Relational and morphological processing within the fronto-temporal brain network

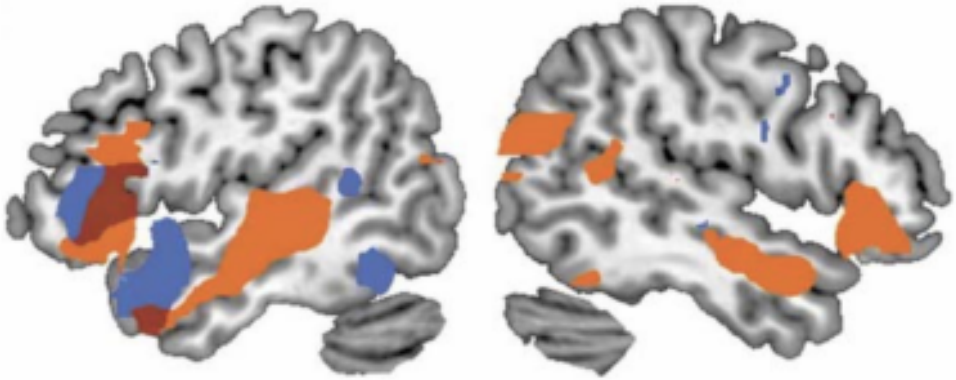
Anastasia Klimovich-Smith
Mirjana Bozic
William Marslen-Wilson
Neurolex group, University of Cambridge

General background

What is the organisation of language processing in the brain?
2 networks, with potentially different functions were suggested:

Bilateral distributed (orange)*:* lexical information access (Scott & Johnsrude, 2003), sound to meaning mapping (Binder et al., 2000, Hickok and Poeppel, 2000) and non-linguistic complexity (Bozic et al., 2010)

Left lateralised fronto-temporal (blue): more specialised, complex linguistic and grammatical information processing. Active when linguistically relevant processing demands are increased (Friederici et al., 2009, 2011, Tyler et al. 2013).



Bozic et al., 2010

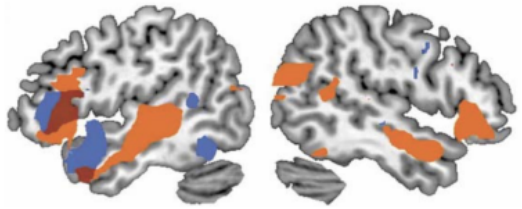
Functional organisation of the LH fronto-temporal network is debated.

- It is active for both **Inflections** and **Phrasal Syntax**
- These are **functionally similar** linguistic devices – express information about grammatical relations
- But require **different morpho-phonological parsing** strategies

Inflections	**Phrasal Syntax**
Plays = play + s	**I play = I + play**

Which linguistic properties of inflections and phrasal syntax contribute most to the left fronto-temporal activation?

Inflected words produce a distinct LH fronto-temporal activation pattern



Bozic et al., 2010

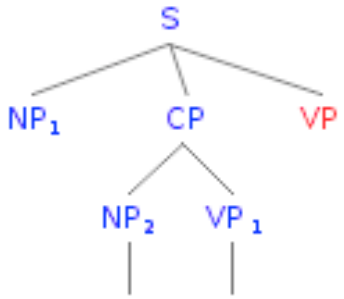
•Inflections produce greater Left BA 44/45, STG activation when compared to simple words and words with embedded stems (Bozic et al., 2010.)

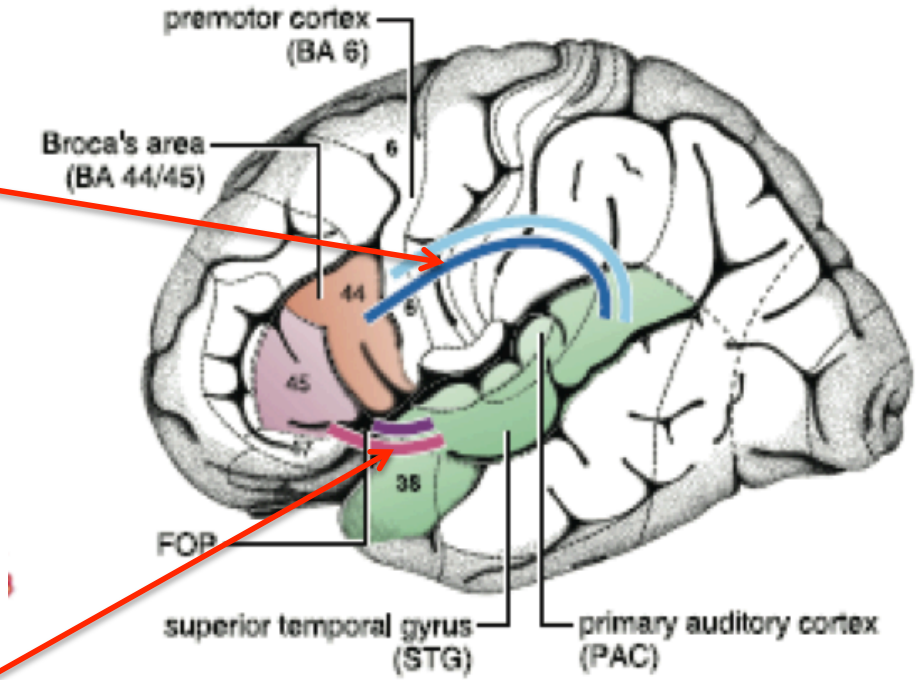
• This activation is associated with inflection specific **mopho-phonological parsing** mechanisms - stem+affix combination

• Also potentially integration of the grammatical (relational) information associated with those suffixes (Marslen-Wilson & Tyler, 2007; Shtyrov et al., 2003, Pulvemuller and Shtyrov, 2003).

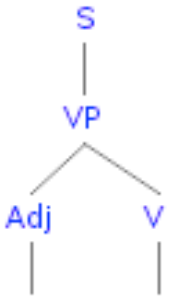
LH fronto-temporal areas are sensitive to grammatical structure - linear versus hierarchical

• Complex **hierarchical** structure– greater BA44, pSTG





• Simple **linear** structure - BA 45, FOP, aSTG



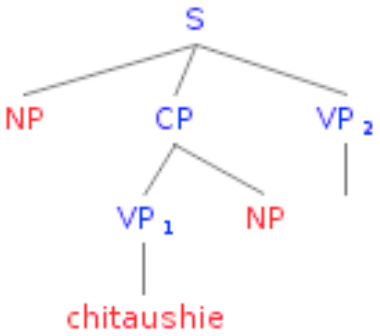
(Friederici et al., 2011, 2013)

Question 1

To what extent does the LH fronto-temporal activation reflect morpho-phonological parsing versus grammatical information processing?

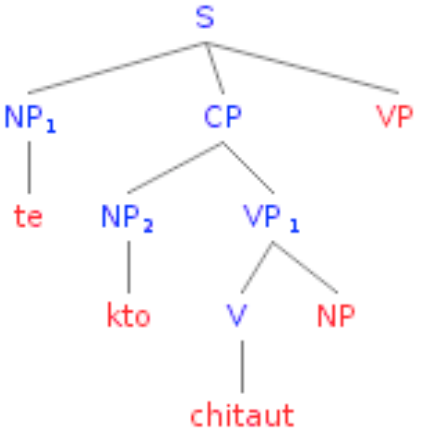
Inflection

(those who) read
chita-ushi-e
читающие



Phrasal Syntax

those who read
te kto chita-ut
те кто читают



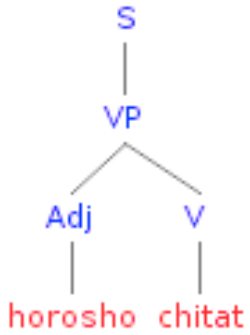
- In Russian inflections are similar to phrasal syntax in their relational information
- But Inflection requires more intensive morpho-phonological parsing
- Would this result in greater activation of the left fronto-temporal network (when grammatical information is controlled for)?

Question 2

Is there an effect of grammatical structure - **linear** versus **hierarchical** in both inflections and phrases?

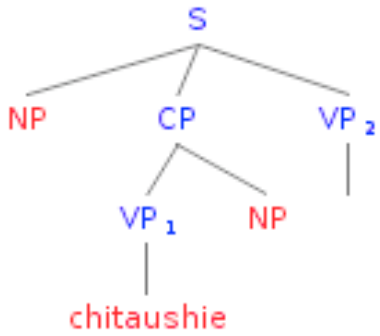
Simple **linear**

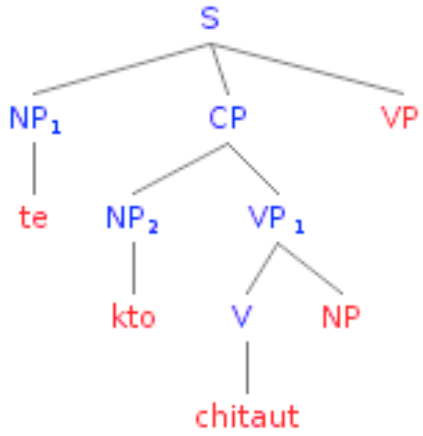
Inflection	**Phrasal Syntax**
to read	to read well
chit-at	horosho chit-at
читать	хорошо читать



Complex **hierarchical**

Inflection	**Phrasal Syntax**
(those who) read	those who read
chita-ushi-e	te kto chita-ut
читающие	те кто читают





- Inflections and phrases can be associated with **hierarchical** and **linear syntactic** structures
- Will complex hierarchical structures (for both inflections and phrasal syntax) produce a greater effect the LH fronto-temporal network compared to simple (linear) ones?

Experimental design

Conditions	Simple	Complex
Inflection	**chit-*at*** to read (infinitive suffix)	**chitau-*shi-e*** those who read (3rd person participle, plural suffix)
Syntax	**horosho chita-*at*** to read (inf. suffix) well	**te kto chita-*ut*** those who read (3rd person plural suffix)
Derivation	**prikaz** an order	**perevozshik** delivery man

Why include **Derivation**?

• *Regular derivations are (arguably) morpho-phonologically complex but do not produce preferential LH fronto-temporal activation, provide no relational information (Bozic et al., 2013,). Can be used as a control condition.*

Experimental methods

Participants: 20 right-handed Russian native speakers

Baseline: Musical rain (MuR) – unintelligible; matched to speech in acoustic complexity; length control

Stimuli: 6 conditions of 40 items each, matched on lemma freq. Complex stimuli length: 1.8-2.3 sec. Simple stimuli: 0.7 – 1.2 sec.

Design: event-related fMRI. Test items (240) , acoustic baseline (240) , null events (200) pseudo randomized across 4 blocks.

Procedure: passive listening, one back recognition task (10%)

Analysis: pre-processing with aa4 (Automatic Analysis 4); SPM8 standard univariate analysis and analysis of variance (ANOVA); RSA (Representational similarity analysis) Searchlight.

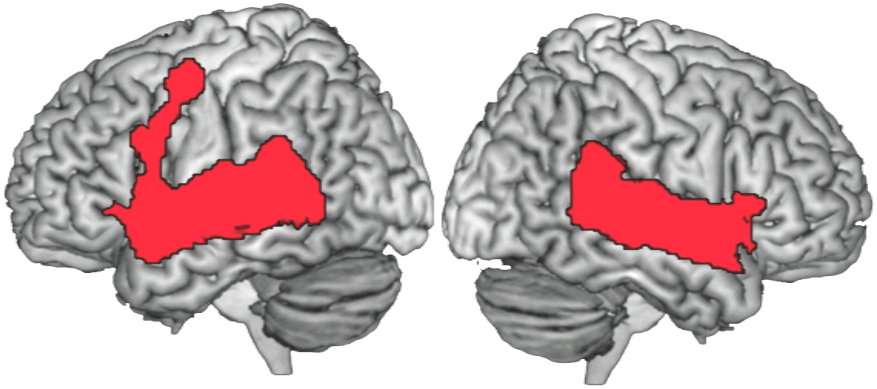
Threshold $p<.001$ voxel level and $p<.05$ cluster level corrected for multiple comparisons

Results Q1

Complex inflection – baseline

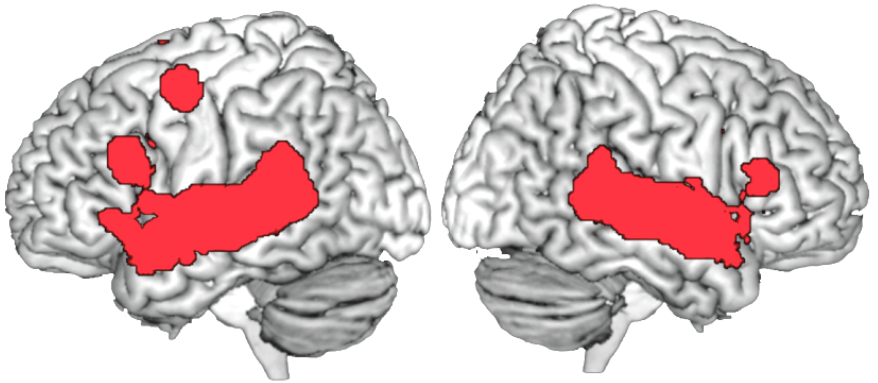
‘

(those who) read
chita-ushi-e
читающие



Complex Syntax– baseline

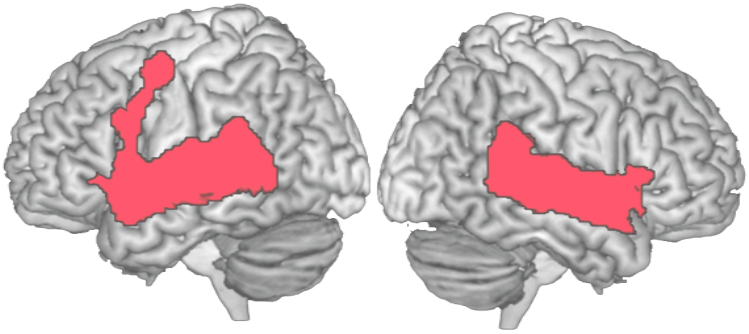
those who read
te kto chita-ut
те кто читают



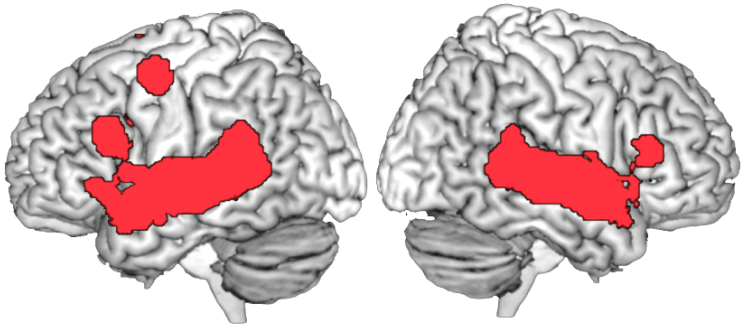
- No difference between Complex Inflection and Complex Syntax conditions
- Both activate middle and posterior STG, MTG bilaterally, left BA 44, 45, pre-central gyrus, right BA45.
- Hypothesised effects of the morpho-phonological parsing in the network are not visible at the univariate level

Results Q1

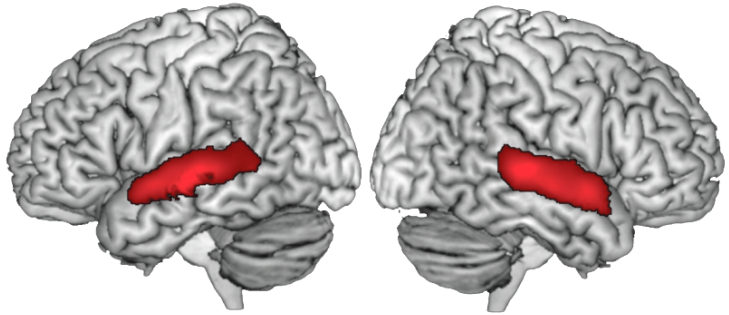
Complex Inflected words



Complex Phrasal syntax



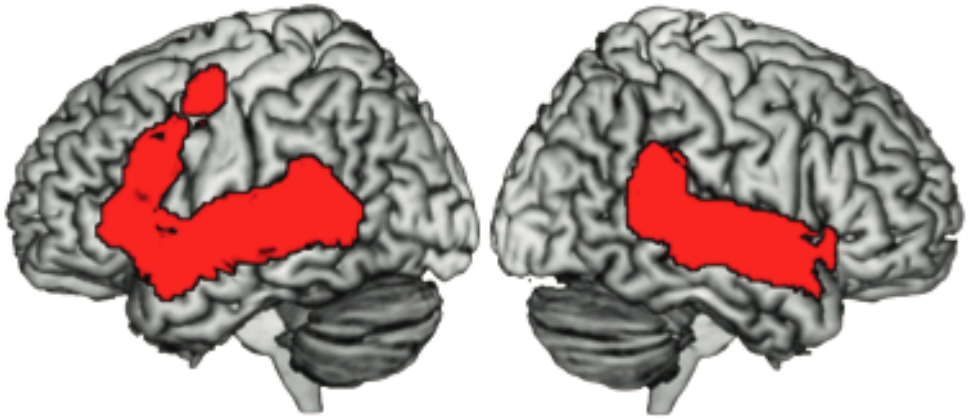
Complex Derived words



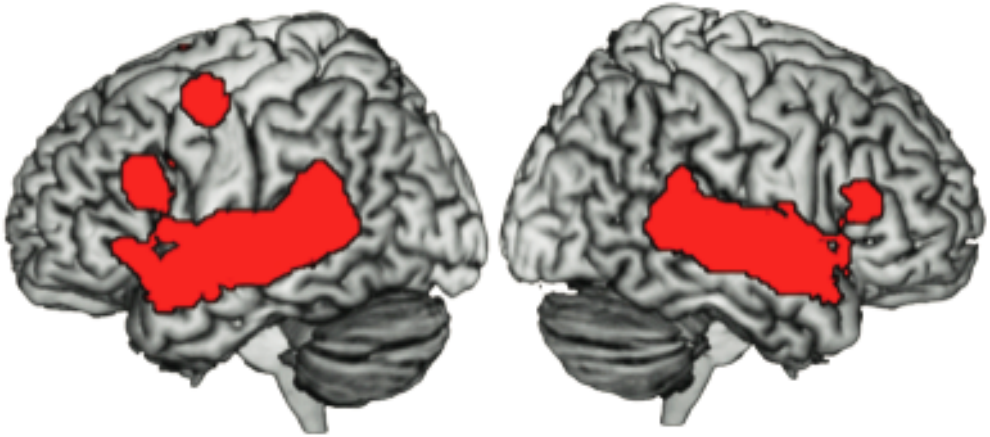
• Derived words produce bilateral temporal and no preferential left fronto-temporal activation;
• Consistent with previous results in English and Polish (Szlachta et al., 2012.)

Results Q2

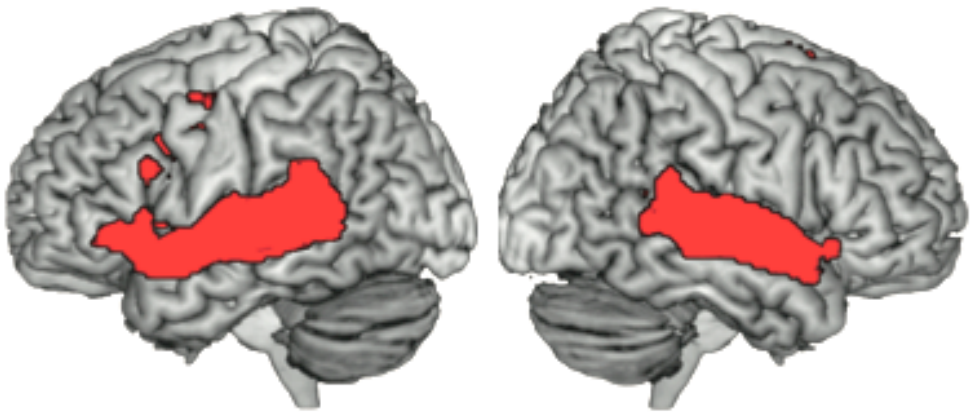
Syntax Simple



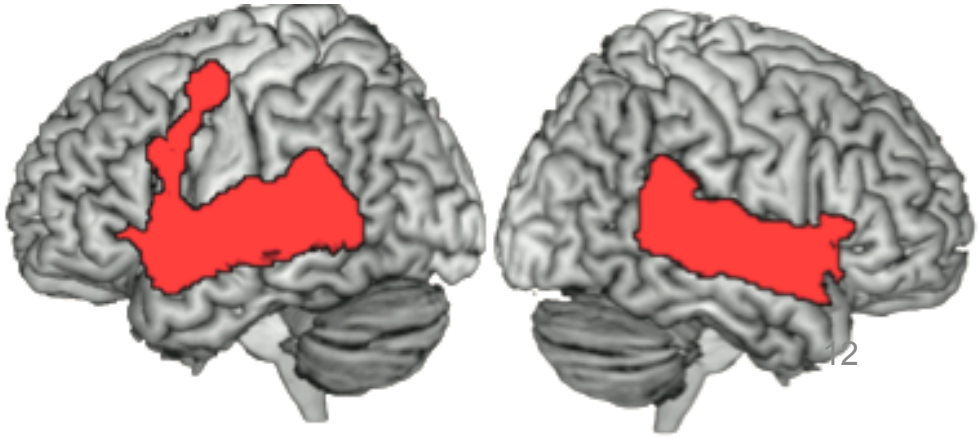
Syntax Complex



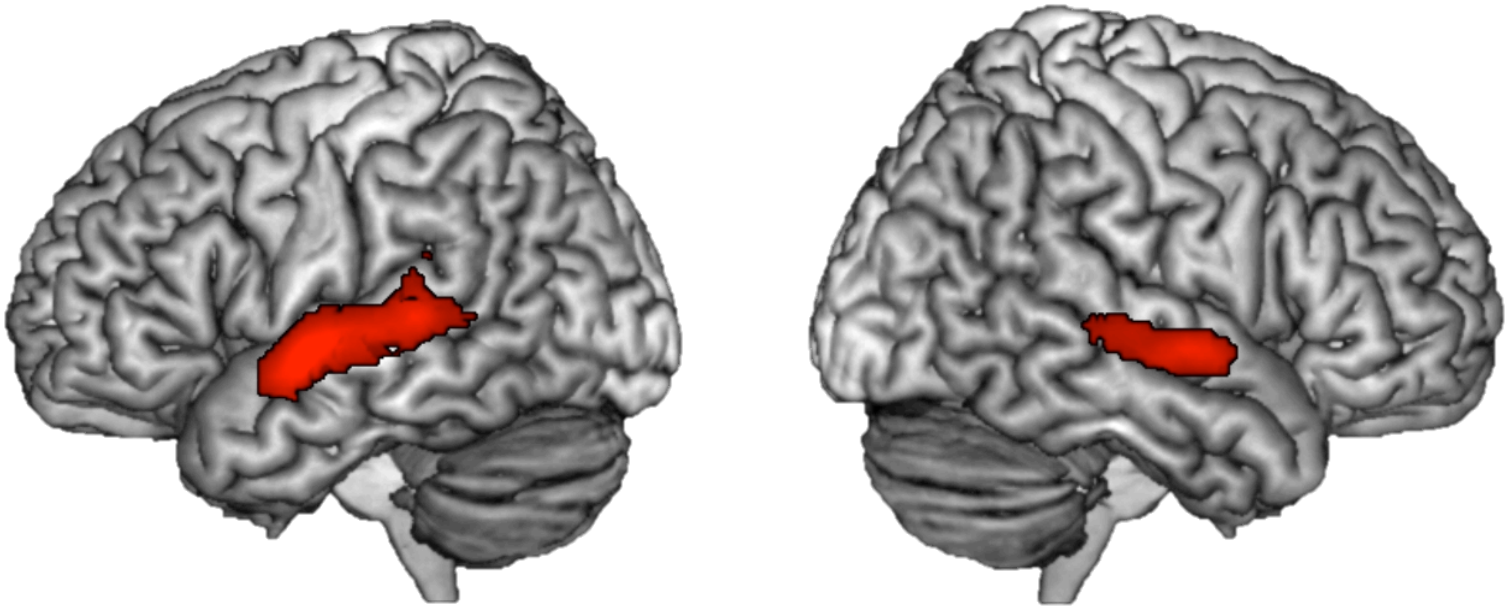
Inflection Simple



Inflection Complex

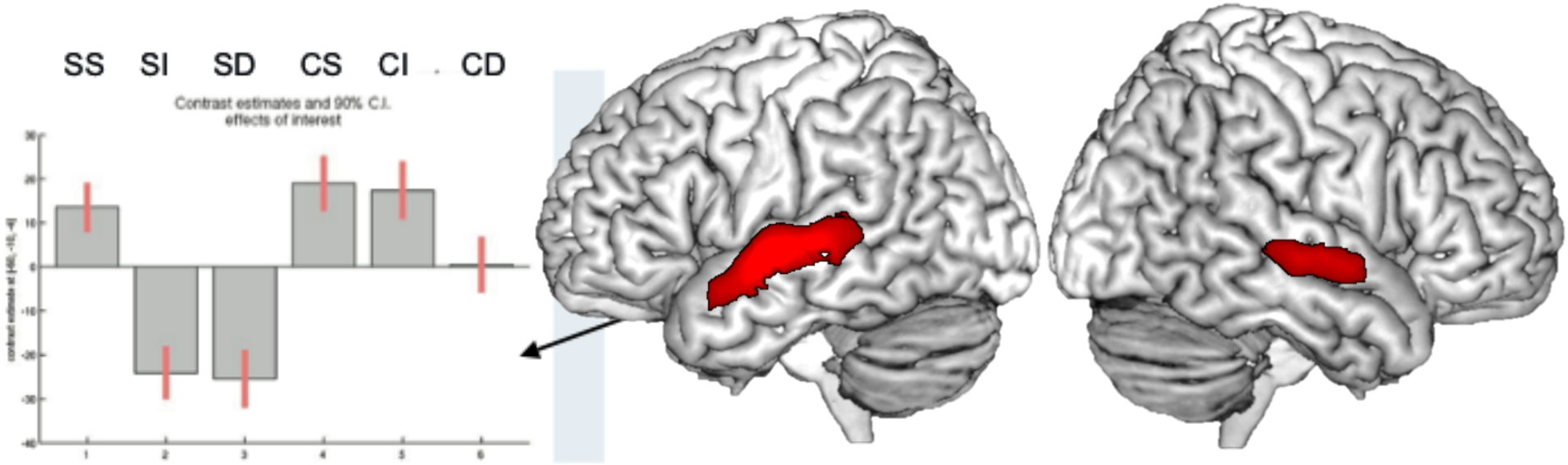


Complex Inflection minus Simple Inflection



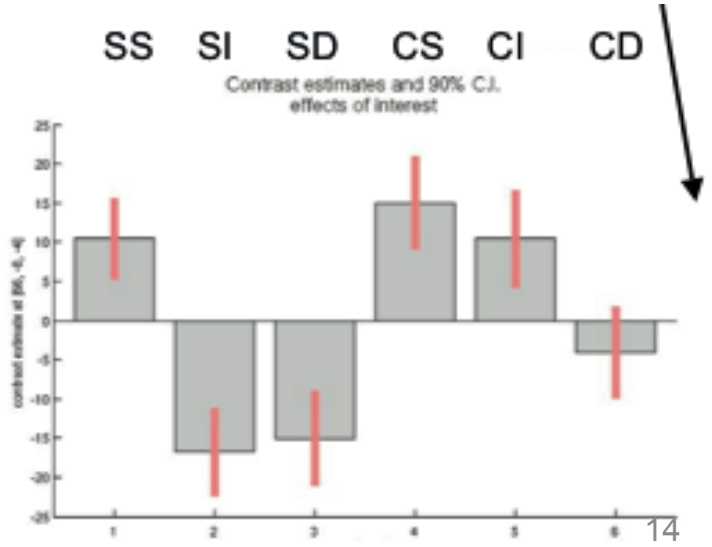
- L and R STG activation

Results Q2 - ANOVA



% signal change, all six conditions

SS – Simple Syntax
SI - Simple Inflection
SC – Simple Derivation
CS – Complex Syntax
CI – Complex Inflection
CD – Complex Derivation



Summary – Univariate analysis Q1 and Q2

- Grammatically informative Inflection and Syntax – LH BA 44, 45 and greater posterior STG and MTG bilaterally. Access grammatical information in a comparable way.

- No effect of increased morpho-phonological parsing demand (Complex Inflection) when the grammatical information was controlled.

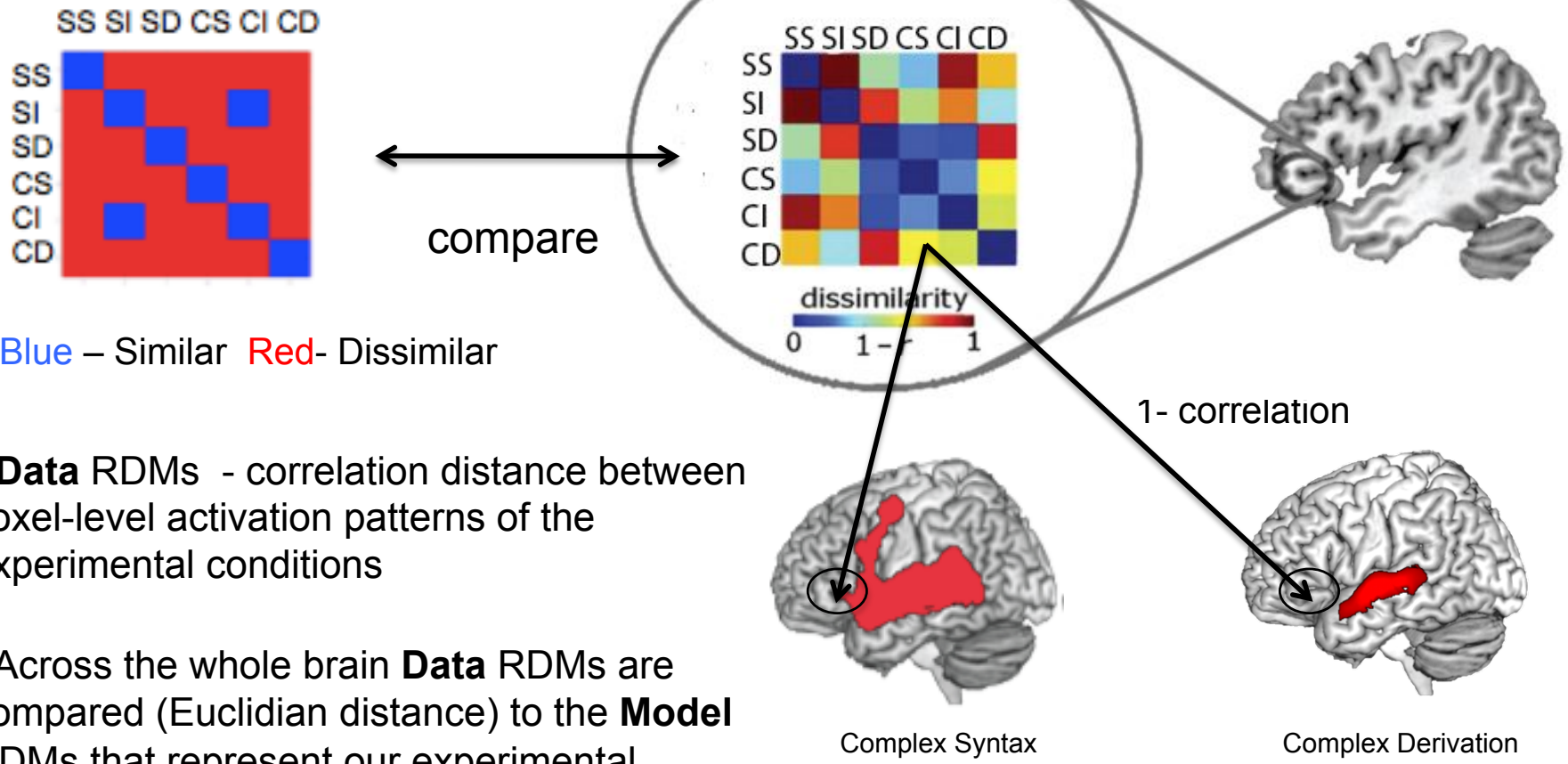
- No difference between hierarchical versus linear syntactic structures (Complex versus Simple conditions)

- Effects in the mid and posterior STG bilaterally.

RSA SEARCHLIGHT

Model RDMs

Data RDMs



Blue – Similar Red- Dissimilar

• **Data** RDMs - correlation distance between voxel-level activation patterns of the experimental conditions

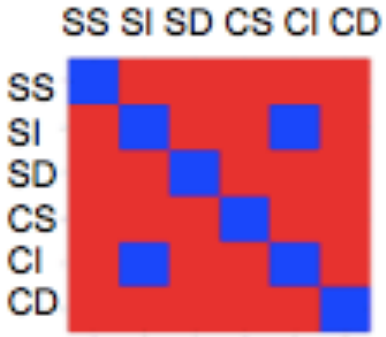
• Across the whole brain **Data** RDMs are compared (Euclidian distance) to the **Model** RDMs that represent our experimental hypotheses

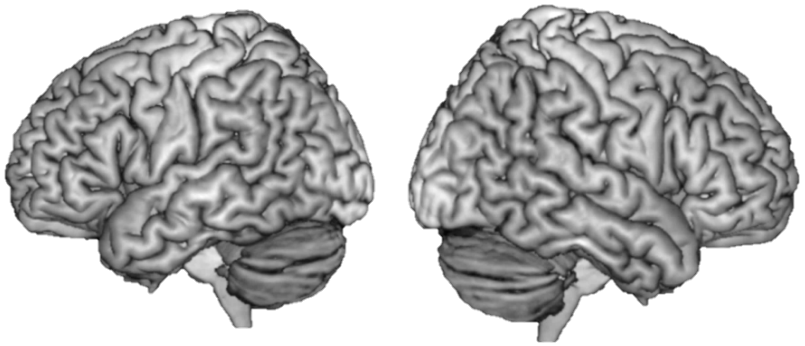
Searchlight RSA allows to access the 'information' carried by the voxel level activation patterns and is complementary to the mainstream univariate analysis

(Su et al., 2010; Kriegeskorte et al., 2008)

RSA Results – 2

1. '**Inflection**' model – Simple and Complex Inflection are similar; other conditions – dissimilar

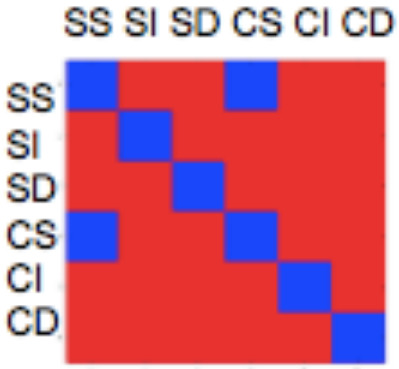


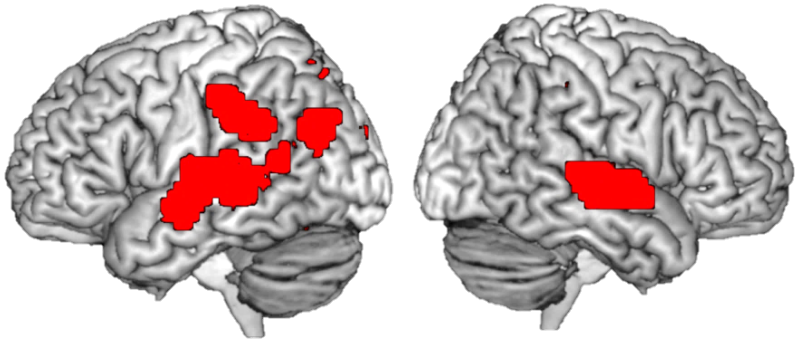


Blue – Similar

Red- Dissimilar

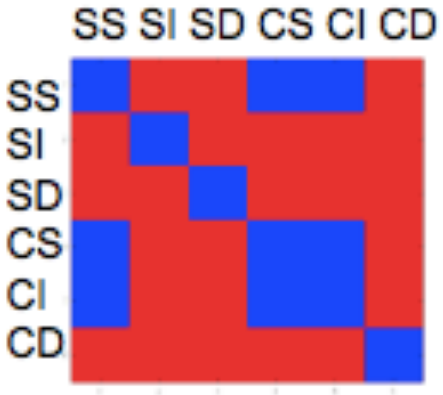
2. '**Phrasal syntax**' model –Simple and Complex Syntax are similar; other conditions – dissimilar

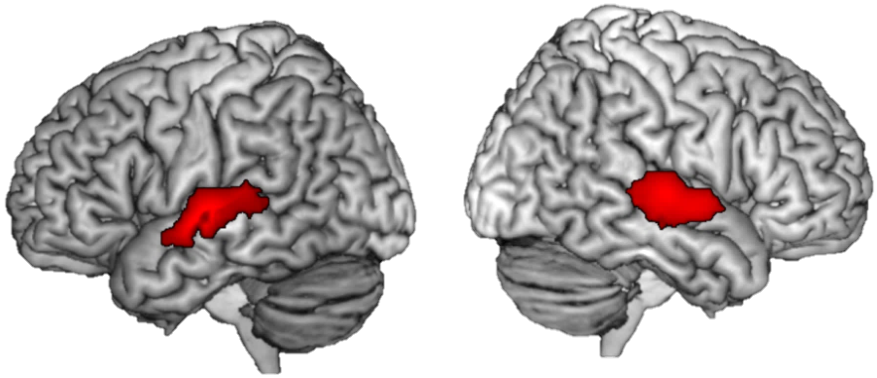




RSA Results – 3

3. ‘relational processing’ - Complex and Simple Syntax and Complex Inflection are similar; other conditions – dissimilar

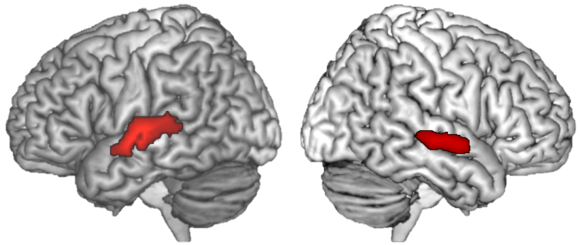




Blue – Similar

Red- Dissimilar

- Complementary to the ANOVA analysis



- Conditions with more relational information generated temporal activation increase AND produced similar voxel-level activation patterns

RSA Searchlight and Univariate conclusions:

- Grammatically more informative conditions Inflection and Phrasal Syntax activate LH fronto-temporal network in a comparable way, while Derivation does not.

- This suggests that for Inflections and Phrasal Syntax grammatical/ relational information is accessed and integrated in a similar way.

- However LH network shows no specific sensitivity to:

a) Increased morpho-phonological parsing demands;
b) Hierarchical versus linear syntactic structure processing

→ Bilateral temporal network shows a similar activation profile for conditions that provide more relational information.