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Quantity and Relationality:
MEG Investigations of Semantic Processing in the left Inferior Parietal Lobule

collaborative work with Liina Pylkkänen (NYU)
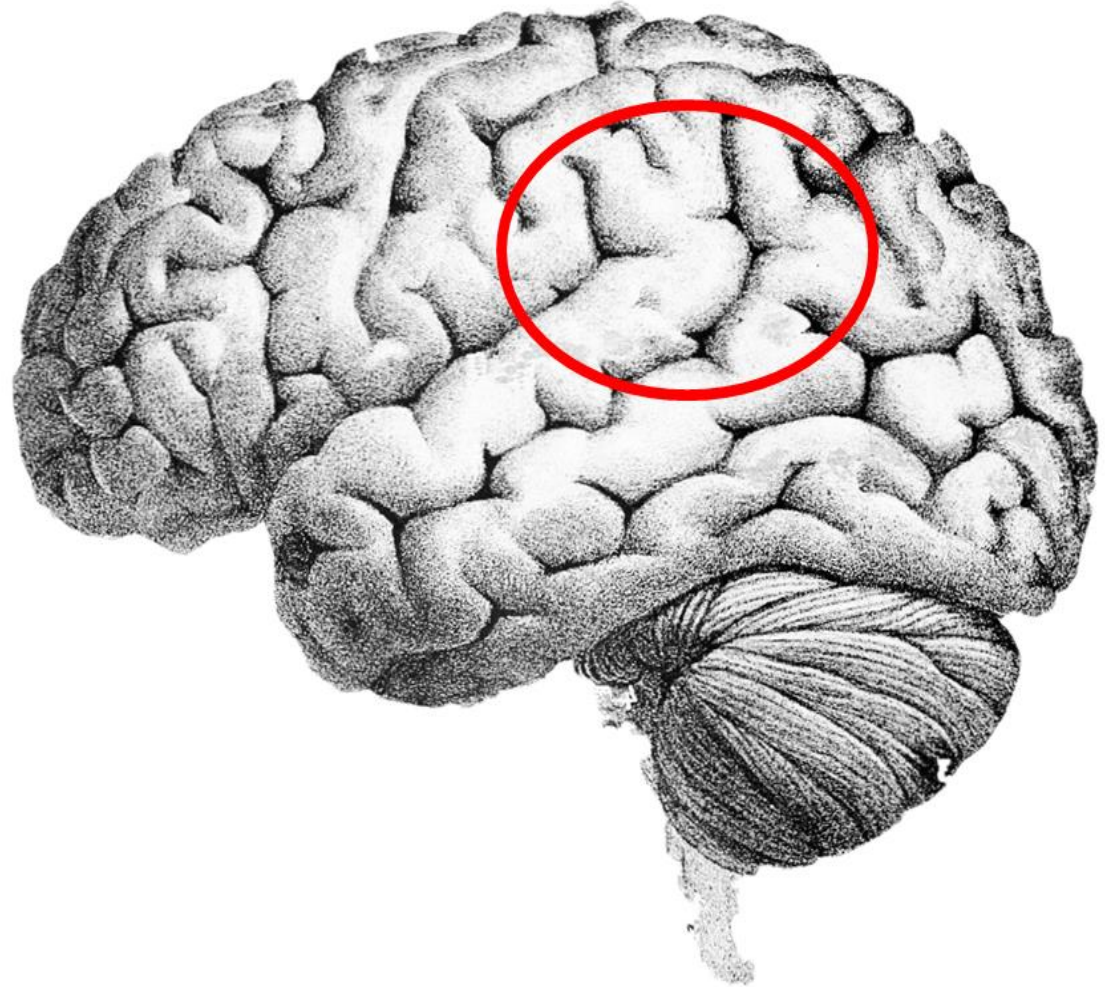
How does the brain process meaning?

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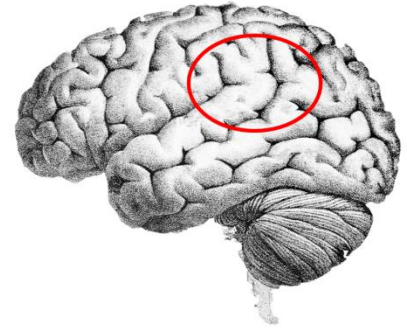
Left Inferior Parietal Lobule

(Supramarginal & Angular Gyri)

Angular Gyrus has received a lot of attention recently as a "semantic hub" (Binder & Desai 2011)

▸ **Most often activated region for semantic tasks!**

▸ **What functions might underlie activity in this brain region?**

Literature Background - AG

"Relationships"

1. Noun + Noun: (Lewis et al. 2015, de Zubicaray et al. 2013)
2. NN Compounds: Boylan et al (2014), Graves et al (2010), Estes (2003)
3. Isolated Noun: Bar et al (2007), Aminoff et al (2006), Bar (2004), Bar & Aminoff (2003)

Both
Verbal Argument Structure

1. Verbs in isolation varying number of arguments: Meltzer-Asscher et al. (2013), Thompson et al. (2010), Thompson et al. (2007)
2. Verbs>Nouns: Bedny et al (2014)
3. Verbs v. Nouns in context: Boylan et al (2015)

"Events"

1. Integration of event information (Binder & Desai 2011, Binder et al 2009, Lau et al 2008)
2. Naming Actions (Damasio et al 2000)
3. Linguistically v. non-linguistically encoded events in movies and scenes : Sitnikova et al (2008a, 2008b)
4. Episodic Memory (Andreasen et al 1995)

Summary

To the extent that research has been done on neural correlates of **argument structure**, it has mostly grown out of work on **the neural correlates of verbs**.

Predicates are often eventive and often packaged as verbs.

▸ But, as linguists, we know there are **nominal** predicates that are **non-eventive** (Löbner 1989, Löbner 1991, Barker 1995, Barker 2016)
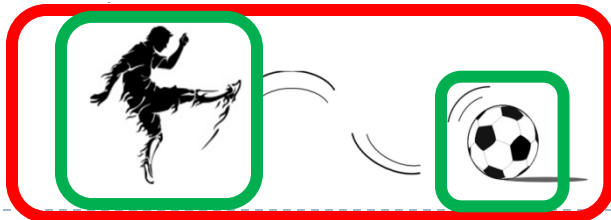
Non-Eventive Relational Predicates
adapted from Barker & Dowty 1993, Barker 1995

"relational nouns"

- ▶ Kinship terms
- ▶ Intrinsic aspects

kinship terms denote static relationships between individuals
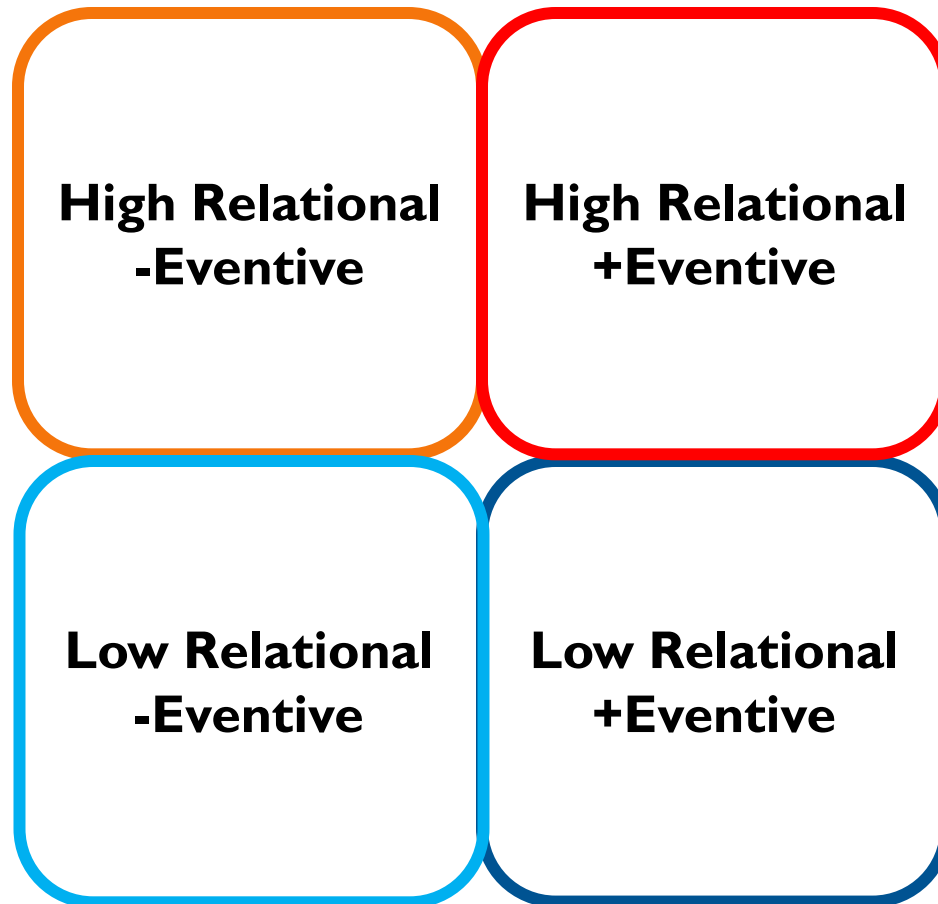
- ▶ MOTHER names a static relationship between kin

Experiment 1

Williams, Reddigari, Pylkkanen (2017)

Early sensitivity of left perisylvian cortex to relationality in nouns and verbs
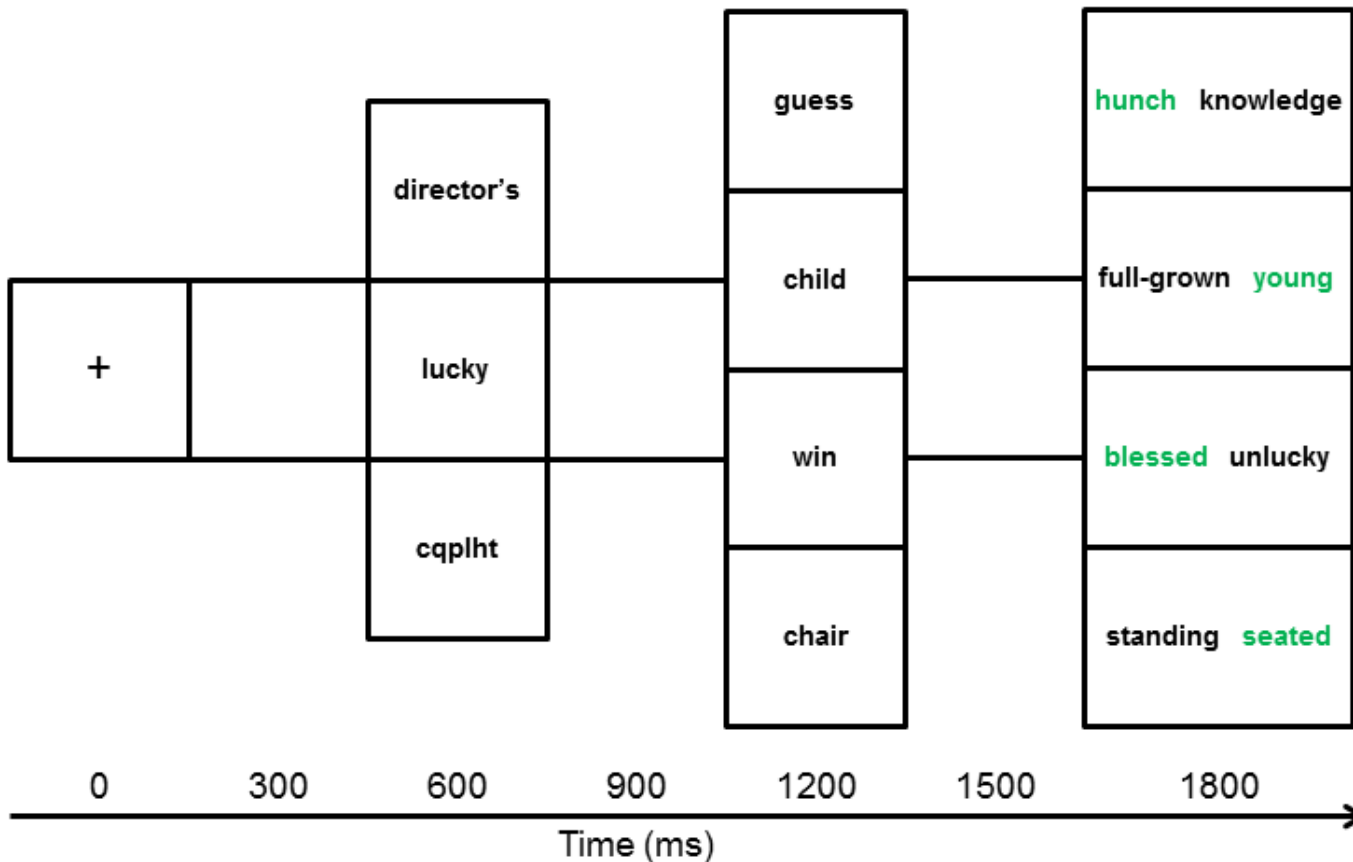
Our experimental design:

High Relational -Eventive	**High Relational +Eventive**
Low Relational -Eventive	**Low Relational +Eventive**

Relationality v. Eventivity

nephew

complaint

headset

yawn

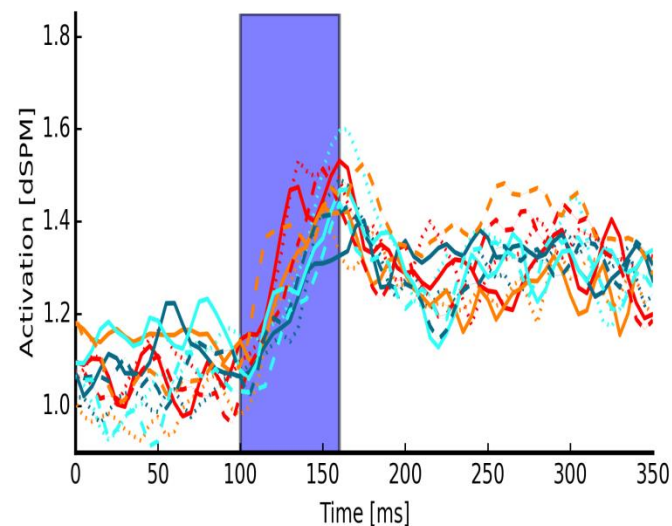We presented words in 3 contexts:
- Isolation
- Modification
- Possession

Methods

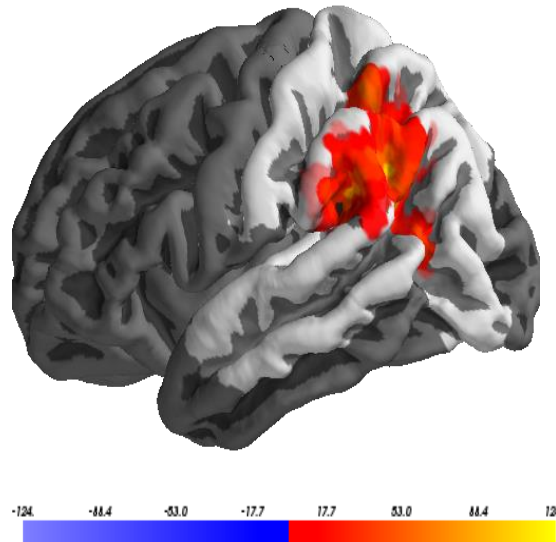Procedure: Which of the options is the best fit for the stimulus?
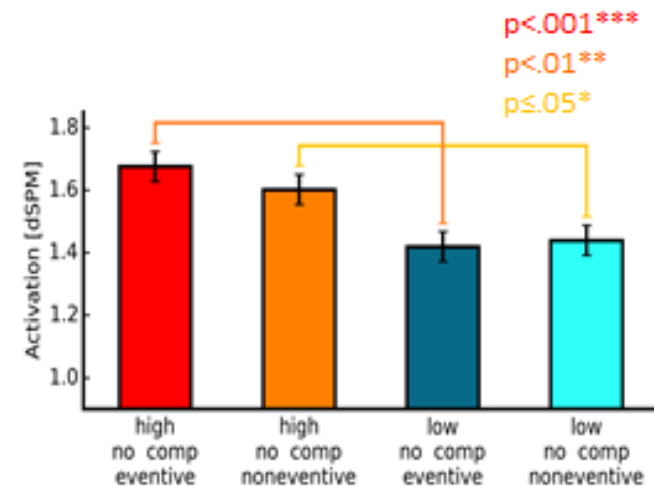
Results – Reading Results

1: Waveforms

- dark bar: cluster duration
- dSPM: "dynamic statistical parametric mapping" unit
  - Output of parametric tests

2: Brains

- light grey: search area
- dark grey: unsearched
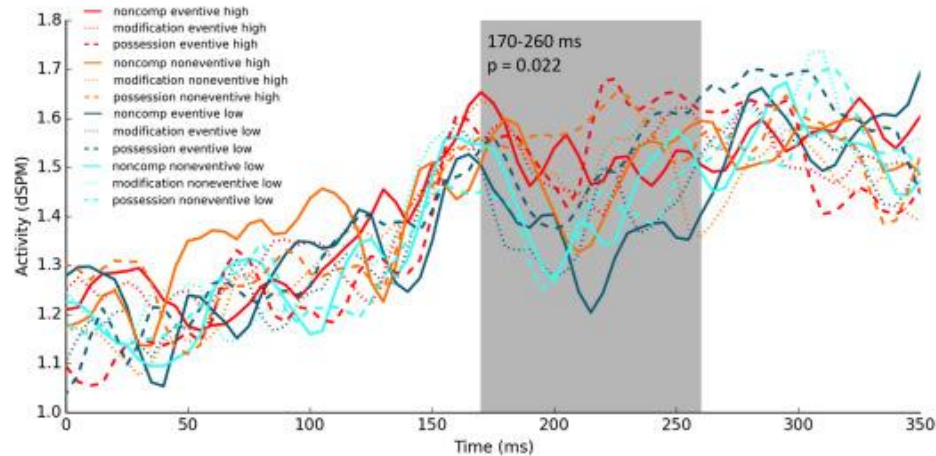- colored portion: brain activation
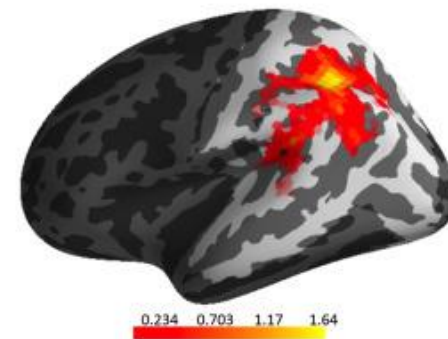- color bar: test statistic

3: Bargraphs

- Bar colors: indicate design
- Significance: colored lines indicate significance
- Pairwise t-tests: Uncorrected
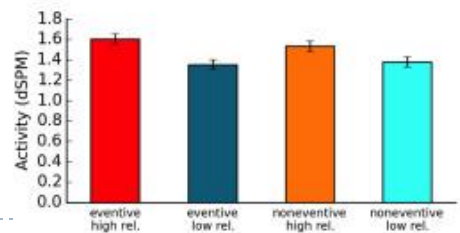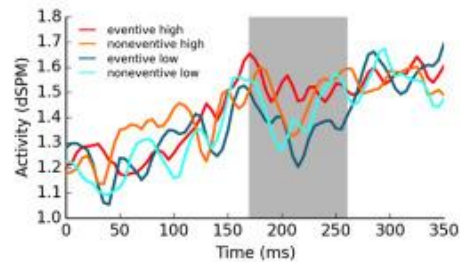
Results – Left Hemisphere

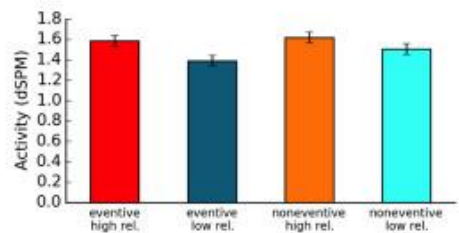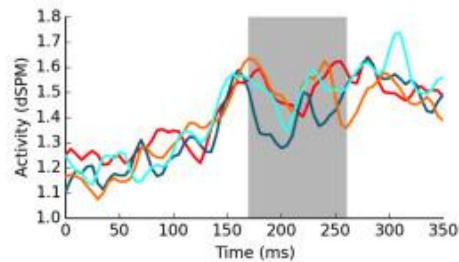A) Average brain activity in cluster sources

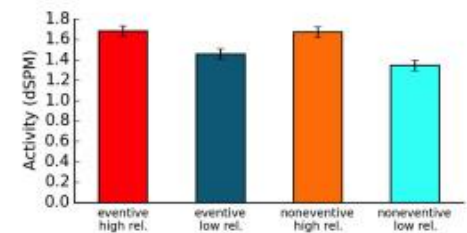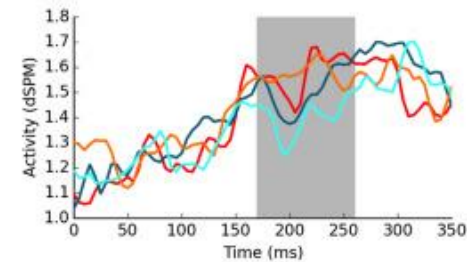B) Mean F-values over cluster duration

C) No Composition

D) Modification

E) Possession

Take home from Experiment 1:

Left IPL is sensitive to **relationality** of a word,

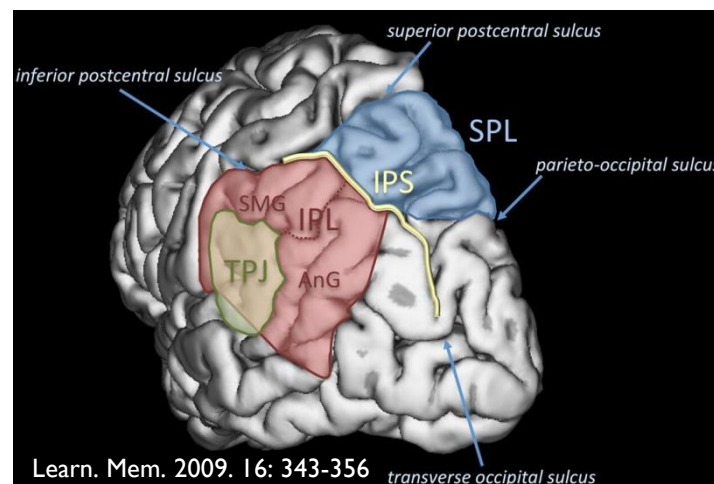not its **eventivity**,

not its **context.**

What function underlies left IPL activity?

Although the left IPL is sensitive to argument structure manipulations, it is not **selectively** sensitive to only argument structure

Left IPL has also been implicated in
Quantity Processing

"The human intraparietal sulcus is systematically activated in all number tasks and could host a **central amodal representation of quantity**." (Dehaene et al 2004a)

▸ IAG does language-related, verbal mathematical calculation (Dehaene et al 2003)
- ▸ "Mental Number Line" (Göbel et al 2001): greater or lesser than # task, rTMS
- ▸ Arithmetic Fact-Retrieval (Grabner et al 2009): self-report, fMRI
- ▸ Easier > Difficult arithmetic problems (Stanescu-Cosson et al., 2000)
- ▸ Magnitude Estimation (Dehaene et al 2004b): auditory or visual objects
- ▸ Trained multiplication (Delazer et al 2003): IPS → IAG through training
- ▸ Linking two-sentence discourses to plural rather than singular subjects (Boiteau et al 2014)
- ▸ Number, case agreement violations (Carreiras et al., 2010)

Learn. Mem. 2009. 16: 343-356
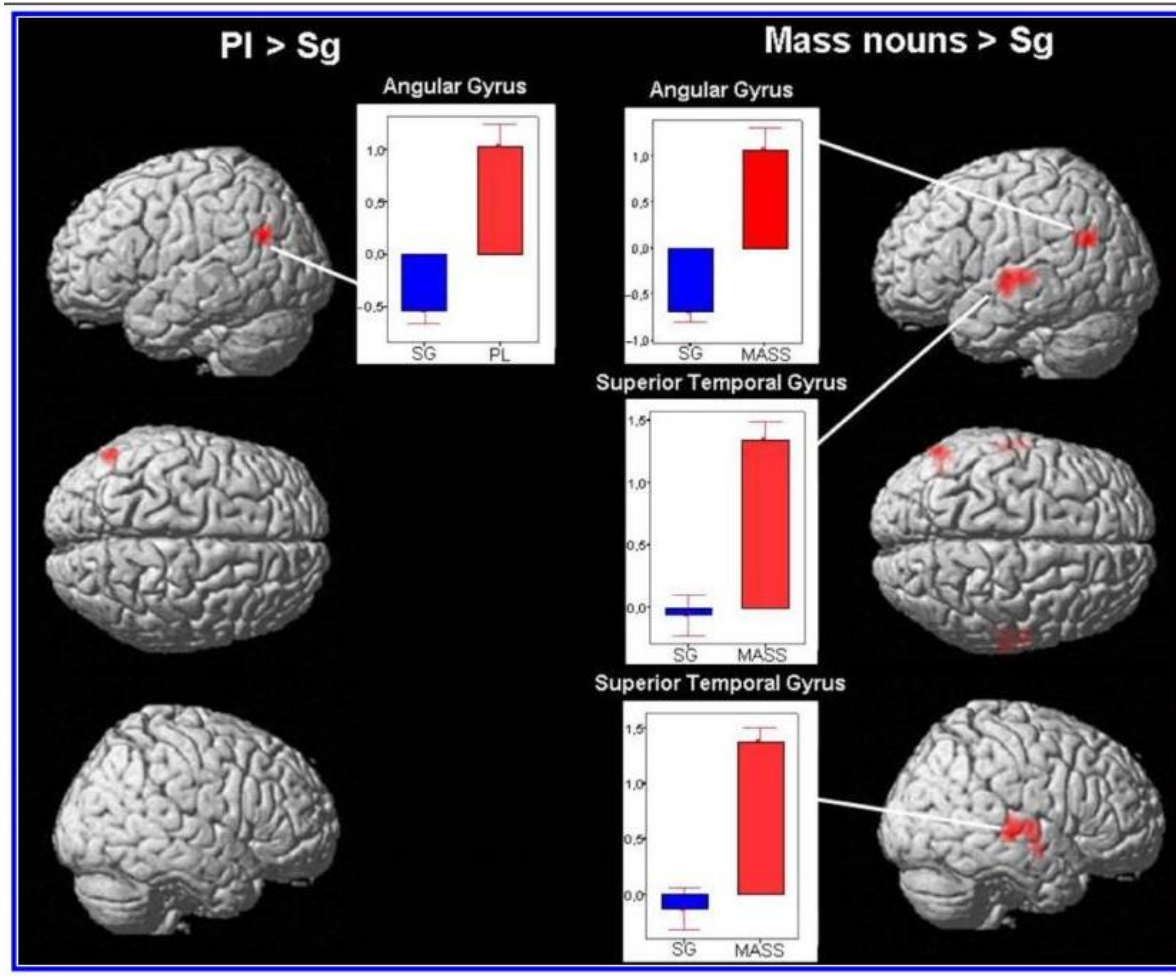
Number Cognition (Domahs et al 2012)

Figure 1. Cortical activations for the contrasts plural > singular (Pl > Sg) and mass > singular (Mass nouns > Sg; FDR-corrected, k = 5 voxels). The bar charts indicate beta values for singular nouns (blue) and plural nouns (red) referring to the marked cortical region.

Count Singular	Count Plural	Mass
palm *Palme*	palm**s** *Palme**n***	water *Wasser*

Plurals: umlaut, suffix, or by agreement in determiner or verb
Singulars: unmarked, or agreement
Masses: substances (e.g. *Wasser*, water) or abstracts (e.g. *Armut*, poverty)

MRI, event recall task, auditory presentation, fluent speech, German

If one function underlies left IPL Activity, it must be broad enough to subsume both **quantity** and **argument structure** effects

Idea

Perhaps **argument structure** effects can be subsumed under **quantity** effects

▸ If predicates *activate* their arguments, multivalent predicates activate more arguments than monovalent ones

KICK

"the thing that gets kicked"

"the thing that kicks"

DANCE

"the thing that dances"

Proposed Design

▸ 2 x 2 Basic Design

▸ Relational nouns activate left IPL more than non-relational ones

▸ Plurals activate IAG more than singulars (Domahs et al 2012)

Count		Unmarked	-s marked
	Relational	**mother**	mothers
	Non-rel	**lady**	ladies

MOTHER

relational nouns: *mother, bride, king, height, enemy, assassin…*

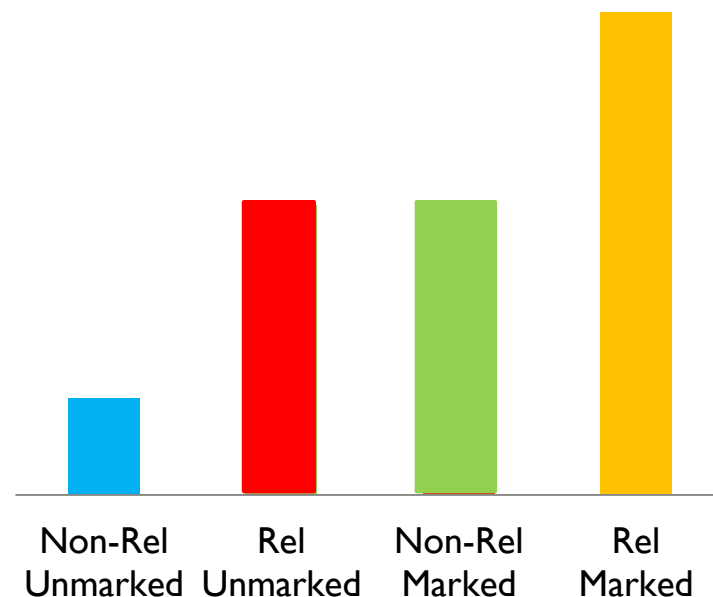If relational nouns activate their arguments:

mother > lady

If we replicate Domahs et al. (2012):

ladies> lady and *mothers>mother*

If both hold (perhaps):

mothers>ladies, mother>lady

Count		Unmarked	-s marked
	Relational	mother	mothers
	Non-Rel	lady	ladies

Non-Rel Unmarked | Rel Unmarked | Non-Rel Marked | Rel Marked

Problem!

Morphological complexity varies too…

Proposed Design 2 x 2 x 2 - Baselines
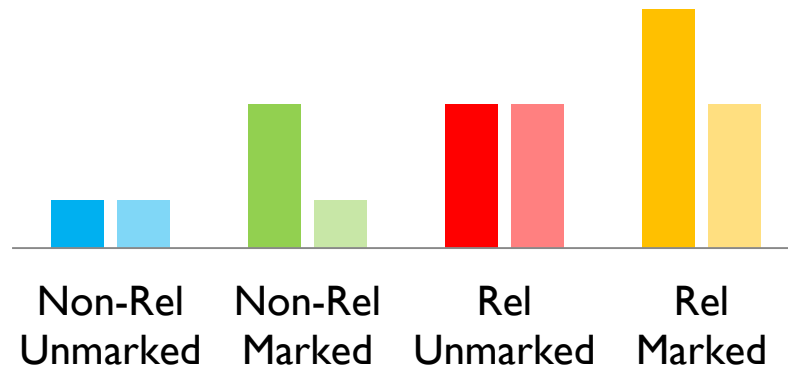
‣ **Solution: add a morphological control**

  ‣ Verbs can vary in relationality and take s-marking

  ‣ Verbal s-marking should **not** result in multiplicity

  ‣ English is ideal in this respect because present tense marker is homophonous with plural marker

	Nouns		Verbs	
	Unmarked	-s marked	Unmarked	-s marked
Relational	mother	mothers	flog	flogs
Non-rel	lady	ladies	soar	soars

Proposed Design 2 x 2 x 2- Predictions

▶ **Verbs and nouns both take s-marking**

    ▶ If morphological marking affects activation, we can residualize

▶ **Verbal s-marking should not result in multiplicity**

    ▶ No difference anticipated between *flog* and *flogs*, *soar* and *soars*

▶ **Replicate verbal relationality effect** (Thompson et al 2007, etc.)

    ▶ *flog, flogs > soar, soars*

	Nouns		Verbs	
	Unmarked	-s marked	Unmarked	-s marked
Relational	mother	mothers	flog	flogs
Non-rel	lady	ladies	soar	soars

Non-Rel Unmarked   Non-Rel Marked   Rel Unmarked   Rel Marked

Problem!

s-marked verbs can get **habitual** interpretation

Habitual could be a multiplicity of events taking place over multiple episodes…

Multiplicity Study Design Table

Solution: add another morphological control

- -ed is another short inflectional suffix
- We now have the opportunity to test one more contrast!
  - Some of the eventive stimuli in Exp1 were **N-V ambiguous**, does that affect the results?

		Nouny		Verby		N/V-Ambiguous	
		Unmarked	-s marked	Unmarked	-s marked	Unmarked	-ed marked
Count	Relational	sister	sisters	adopt	adopts	taunt	taunted
	Non-rel	lady	ladies	erupt	erupts	bubble	bubbled

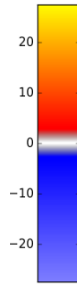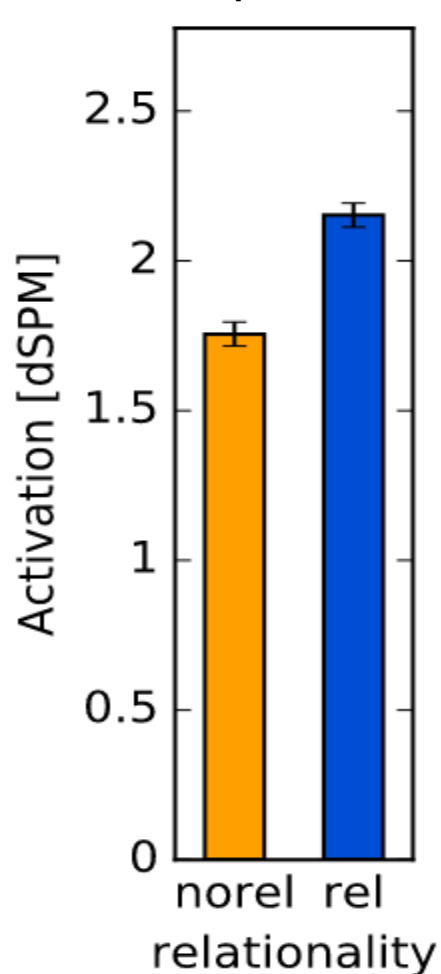Counts = 50 per condition, total 700 stimuli.

Very Preliminary Results – Just for Count Nouns

Subject to change, no controls checked yet.
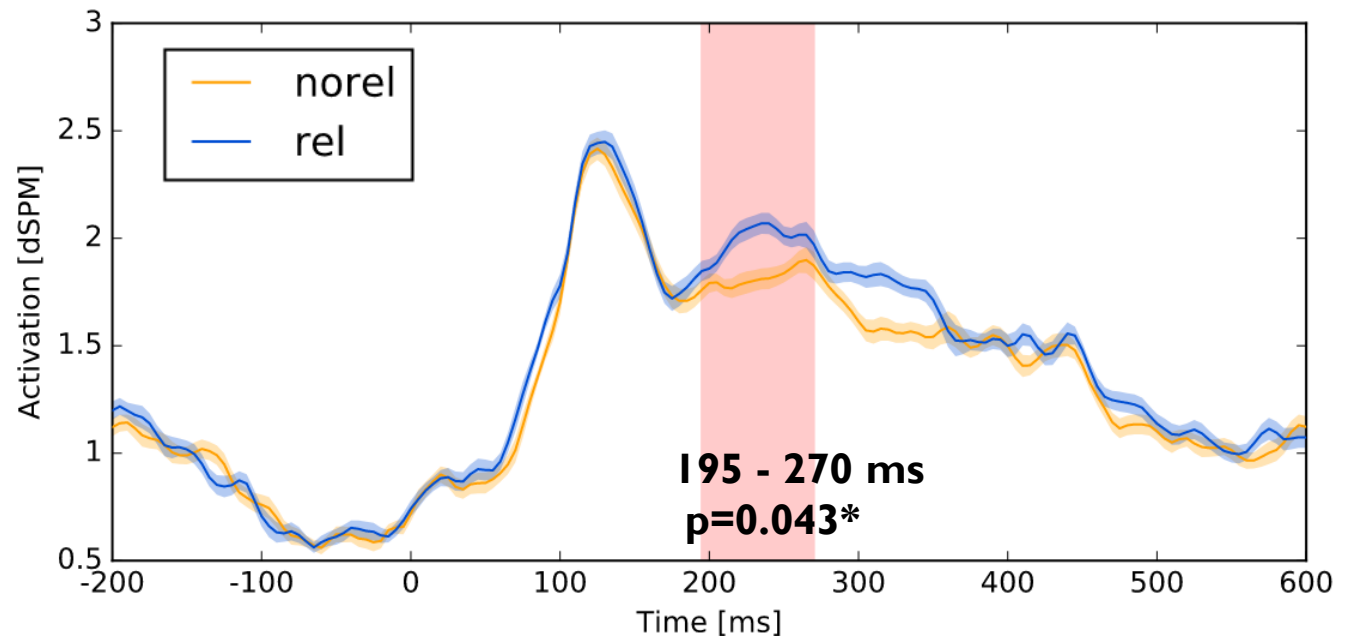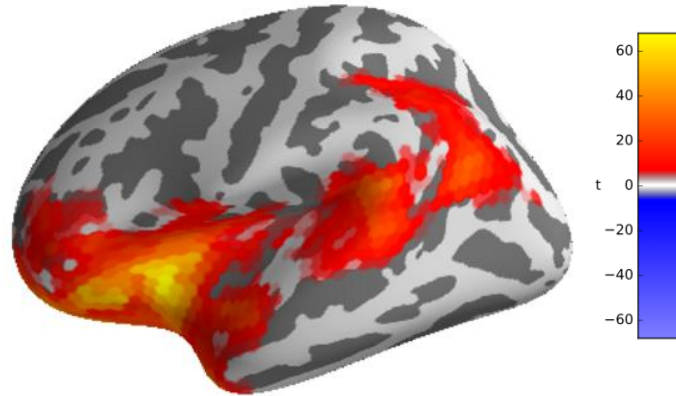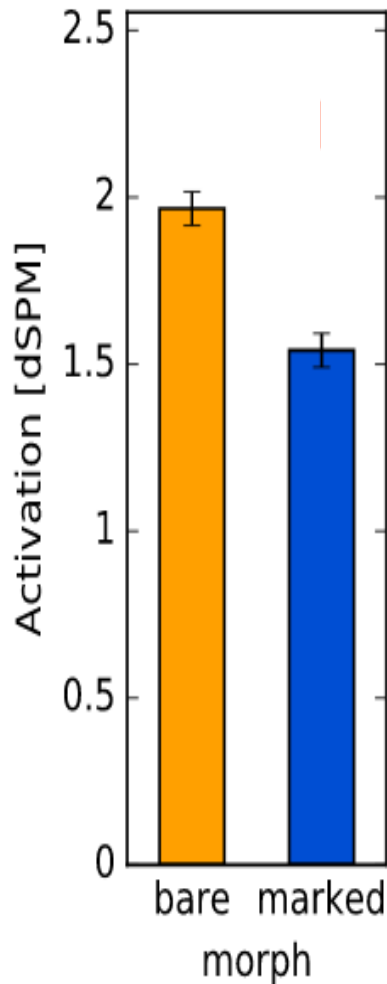
Relationality Effect – Replicated!

lady < sister

Spatio-temporal cluster test, p=0.05, min 10 contiguous, min 25 ms
- test spatial region same as experiment 1
- Test temporal extent chosen based on experiment 1(150-300ms)
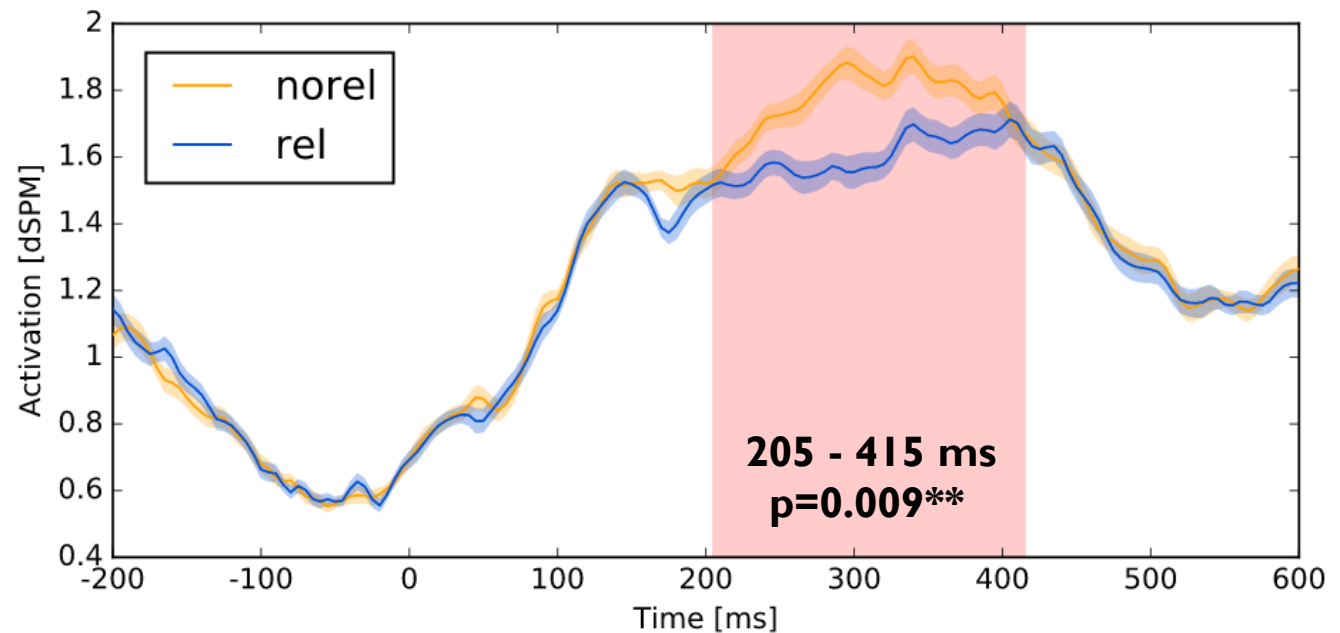
195 - 270 ms
p=0.043*

Plurality Effect?

lady, sister < ladies, sisters

Spatio-temporal cluster test,
p=0.05, min 10 contiguous,
min 25 ms
- region: left hemi.
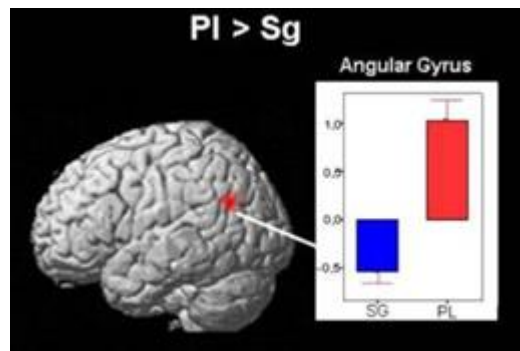- time :100-500ms

205 - 415 ms
p=0.009**
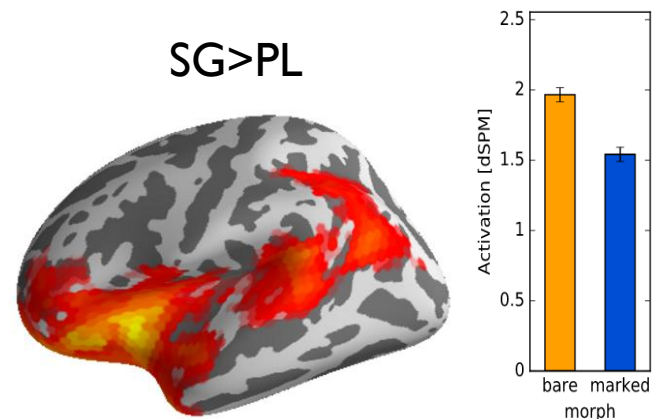
Discussion

Domahs et al. 2014

- **More** activation for plurals than singulars
- Task was *naturalistic listening*, German, fMRI

This study

Replication: AG region is activated for quantity

- **Less** activation for plurals than bare forms
- Task was *single word reading*, English, MEG

SG>PL

Discussion & Conclusion

LIPL cares about **quantity**

Directionality of the effect is not replicated

Discussion & Conclusion

In DP Context: Domahs et al. 2012

Singulars:

▸ **Atomic** individuals

Plurals:

▸ **Sum** individuals

In Isolation: this study

Singulars: perhaps interpreted as:

▸ Atomic individuals
▸ properties with only atoms in their extensions

Plurals: plural marked nouns could be taken to be:

▸ Sum individuals
▸ Kinds
▸ properties with just sums in their extension OR with sums and atoms in their extensions

Acknowledgments

▸ **Collaborative work with Liina Pylkkänen**

▸ Special thanks to: NYU NELLAB, Samir Reddigari, Alec Marantz, Chris Barker, Becky Laturnus, Yohei Oseki