Characterizing lexical complexity computations in the fronto-temporal language network

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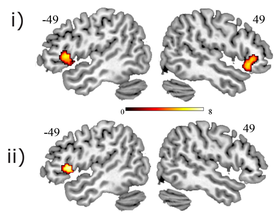
Fronto-temporal language network

Speech comprehension engages a network of bilateral fronto-temporal brain regions. The network arguably consists of two functionally distinct subsystems [1]:

a) *a distributed bilateral subsystem*, supporting general perceptual processing for lingustically simple words (e.g. *dark*)
b) *a specialised left-lateralised subsystem*, supporting combinatorial morpho-phonological processing of lingustically complex words (e.g. *played*)

Condition	Example	Embedded stem	Suffix IRP
1. regular past tense	*played*	? (*play*)	Y
2. pseudoregulars	*trade*	Y (*tray*)	Y
3. no stem, with IRP	*trend*	N	Y
4. stem only	*claim*	Y (*clay*)	N
5. simple	*cream*	N	N

i) increase in general processing complexity (trade, claim - cream)
ii) increase in lingustic complexity (played, trade, trend - cream)



[2]

In the current experiment we test how different types of lexical complexity modulate the computations in the fronto-temporal language network. We use the Representational Similarity Analysis to assess the patterns of activity evoked by lexical computations across fronto-temporal brain regions.

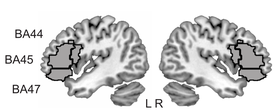
Representational Similarity Analysis (RSA)

RSA is a multivariate pattern analysis method that allows us to assess the information carried by a pattern of activation across multiple voxels [3]

In RSA, patterns of activation are expressed as Representational Dissimilarity Matrices (RDMs), which show the correlation distance (one minus the correlation value) between patterns elicited by different conditions.

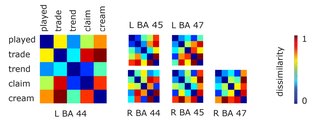
Neuroscientific inference is drawn from a second level analysis that compares RDMs to theoretical models, also characterized by RDMs.

1. Regions of interest (ROIs)



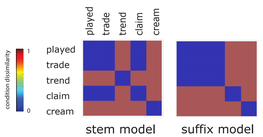
ROIs based on the univariate results (above), to test the information carried by activation patterns in each region.
Regions defined anatomically using WFU pickatlas.

2. RDMs extracted from ROIs



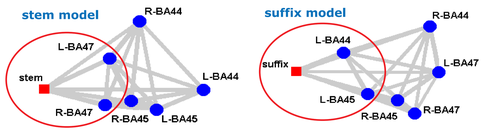
RDMs are extracted from non-smoothed and non-normalised beta images for each participant.
Individual RDMs are averaged across participants to obtain one RDM per region.

3. Theoretical models expressed as RDMs



Stem model codes for the presence of embedded stems. *Suffix model* codes for the presence of a suffix ending. Blue squares indicate that activation patterns correlate due to a shared property.

4. Comparing the RDMs using Multi-Dimensional Scaling



Diagrams show Euclidean distances betwen RDMs in the multidimensional space. They are flattened for presentation in two-dimensional space. Line area (length * thickness) specifies the distance between model and region RDM

RSA results confirm the previously obtained univariate results. Importantly, they reflect the actual patterns of activity, rather than levels of activation averaged across voxels. They provide a systems level view of the regions involved in different computations.

Applying RSA to characterize lexical complexity computations in the fronto-temporal network

We are testing the computations triggered by the increase in combinatorial and general processing demands in two different types of complex words: inflected words (e.g. *play+ed*) and derived words (e.g. *build+er*).

We manipulate the general processing demands and combinatorial processing demands in spoken words by varying the presence of embedded stems and morphological suffixes.

Inflections and derivations present different challenges to the language processing system:

Inflections are regular and fully compositional combinations of stems (e.g. *play*) and inflectional suffixes (e.g. *-ed*).

Evidence suggests that they are processed and represented with respect to their morphological structure (i.e. decomposed into stem+suffix) [1]

Derivations are combinations of stems (e.g. *build*) and derivational suffixes (e.g. *-er*). They are less regular than inflections, and vary in compositionality (e.g. *build+er* vs *corn+er*).

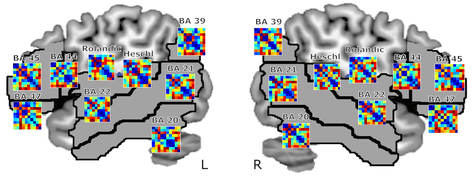
Evidence suggests that they may be processed and represented as full forms, with preserved information about the morphological structure [4]

1. Experimental conditions

Inflected	Derived	Embedded stem	Suffix
1. played	*6. builder*	Y?	Y
2. trade	*7. corner*	Y	Y
3. trend	*8. blemish*	N	Y
4. claim	*9. scandal*	Y	N
5. cream	*10. giraffe*	N	N

40 words per condition (matched on frequency and semantic distance), acoustic baseline.
Inflections are monosyllabic, derivations are bisyllabic (second syllable = suffix).
Gap detection task, fast sparse acquisition, 14 participants, data analysed in SPM5.

2. Representational Dissimilarity Matrices

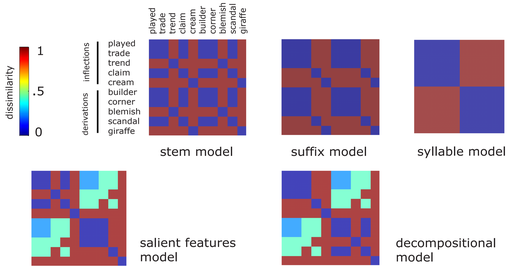


Regions of Interest (bilaterally):

BA 44 - pars opercularis
BA 45 - pars triangularis
BA 47 - pars orbitalis
Rolandic operculum
BA 41 - Heschl's gyrus
BA 20 - inferior temporal gyrus
BA 21 - middle temporal gyrus
BA 22 - superior temporal gyrus
BA 39 - angular gyrus

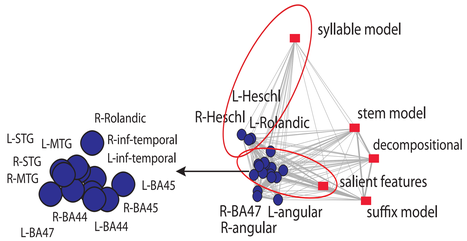
Regions of interest are selected to cover the brain areas that form the bilateral fronto-temporal language network.
RDMs are 10x10 matrices, extracted for each subject and each region, then averaged across participants.

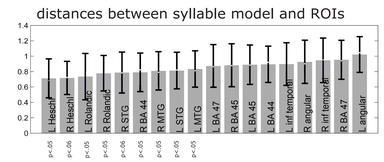
3. Theoretical models

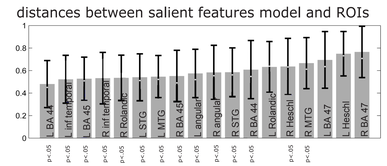


Stem model tests for the effects due to increases in general processing demands (presence of an embedded stem) that are comparable across inflections and derivations. *Suffix model* tests for comparable effects across inflections and derivations due to the increase in combinatorial processing (presence of a suffix). *Syllable model* tests for processing differences between the two sets due to the number of syllables/length. *Salient features model* assumes that the processing is affected by the most salient feature: an embedded competitor for short words, and the presence of the second syllable (suffix) for longer words. *Decompositional model* tests for the effects driven by word's decompositionality. Here, the processing of inflections is determined by the presence of a suffix, and the processing of derivations is driven by the presence of embedded stems.

4. Models to data fit







Stem and suffix models alone do not significatly correlate with the patterns of activation observed. The *syllable model* significantly correlates with the patterns of activation in bilateral Heschl's gyrus and the surrounding regions. The *salient features model* best explains the patterns of activation in the fronto-temporal language regions. It confirms that general processing demands (i.e. presence of a competing embedded stem) strongly modulate the processing of short, monosyllabic words. In bisyllabic words, the second syllable - morphological suffix - is the most salient feature which determines the type of computation performed. Finally, the *decompositional model*, which is based on decompositionality of inflected and derived words, does not correlate well with the patterns of activation in fronto-temporal regions of interest. The results suggest an adaptive system, where the most salient features dynamically modulate the lexical computations performed.

Conclusions

The fronto-temporal language processing network is a dynamically modulated system. The computations it performs on words with different types of lexical complexity are adapted to the most salient and informative feature of the processed words.

Representational Similarity Analysis (RSA) provides a comprehensive and systems-level insight into the types of computations performed during spoken language comprehension in the fronto-temporal language network.

References

[1] Marslen-Wilson WD & Tyler LK (2007) Morphology, language and the brain: the decompositional substrate for language comprehension. Phil Trans R Soc B 362:823–836; [2] Bozic M, Tyler LK, McGettigan C, Randall B & Marslen-Wilson WD (2007) Morpho-phonological and lexical properties of spoken words and the fronto-temporal language network. J of Cogn Neurosci 19:E65, Supplement; [3] Kriegeskorte N, Mur M & Bandettini PA (2008) Representational similarity analysis: connecting the branches of systems neuroscience, Front. Syst. Neurosci, 2, 1-27; [4] Clahsen H, Sonnenstuhl I & Blevins JP (2003). Derivational morphology in the German mental lexicon: A dual mechanism account. Morphological Structure in Language Processing, ed. by RH Baayen and R Schreuder, 125-155. Mouton de Gruyter: Berlin.