Neurocognitive systems for nonconcatenative morphology in Arabic

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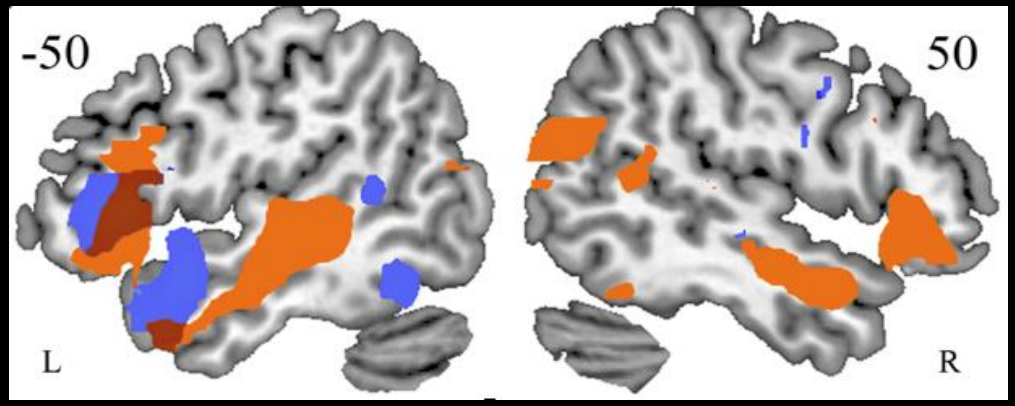
Dual neurobiological framework

- Human language relies on two interacting but separable systems



- Bi-hemispheric fronto-temporal system supporting perceptual, semantic and pragmatic processing of whole word forms

- Left lateralised fronto-temporal system specialised for the processing of grammatical combinatorial sequences

Bozic et al. 2010, Marslen-Wilson & Tyler, 2011

Dual neurobiological framework

- An open question is how different languages distribute linguistic functions across these two systems
- Do language-specific morphological properties require different neurocomputational strategies?

Cross-linguistic background

- Previous work from English and Polish suggests that inflectionally complex words - analysed decompositionally - selectively engage the left fronto-temporal system (Bozic et al. 2010, Szlachta et al., 2012)

- No left frontotemporal activation for derivationally complex words (Bozic et al., 2013; in press)

- Derivationally complex words are analysed as whole forms and involve the bilateral frontotemporal system just as simple words (Bozic et al. 2010)

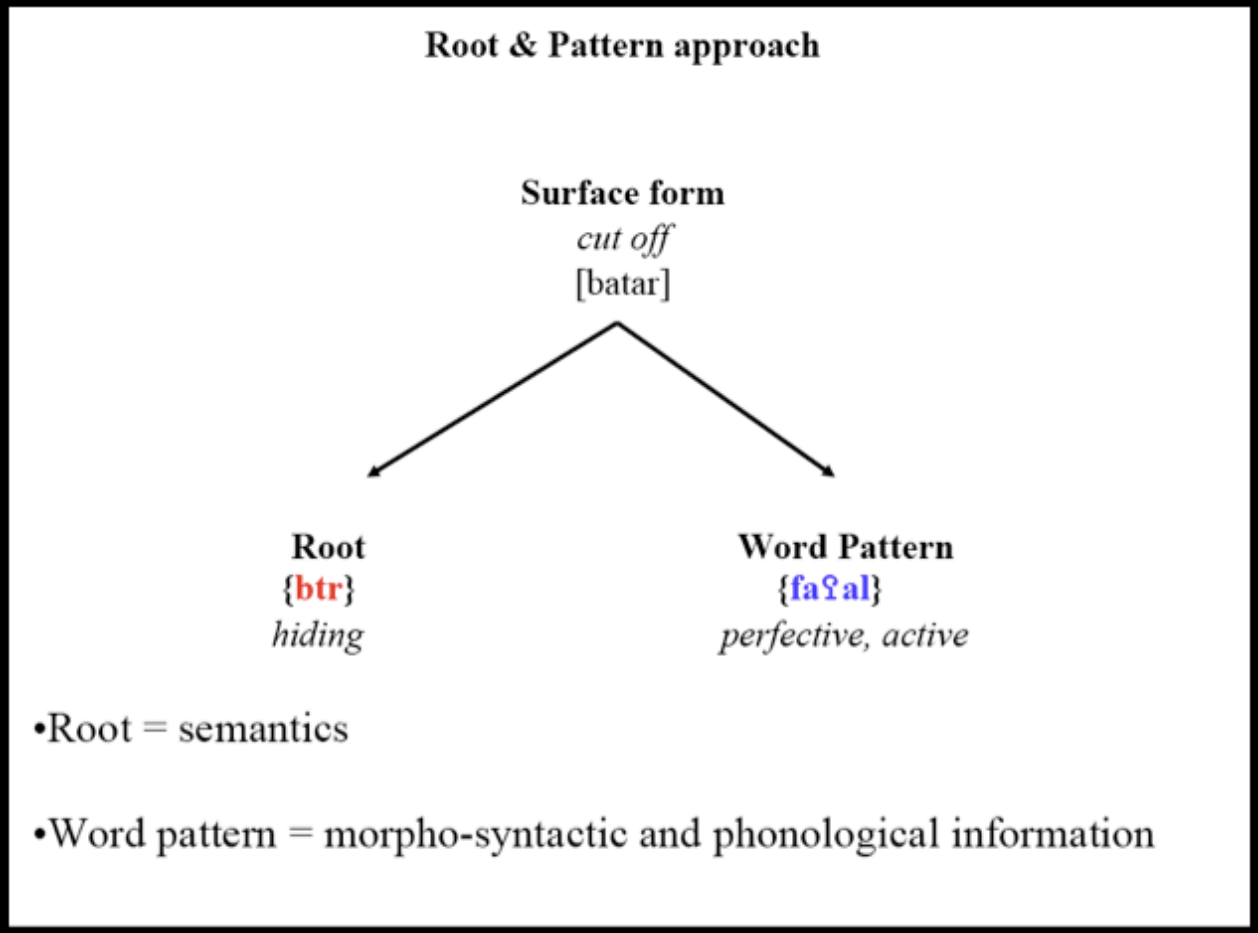
Cross-linguistic background

- Does this distribution of linguistic functions reflect a neurocognitive universal mechanism for morphological processing?

- Is it generalizable to typologically different languages?

Arabic morphological system

- The distinction between inflection and derivation differs from Indo-European languages



- Nonconcatenative morphological complexity

Arabic morphological system

Word pattern is a composite morpheme with both inflectional (e.g., mood, aspect) and derivational (e.g. lexical category) properties

Verbal Roots: *{ktb}* *28 derived surface forms (e.g.)*

- *[kataba] = write*
- *[kutiba] = it was written*
- *[kaatib] = writer*
- *[maktuub] = written*
- *[kitaab] = book*
- *[mukaataba] = correspondence*
- *[ʔaktaba] = he caused to write*

Psycholinguistically very decompositional (Boudelaa & Marslen-Wilson, 2011)

Arabic morphological system

- In addition to non-concatenative complexity, Arabic employs concatenative processes to combine stems and affixes

- Enclitic affixes can be added to a stem: kitabuhaa "her book"

- These properties define a complexity gradient, from simple function words to nonconcatenatively complex words (root & pattern) to concatenatively complex (root & pattern + enclitic)

fMRI study

Experimental conditions

Condition	Complexity	Example	
1. Function words 1	Simple	[munðu] *since*	منذ
2. Function words 2	Root + Word Pattern	[kayfa] *how*	كيف
3. Primitive nouns	Root + Word Pattern (?)	[kalb] *dog*	كلب
4. Deverbal nouns	Root + Word Pattern	[ʕadl] *fairness*	عدل
5. Verbs	Root + Word Pattern	[tarak] *leave*	ترك
6. Prim.noun +enclitic	Root + Word Pattern + Inflectional Affix	[ʕaynuhu] *his eye*	عينه
7. Dev.noun +enclitic	Root + Word Pattern + Inflectional Affix	[ħusnuha] *her beauty*	حسنها
8. Verbs +enclitic	Root + Word Pattern + Inflectional Affix	[katamuu] *they hid*	كتموا

SIMPLE FUNCTION WORDS

NONCONCATENATIVELY COMPLEX WORDS

NONCONCATENATIVELY + CONCATENATIVELY COMPLEX WORDS

Questions

- Do nonconcatenative and concatenative processes elicit distinct or similar neural responses within key cortical regions of the neural language system?

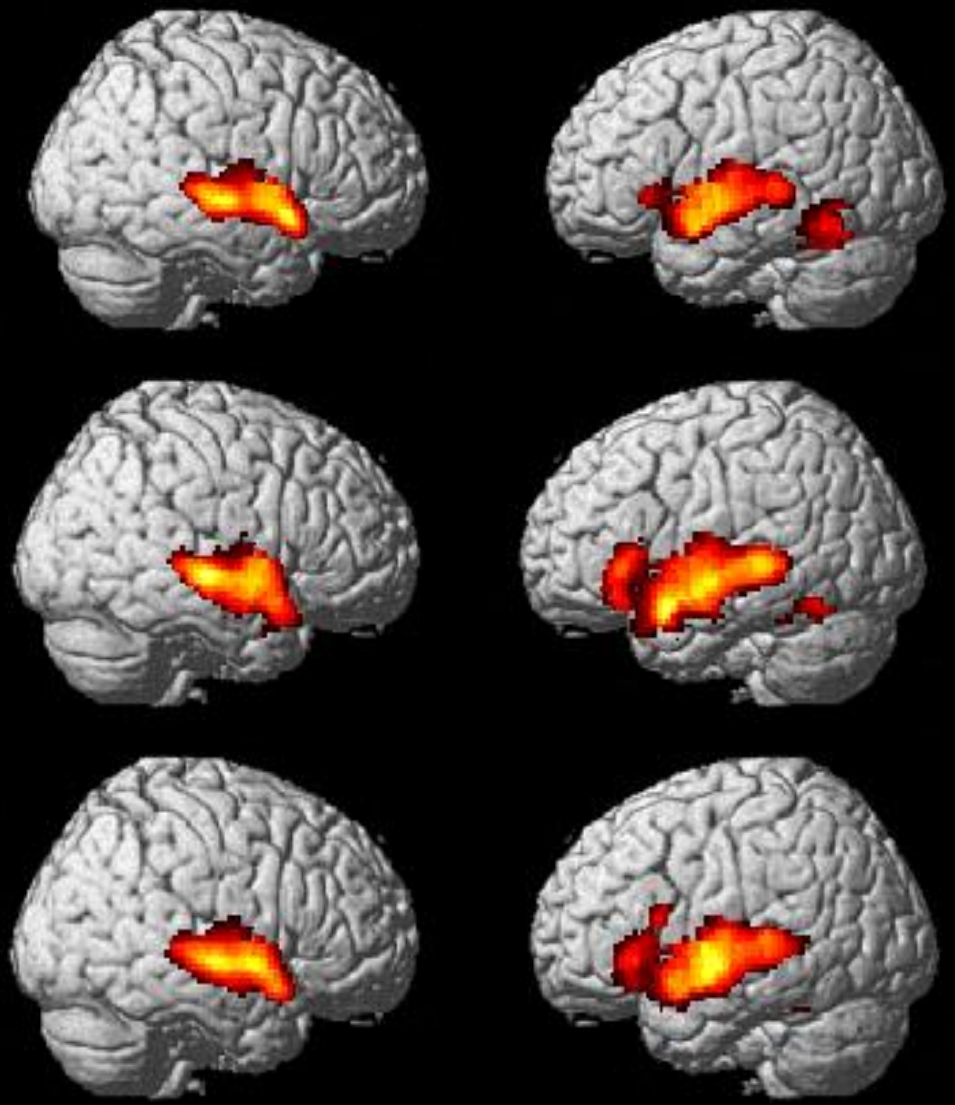
- Which neural structures support these processes?

Results from univariate analysis

SIMPLE WORDS

NONCONCATENATIVELY COMPLEX WORDS

NONCONCATENATIVELY + CONCATENATIVELY COMPLEX WORDS



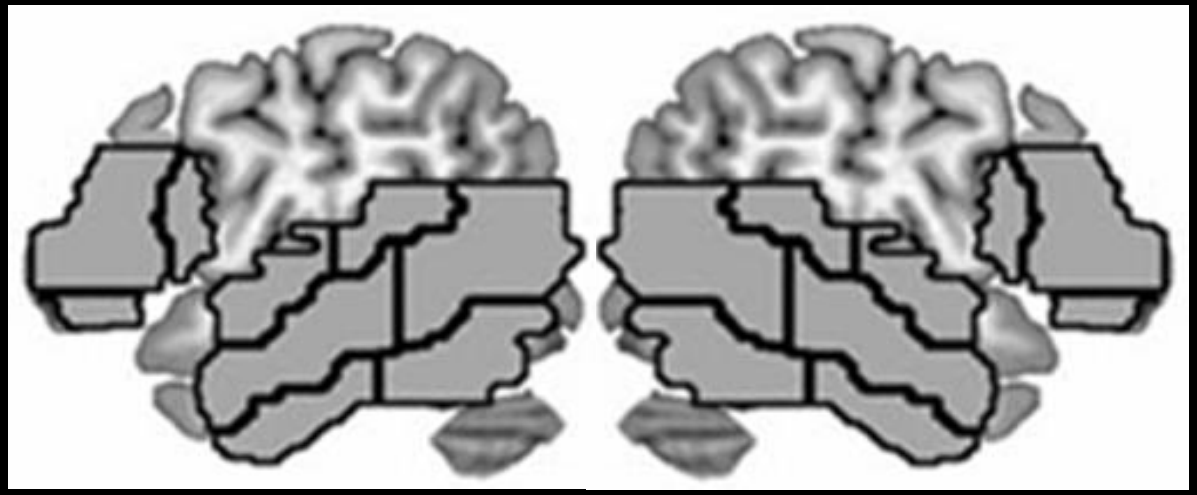
* all contrasts relative to length-matched “Musical Rain” complex auditory baseline

Univariate results:summary

- Left lateralised activation of IFG pars opercularis (BA 44) and triangularis (BA 45)
- No difference in these LIFG activation between nonconcatenative and concatenative complexities
- Both processes involve the LIFG regions essential for the analysis of linearly suffixed inflectional words in English
- LIFG activation may be due to
    a) the combination of inflectional and derivational properties in the Arabic morphologically complex words;
    b) the general stimulus complexity and cognitive load, irrespective of the presence/absence of linearity in word structure

Questions

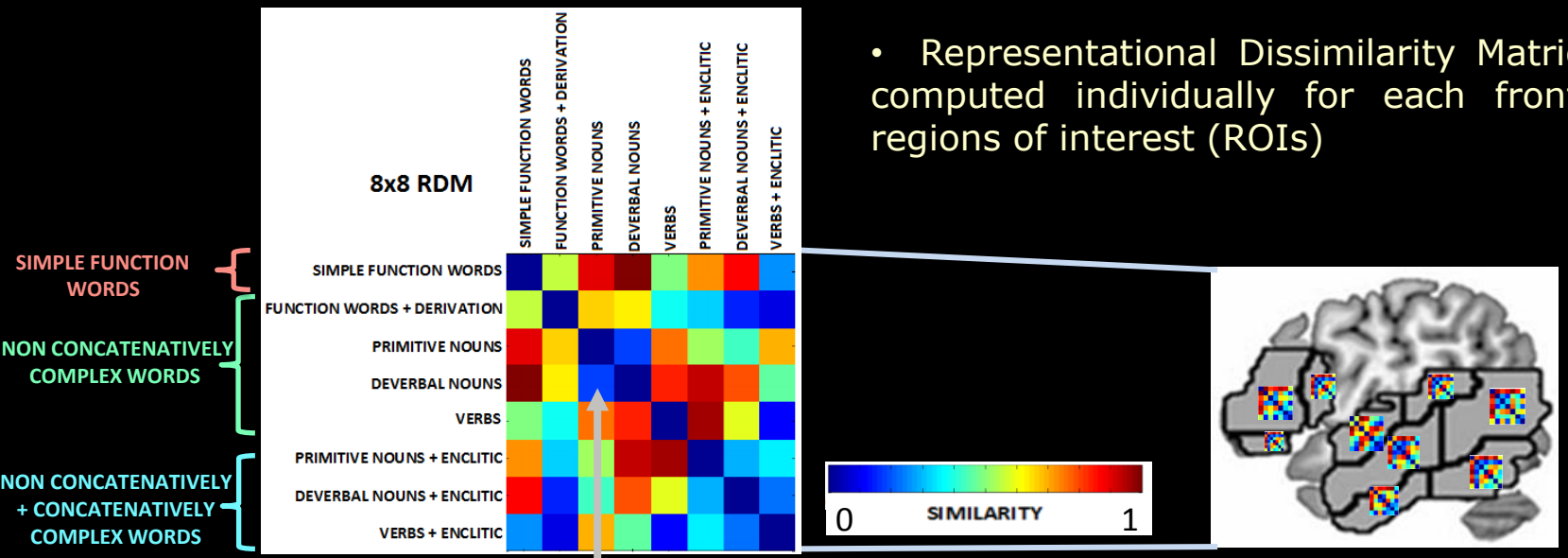
- How are these different types of complexity encoded WITHIN the cortical regions composing the neural language system?



- Finer-grained brain activity patterns?

Representational Similarity Analysis

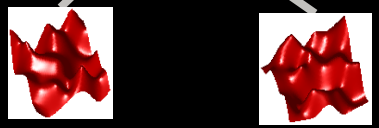
Representational Dissimilarity Matrix



- Representational Dissimilarity Matrices (RDMs) computed individually for each fronto-temporal regions of interest (ROIs)

Computing similarity (1-correlation)

Brain response patterns



RSA measures the co-variations between activation patterns across multiple voxels

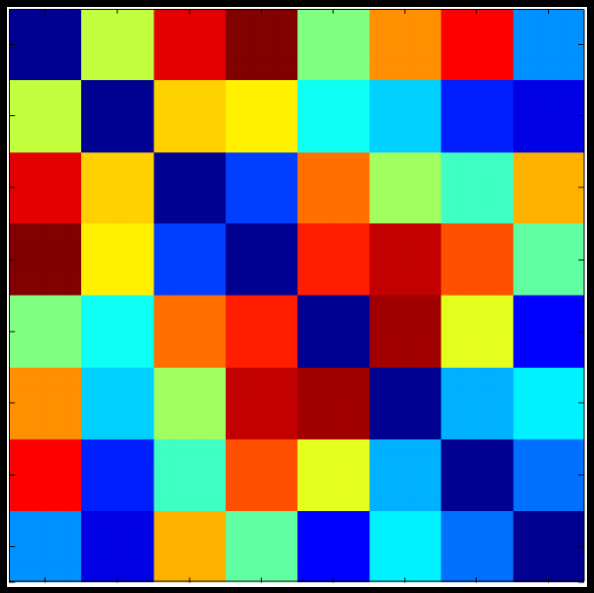
Conditions

NONCONCATENATIVE CONCATENATIVE

Kriegeskorte et al., 2006; Su et al. 2010

Representational Similarity Analysis

Brain activity RDM



SIMPLE FUNCTION WORDS

NON CONCATENATIVELY COMPLEX WORDS

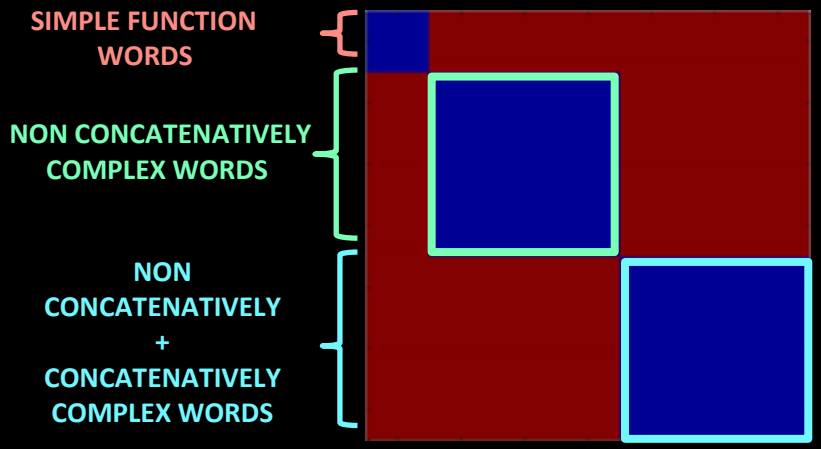
NON CONCATENATIVELY + CONCATENATIVELY COMPLEX WORDS

Theoretical model RDM

?

Theoretical Models

Combined complexities model

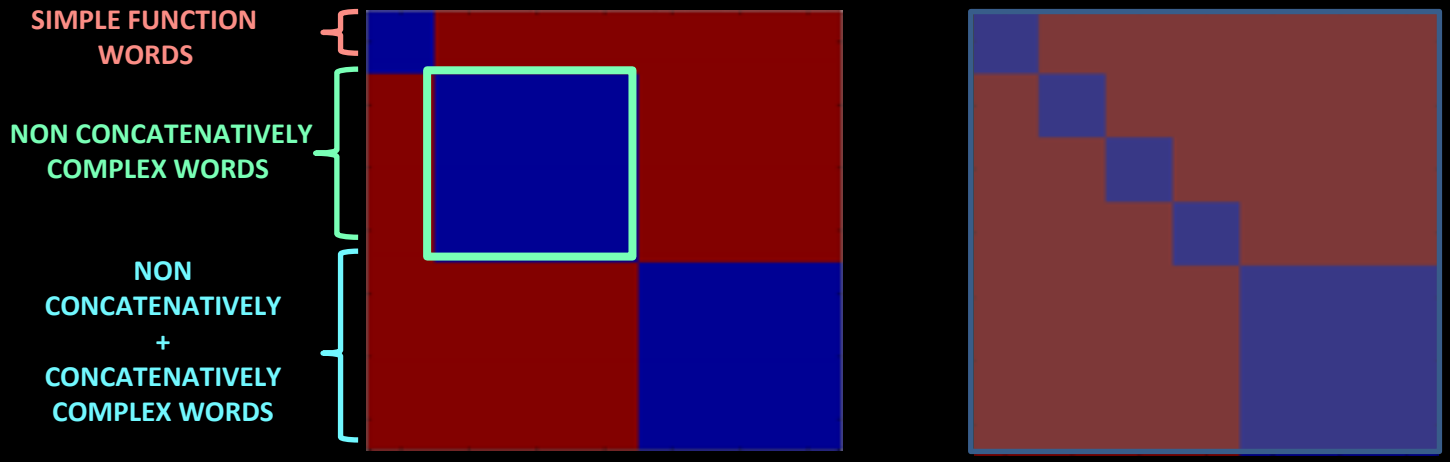


Blue = high correlation between experimental conditions
Red = absence of correlation

- Distinguishes between nonconcatenative and concatenative complexity, predicting that these two processes determine distinct brain activity patterns, which are also different from the activation to simple words

Modeling nonconcatenative complexity

Nonconcatenative complexity



Blue = high correlation between experimental conditions
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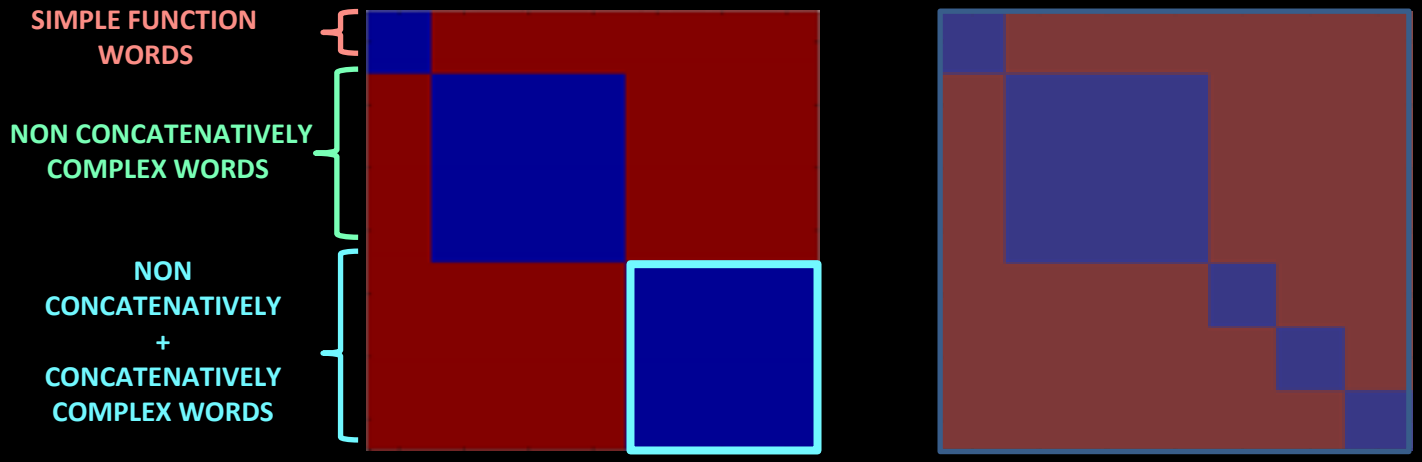
The effects due to the concatenative processes removed by partial correlation

Modeling concatenative complexity

Concatenative complexity



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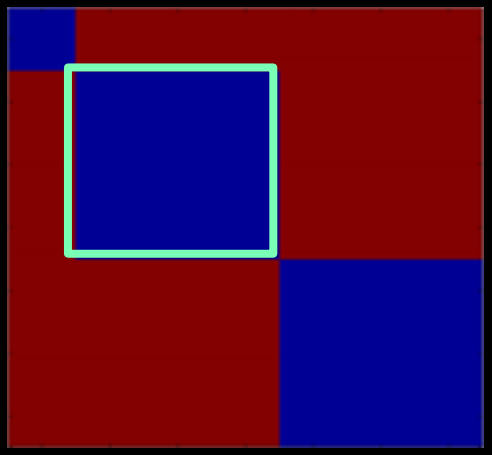
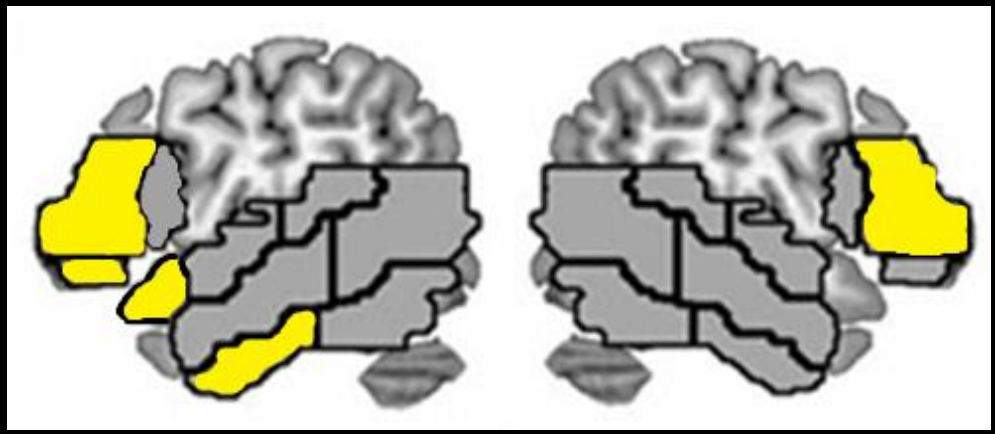
The effects due to the nonconcatenative processes removed by partial correlation

Multivariate results

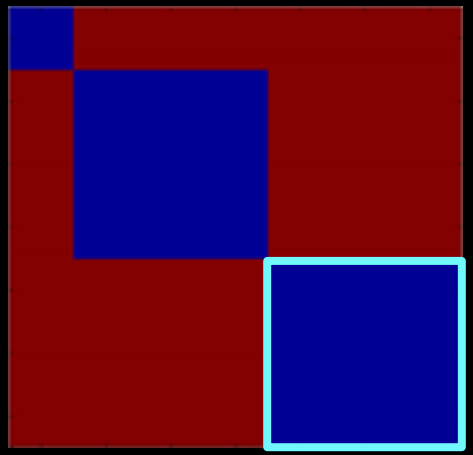
Nonconcatenative complexity

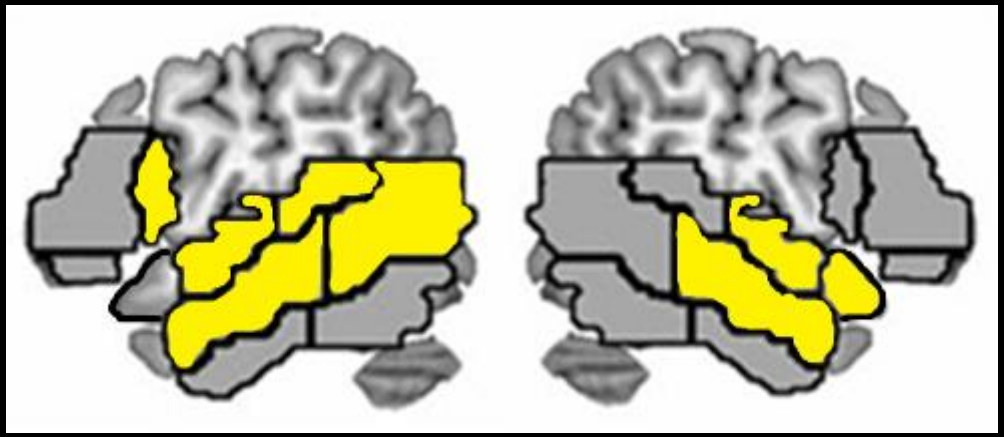




Yellow = significant correlation with the model

Nonconcatenative + concatenative complexity





p<.05, permutation test

Summary

- RSA revealed fine grained neural encoding of nonconcatenative and concatenative processes

- Nonconcatenative complexity engages a cortical network including bilateral inferior frontal (BA45-47), left temporal pole, and left inferior temporal areas relevant to semantic comprehension

- Concatenative complexity engages left inferior frontal (BA44), and - bilaterally - superior/middle temporal areas relevant to the processing of local syntactic structure

Conclusions

- The results suggest that the typological properties of Arabic morphology modulates the neural activity of the language system in a language-specific fashion

- The assignement of linguistic functions to different neurobiological subsystems on the basis of evidence from Indo-European languages such as English and Polish will need to be revised on the light of evidence from Semitic languages

Thank you for your attention!