Parsing sentences are unlikely: Corpus-based analyses of the neural processing of verbs

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Background & Motivation

- **How does our knowledge of verb subcategorization frame (SCF) preferences influence the resolution of local ambiguities during sentence comprehension?**
- **Is this knowledge reflected in neural activity?**
- **What can statistical data about such preferences tell us about verb lexico-syntactic representation and processing?**
- Several studies suggest verb SCF preferences affect sentence processing by placing constraints on how potential arguments are incorporated into the emerging representation (e.g. McDonald 1994)
- **However:**
  - Most studies have used measures of syntactic preference derived from subjective human judgments.
  - Most studies have used stimuli where the verb heads a verb phrase, rather than sentences where the role of the verb is more ambiguous.

Our approach: investigate the neural effects of corpus statistics on verb syntactic properties

- Correlate SCF statistics derived from cross-domain corpora with patterns of neural activation as listeners process verbs in sentences
- **Stimuli:** 126 spoken sentences containing a phrase which could be locally syntactically ambiguous:

  "He knew that **insulting neighbours** is not encouraged"

  → "insulting" is a gerund

  "He knew that **insulting neighbours** are not respected"

  → "insulting" is an adjectival modifier
- The ambiguous phrases were disambiguated by the next word in the sentence ("is", "are")

Experiments

Behavioural pre-test

- 23 participants heard the sentences up to the end of the potentially ambiguous phrase and wrote down completions to the sentences.
- Responses were coded as consistent with adjectival/gerundive readings.

fMRI Study

15 new participants (18-35 yrs) listened to the sentences (+ fillers & non-speech stimuli). No explicit task.

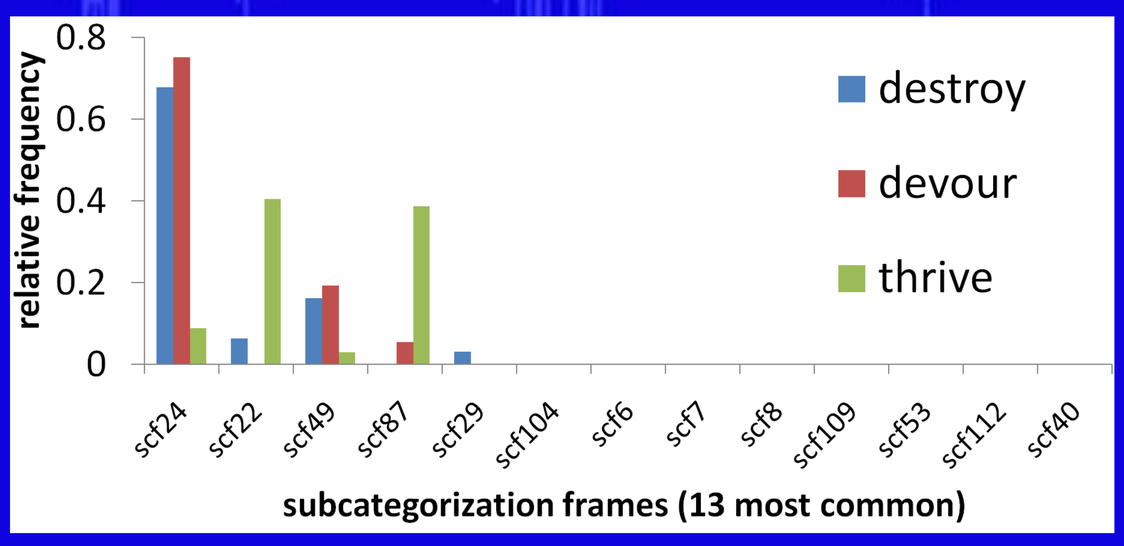
- Rapid event-related presentation; jittered interstimulus interval; 3x15 min functional scans
- Functional: continuous EPI, TR = 2s, TE = 30ms, voxel size = 3x3x3mm3 (0.75 gap)
- Structural: T1-weighted MPRAGE, voxel size = 1 mm3
- fMRI analysis (SPM5): slice time correction, re-alignment, unified segmentation-normalisation, 8mm isotropic smoothing kernel, FFX GLM -> RFX correlations

Behavioural post-test

4 weeks after scanning. Unacceptable filler items.

Corpus data

- We obtained SCF frequency distributions for each verb from **VALEX** (a subcategorization lexicon for English verbs derived from large cross-domain corpora; Korhonen, Krymolowski & Briscoe, 2006)



SCF complement structure:
scf22 = intransitive; scf49 = NP PP; scf24 = NP; scf87 = PP

We reduced the dimensionality of the relative frequency data over the SCFs using **principal components analysis** (PCA)

Frame	arguments	Example of argument structure	pca1	pca2	pca3	pca4	pca5	pca6
SCF22	INTRANS	*He went*	**-0.81**	-0.17	0.00	-0.10	0.02	-0.30
SCF24	NP	*He loved the girl*	**0.83**	0.14	-0.13	-0.01	-0.29	-0.17
SCF49	NP-PP	*She added the flowers to the bouquet*	**0.76**	0.18	-0.30	-0.03	-0.24	0.02
SCF87	PP	*They apologized to him*	**-0.78**	-0.16	-0.26	-0.24	0.18	-0.16
SCF6	NP-S	*It annoys him that she left*	0.22	**0.96**	-0.07	-0.07	-0.07	0.00
SCF7+8	S-SUBJ NP-OBJ	*That she left annoys them*	0.22	**0.95**	-0.08	-0.07	-0.06	0.01
SCF104	S	*They thought that she was always late*	0.15	-0.11	**0.89**	-0.05	0.11	0.08
SCF109	That-S	*He complained that they were coming*	-0.26	-0.02	**0.81**	0.02	-0.12	-0.07
SCF29	NP-as-NP	*I sent him as a messenger*	0.32	-0.30	-0.02	**0.71**	-0.07	-0.03
SCF40	NP-P-ING	*I accused her of murdering her husband*	0.18	-0.02	-0.21	**0.72**	-0.08	0.34
SCF112	to-INF	*I wanted to come*	-0.25	0.09	0.18	**0.67**	0.30	0.06
SCF23	INTRANS RECIP	*John and Jill met*	-0.18	-0.01	0.04	0.28	**0.77**	0.00
SCF95	PP-PP	*They flew from London to Paris*	-0.24	-0.13	-0.06	-0.21	**0.78**	-0.05
SCF53	NP-to-INF	*I advised Mary to go*	0.12	0.00	0.03	0.17	-0.03	**0.96**

Component 1 (PCA1) accounted for most variance (29%),
PCA1 reflects **the likelihood of the verb taking a direct object complement**:

- High loadings for NP & NP-PP frames
- Low loadings for INTRANS and PP frames

5 highest valued verbs on component pca1	denounce axe adopt exploit overtake
5 lowest valued verbs on component pca1	sneer yawn chuckle function reminisce

Prediction

Verbs with low values on Component 1 (e.g. "yawn") will lead to a preference for adjectival readings, because in this case the following noun is unlikely to function as the verb's theme (e.g. "yawning audiences").

Results & Conclusions

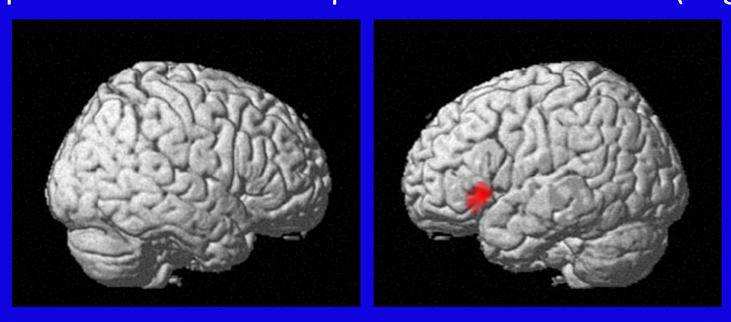
We calculated measures of dominance from the data:

- **Behavioural dominance measure,** on the basis of the pre-test data
- **Corpus dominance measures,** from the PCA components.

As expected, **only the pca1 measure (direct object likelihood) predicts preference:** it predicts the behavioural dominance score, and reaction times and rejection rates from the acceptability post-test.

	behavioral dominance		1/reaction time		rejection rate	
predictor	**t**	**p**	**t**	**p**	**t**	**p**
word 1 freq	not included		0.58	>0.2	-0.44	>0.2
word 2 freq	not included		-0.59	>0.2	-0.15	>0.2
dom_pca1	5.80	<0.0001	2.50	0.013	-4.17	<0.0001
dom_pca2	-0.95	>0.2	0.74	>0.2	0.69	>0.2
dom_pca3	-1.59	0.11	-0.53	>0.2	-0.01	>0.2
dom_pca4	0.07	>0.2	0.19	>0.2	0.31	>0.2
dom_pca5	-1.11	>0.2	-0.38	>0.2	0.54	>0.2
dom_pca6	-0.02	>0.2	-0.67	>0.2	0.07	>0.2

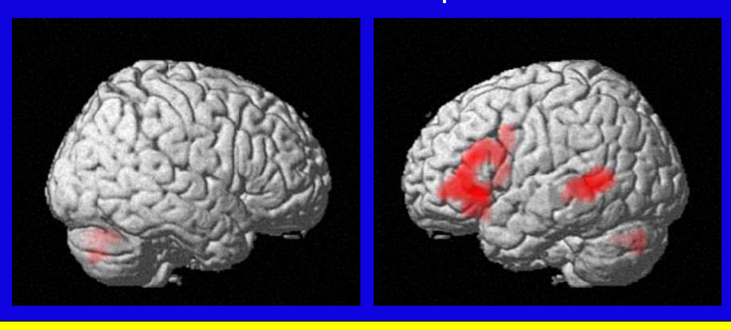
pca1 dominance as a parametric modulator (neg, $p < 0.001$, corrected)



L pars orb.
L pars tri.

(L & R IFG, L MTG & L IPL at $p < 0.01$)

behavioural dominance as a parametric modulator (neg, $p < 0.001$, corrected)



LIFG
L MTG
L & R Cerebellum

- **Sensitivity to continuation preference correlates with activation in LIFG and LpMTG, implicating these regions in syntactic ambiguity resolution** (see also Rodd, Longe, Randall & Tyler, 2010; Tyler et al 2011)
- In particular, **the SCF preference measure, calculated from the likelihood of the verb taking a direct object, correlates at least partly with the neural activation to the sentences**
- Supports a lexicalist account of spoken language comprehension
- The behavioural dominance measure is an overall measure influenced by:
  - syntactic properties of the verb
  - semantic properties of the verb (e.g. selectional restrictions)
  - degree of phrase lexicalization (e.g. "cooking apples"), etc
- Using **corpus measures** allows us to define different measures relating to **specific** aspects of spoken sentence processing, e.g.
  - Lexical-syntactic representation/access (SCF possibilities for verbs)
  - Integration of semantically plausible arguments with syntactic frames

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