Agreement Attraction in the Neural Language System

Matthew A. Tucker, Stephen Politzer-Ahles, Joseph King, & Diogo Almeida
New York University Abu Dhabi

Introduction: Selective Failures in the Processing of Agreement Errors

- Any theory of sentence processing requires a theory of structure-building, which in turn requires dependency formation
- *Agreement* provides a window into a large class of dependencies, incl. verb-argument linking and clausal structural dependencies
- Agreement errors are easy to spot: *the key **are** on the table*
- Neural signatures of regular agreement errors: LAN (sometimes) + P600 (always)
- However, some contexts greatly reduce the ability to spot such errors:

(1) The key to the cabinets are on the table. (Bock & Miller, 1991)

- Known as AGREEMENT ATTRACTION errors, these errors occur when a nonsubject NP intervenes (structurally, linearly) on the "correct" subject-verb dependency
- *Because these errors are selective, they can be leveraged to indirectly examine the structure-building underlying agreement dependencies*
- Occur in both production and comprehension (Wagers, *et al.* 2009)
- Behavioral data well-understood, but neural data only recently emerging (Kaan, 2002; Tanner, *et al.*, 2012; 2014)
- **Questions**: How are these errors neurally represented, how do they compare to non-error contexts, and what are their neural generators?
- **Present Study:** A concurrent EEG and MEG investigation of agreement attraction configurations

Predictions:

EEG:
- Possibly a LAN, definitely a P600 (with ungrammatical sentences)
- P600 amplitude reduced in attraction error configurations (Tanner, *et al.*, 2014)
- If behavioral data ≈ neural data: greatest reduction of P600 when NP1 = Sg

MEG
- A difference with respect to grammaticality in 500-900 ms (direction undetermined)
- Localization to sites responsible for agreement processing

Materials & Participants

- *Materials*: 384 sentences: *NP1 — Prep — NP2 — Adv — Verb — Continuation*
- All drawn from the preambles in the agreement attraction literature.
- Systematic manipulation of number of *NP1*, *NP2*, & *Verb* — all measurements at *Verb*
- Verbs equally distributed across *was/were*, *is/are*, *has/have*, and lexical verbs (*-∅/-ed*)

(2) The door(s) to the office(s) gradually close(s) if not propped open.

- Coding: NP1 number, ATTR(ACTION), GRAM(MATICALITY)
  - NP1: number of NP1 (Sg, Pl)
  - ATTR: does NP1 = NP2? (Yes, No)
  - GRAM: does NP1 = V? (Grammatical, Ungrammatical)
- 475 fillers, from three other experiments (no agreement manipulations)
- Concurrent 32-channel EEG and 208-channel MEG recording + acceptability judgment
- 20 subjects (11 females; mean age 24 years) from the NYUAD community

Grammatical Conditions:

CONDITION	NP1	ATTR	GRAM
The key to the cabinet…is	Sg	No	Gram
The key to the cabinets…is	Sg	Yes	Gram
The keys to the cabinet…are	Pl	No	Gram
The keys to the cabinets…are	Pl	Yes	Gram

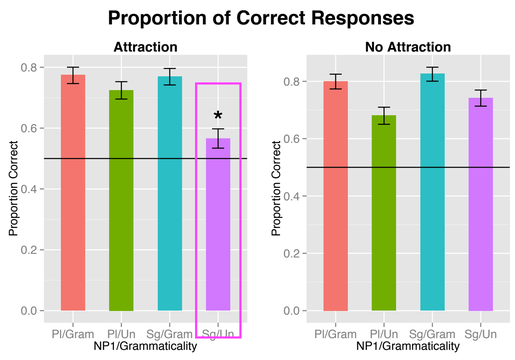
Ungrammatical Conditions:

CONDITION	NP1	ATTR	GRAM
The key to the cabinet…are	Sg	No	Ungram
The key to the cabinets…are	Sg	Yes	Ungram
The keys to the cabinet…is	Pl	No	Ungram
The keys to the cabinets…is	Pl	Yes	Ungram

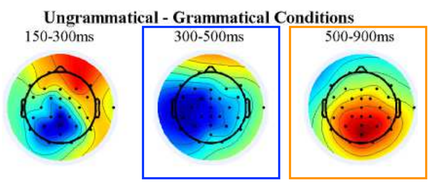
More attraction expected

Less attraction expected

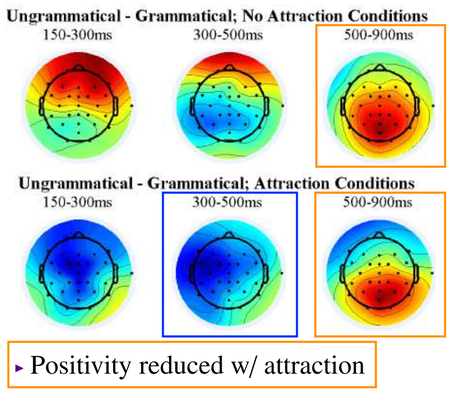
Results — Behavioral & EEG



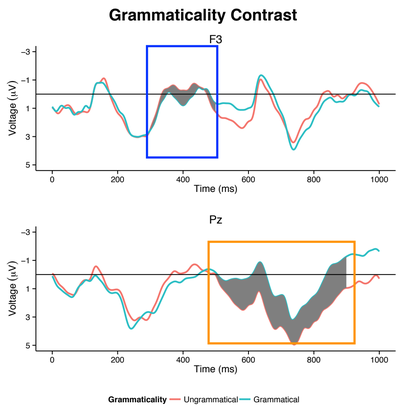
- Illusion of *acceptability* in Sg-Attr-Ungram

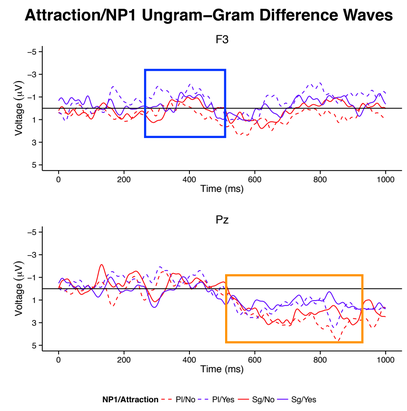


- **P600:** late positivity for ungrammatical sentences
- **L(A)N:** left negativity for attraction conditions *only*

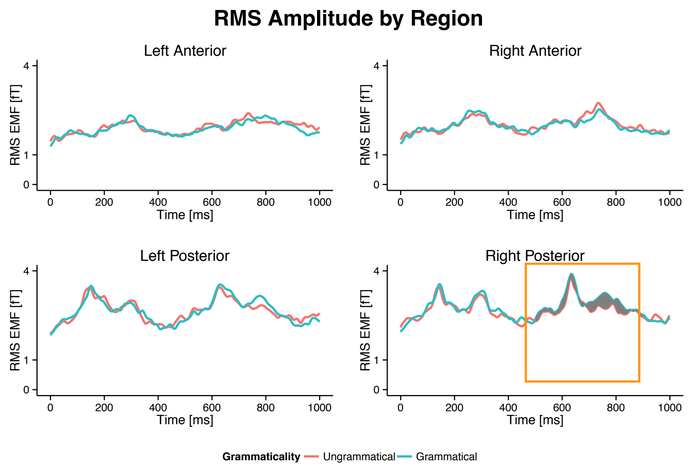


- Positivity reduced w/ attraction





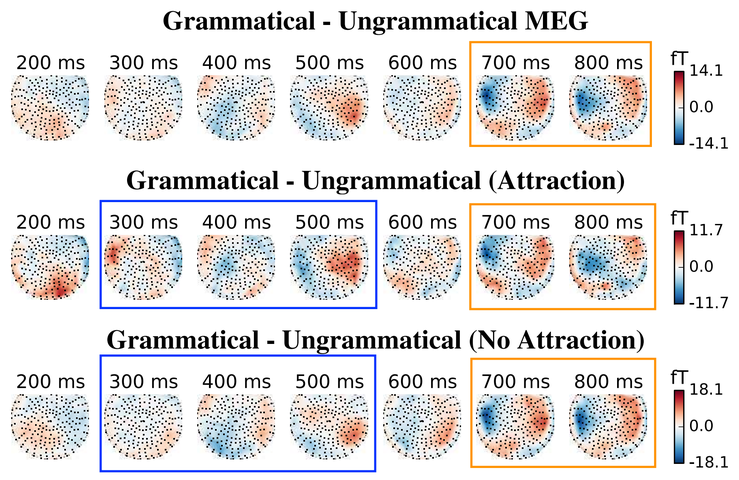
Results — MEG Sensor Space



- Waveforms on the left show RMS amplitude by sensor quadrant

UNGRAM elicits *less* activation than GRAM in 500-900 ms time window

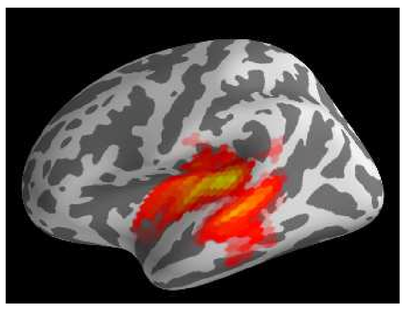
- Localized to posterior sites (lower right plot)
- Topoplots show this is driven by slightly posterior activation
- Mild (nonsignificant) effect of attraction: more activation elicited in attraction contexts
- Consistent with the notion that attraction is an *illusion of acceptability when ungrammaticality is present*
- Appears that early L(A)N impacted by attraction configurations (NP2 considered as controller)

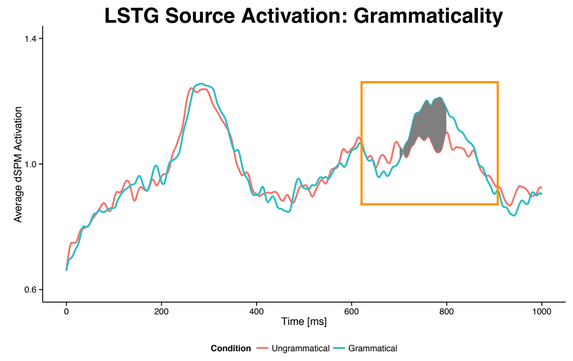


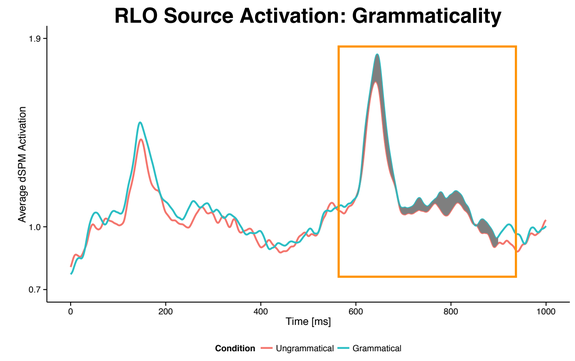
Results — MEG Source Space

- Source modeling with MNE using free orientation
- Preliminary ANOVA using spatiotemporal cluster permutation test
- Activation found in Left Superior Temporal Gyrus (LSTG) in grammatical utterances relative to ungrammatical
- Timecourse matches EEG P600 and MEG sensor activation (700-800 ms peak)
- Similar activation (marginal) in Right Lateral Occipital regions (RLO)
  - Given our ISI, this could be the next word's M150…

LSTG Activation in Gram - Ungram, 700-800 ms







Discussion

- Behavioral results show attraction is occurring
  - More errors in SPP condition relative to others
- **EEG results show an L(A)N and P600 to ungrammatical sentences**
- **L(A)N dependent upon attraction configurations**
- **P600 smaller with attraction (Tanner, *et al.*, 2014)**
- Possibly a result of some subjects simply not noticing errors
- **Greater MEG response to *grammatical* utterances relative to ungrammatical ones**
- *Interpretation:* structure-building is reflected in increased MEG activation
- *Corollary:* P600 effect is an consequence of a *negative* deflection for grammatical utterances
- **Activation seen in two sites: LSTG and right lateral occipital sites**
- More careful work needed to see which structures in the STG are driving the effect
- Occipital sources surely triggered by next word, but why they are distinct by condition remains unclear at present

Future Directions:
- Cluster permutation tests for sensor-space data/EEG
- Correlational analysis between EEG and MEG
- Analysis of brain responses conditioned on correct/incorrect behavioral responses
- Spectral analyses of both EEG and MEG data
- Closer examination of different orthographic verb forms (*was/is/has/-s*)
- Do all grammatical - ungrammatical comparisons result in increased MEG activation?

Acknowledgments & References

Acknowledgments — Thanks to Esti Blanco and Laura Gwilliams for assistance with experimental procedure. Thanks to Christian Brodbeck for invaluable assistance with analysis. Finally, thanks to Alec Marantz, Liina Pylkkänen, Jon Sprouse, and Shravan Vasishth for comments on previous iterations.

Selected References — BOCK, K., & MILLER, C.A. 1991. Broken agreement. *Cognitive Psychology* 23:45–93. TANNER, D., NICOL, J., HERSCHENSOHN, J., & OSTERHOUT, L. 2012. Electrophysiological markers of interference and structural facilitation in native and nonnative agreement processing. In *BUCLD 36*. TANNER, D., NICOL, J.L., & BREHM, L. 2014. The time-course of feature interference in agreement comprehension: Multiple mechanisms and asymmetrical attraction. *JML* 76:195–215. WAGERS, M.W., LAU, E.F., & PHILLIPS, C. 2009. Agreement attraction in comprehension: Representations and processes. *JML* 61:206–237.

✉ matt.tucker@nyu.edu • http://files.nyu.edu/mat11/public/