Dissociating prediction and constituent-structure during naturalistic sentence-structure building processes

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Introduction

Hierarchical relations between words impact sentence comprehension and are often formalized through tree-like structures (Fig. 1A). Their structural complexity has been consistently shown to correlate with activity in core brain areas of the language network (Ben-Shachar et al. 2004; Pallier et al. 2011; Shetreet and Friedman 2014; Nelson et al. 2017).
Along with such structural complexity, different computational parsing strategies can be used to investigate the neural correlates of syntactic structure-building. Modelling how sentence structure can be parsed can reveal different sub-components of sentence processing and syntactic complexity.

Questions

If we computationally decompose sentence structure processing into constituent-structure building and sentence-level predictive processes,
can we observe distinct neural correlates for these two aspects of syntactic structure-building ?

Bottom-up and Top-down Parser Action Count

By comparing the fMRI activation patterns to bottom-up (BU) and top-down (TD) parsing strategies (Fig. 1B&C), we aim to unravel different components of the complex cognitive process of sentence-structure building:

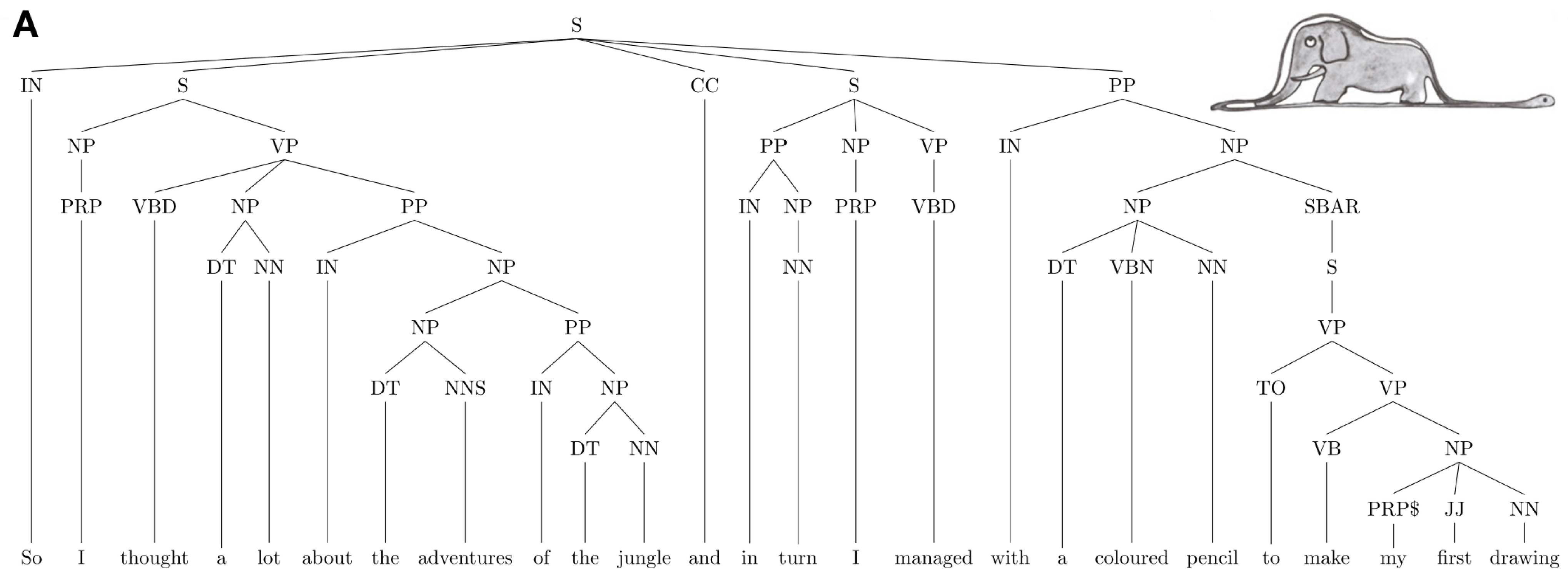
- BU can instantiate constituent-structure building. It builds and collects sub-parses towards the end of the phrase/sentence, while the rules of a grammar are applied at each incoming word (see Fig. 2A left).
- TD better approximates expectation-driven structural processing, as rules are applied predictively, in advance of each word, thus assigning higher scores at the beginning of sentences (see Fig. 2B left).

Data Collection

Participants (n=51) were college-aged, right-handed, native English speakers. They listened to a spoken recitation of *The Little Prince* for 1 hour and 38 minutes across nine separate sections; 15,388 words in total. Comprehension was confirmed through multiple-choice questions at the end of each section.

Predictors

A



B Bottom-up parser action count

1	2	1	1	2	1	1	2	1	1	7	1	1	3	2	3	1	1	1	2	1	1	1	1	10

C Top-down parser action count

3	3	2	2	1	2	3	1	2	2	1	1	3	2	2	2	2	3	1	1	4	2	2	1	1

Figure 1 The number of steps that a phrase structure parsing algorithm would take at each word defines a syntactic complexity metrics depending on the parsing strategy that is adopted. (**A**) depicts the syntactic structure of a single sentence of the naturalistic stimulus text, as recovered by the Stanford parser (Klein and Manning, 2003). (**B**) Bottom-up parsing strategy in orange. (**C**) Top-down parser action count with respect to this tree in purple. Both syntactic complexity metrics were annotated at the offset of each word in the audiobook. In bottom-up parsing the rules of a grammar are applied at each incoming word, while in top-down parsing a maximum number of rules are applied in advance of each word.

fMRI Results

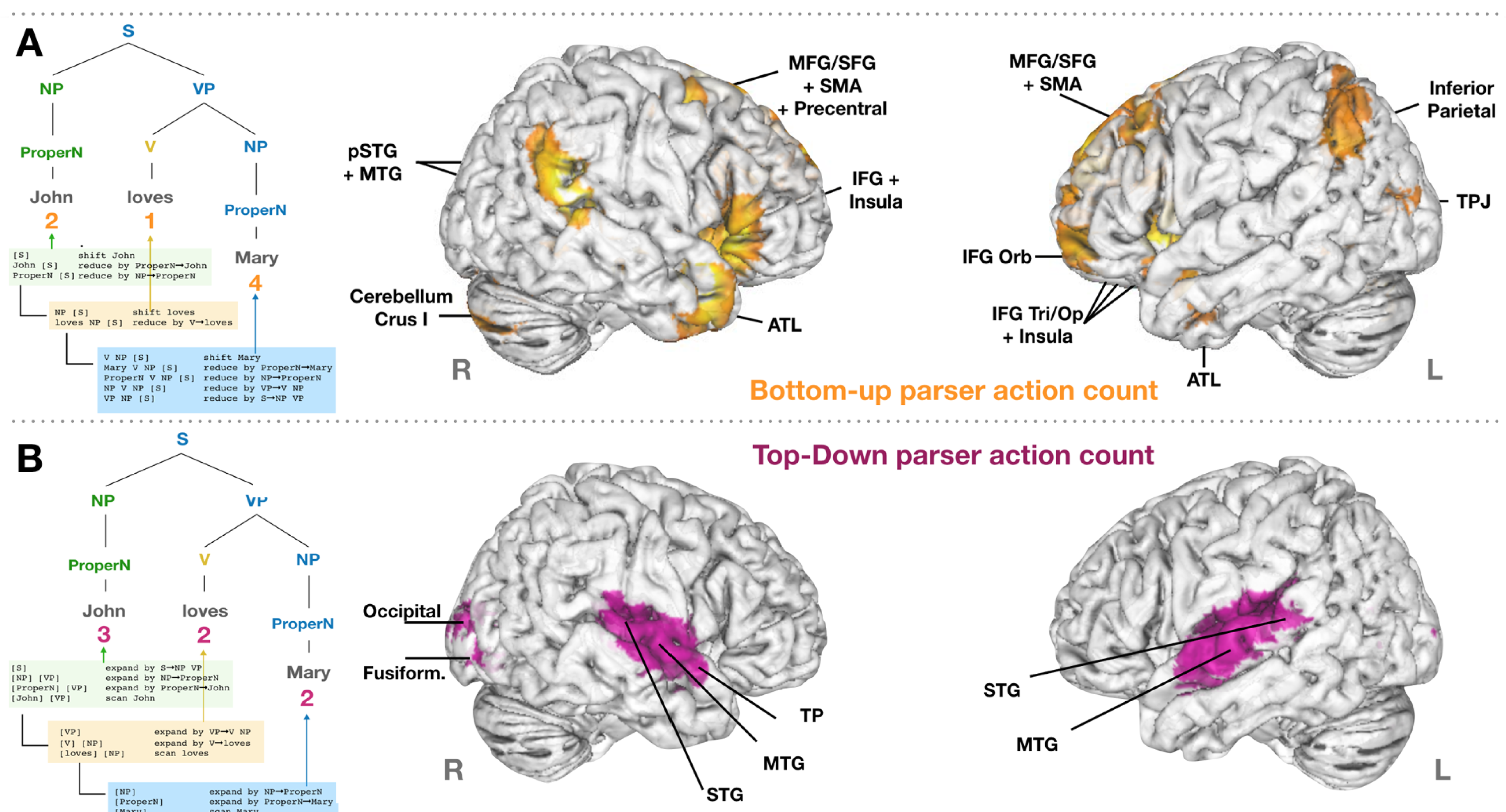


Figure 2 ***Left***: Tree-structures depicting the hierarchical structure for "*John loves Mary* " , built via processes of syntactic composition with the word-by-word parser action counts given in orange for bottom-up (BU) and in purple for top-down (TD) parsing strategy. *Below each tree* : Sequences of parser actions (i.e. shift and reduce) that would build the color-coded tree nodes during BU (**A**) or TD parsing (**B**). *BU applies rule after all daughters are found, and TD applies rule before any daughters are found.* ***Right:*** Whole-brain images with significant clusters for Bottom-up parser action count in orange in (**A**), and for Top-Down parser actions count in purple (**B**). Brain maps are FWE - corrected for multiple comparisons at voxel-level, $p < 0.05$.

Analysis

Preprocessing was carried out with AFNI version 16 and ME-ICA v3.2 (Kundu et al., 2011). The two parser action counts were convolved with HRF and regressed against observed BOLD signal during passive story listening. GLM analysis included four regressors of non-interest: word offset, word frequency, pitch (F0), intensity (rms).

Results

Regression analyses reveal that the activation patterns for BU and TD are largely bilateral and involve different brain areas. For BU the peak activation is observed in the right TP. While ATL involvement is bilateral, one of the main clusters is extending from STG to MTG is right-lateralized.
Increased activation of LIFG and RIFG stretching over Pars Orbitalis and Triangularis, to the anterior Insula (/Putamen) was also observed (Fig. 2A). For TD, two bilateral clusters were observed along STG extending from its posterior portion to MTG, reaching TP in the right hemisphere (Fig.2B).

Conclusion

1. Predictive syntactic processes modeled by TD strategy evoke an activation pattern that is spatially-dissociable from compositional structure-building modeled by BU strategy. Thus, replicating findings about prediction during story listening (*surprisal* Willems et al. 2015).
2. Consistent with previous work (Nelson et al. 2017; Brennan et al. 2016), these findings show that, under naturalistic conditions, sub-parts of the language network functionally contribute bilaterally to different dimensions of sentence-structure building.

Acknowledgements

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Selected References

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