between model and region RDM.





The verb dominance and the suffix models, when interacting with phrasal context, correlate with the patterns of activation observed in the left frontal areas. This suggests that integration of cues from a phrasal context is modulated by the presence of a suffix and also by verb dominance. RSA reflects the actual patterns of activity, rather than levels of activation averaged across sensors and could also provide a systems level view of the regions involved in different computations.

Discussion

• The presence of a phrasal context seems to have the dominant effect on spatio-temporal patterns of verb processing. Effects of verb dominance and of an inflectional morpheme are seen only in terms of interactions with phrasal context.
• Interactions with phrasal context can be detected very early. Verb dominance interacts with the context as early as 150 ms after verb onset (seen in both univariate and RSA results).
• These results are generally consistent with a process-oriented account of word category effects. There is no effect of verb dominance per se, but only in interaction with other variables (especially phrasal context) [1].
• Multivariate analyses (such as RSA) are sensitive to linguistic processing dimensions and allow researchers to investigate more complex neuro-cognitive processing models.

References

[1] Tyler, LK, Randall, B. & Stamakis, E.A. (2008) . Journal of Cognitive Neuroscience, 20(8):1–9.
[2] Kriegeskorte, N, Mur, M & Bandettini, PA (2008). Front. Syst. Neurosci, 2:4. doi: 10.3389/neuro.06.004.2008.
[3] Henson, R.N., Mouchlianitis, E., Matthews, W.J., & Kouider, S. (2008). Neuroimage, 40, 884-895.

Info elisabeth.fonteneau@mrc-cbu.cam.ac.uk