

# Nouns and Verbs, Adjectives and Adverbs:

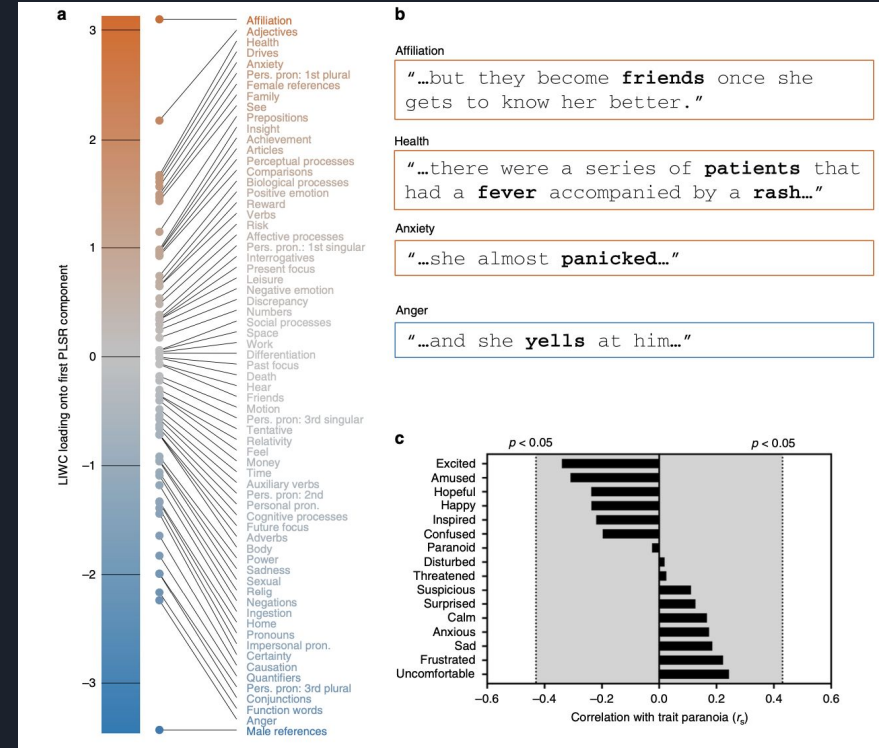
An investigation into syntactical  
localization using fMRI

By: Rachel McLaughlin

# The Original Study:

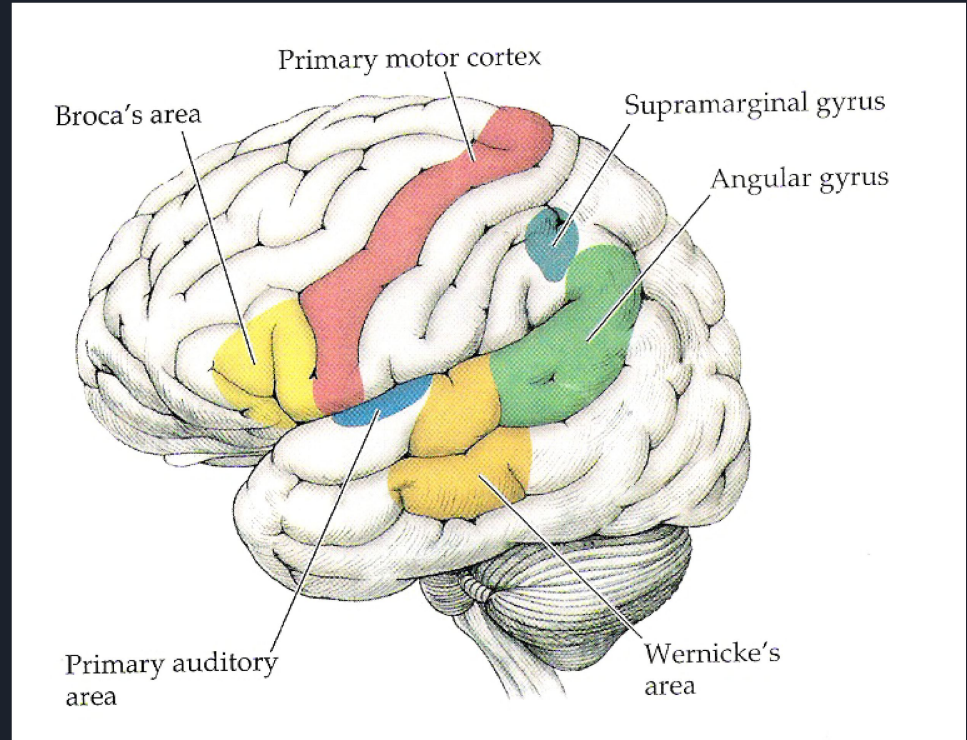
Trait paranoia shapes inter-subject synchrony in brain activity during an ambiguous social narrative (Finn et. al, 2018)

- 22 participants: right handed, native English speakers, with no history of psychiatric disorders or medication
- Naturalistic language paradigm:
  - Audio-recorded story segmented into three sections
    - Roughly 22 minutes total
- Paranoia evaluation
  - Subjects ranked on a sliding scale of paranoid behaviors
  - Evaluated activation in various regions via intersubject correlation
    - Examined effects of paranoia on specific word activations



# Language in the Brain: A Primer

- Broca's Area
- Wernicke's Area (Superior Temporal Gyrus)
- Angular Gyrus
- Supramarginal Gyrus
- Visual Word Form Area (occipitotemporal gyrus)
- Arcuate Fasciculus





# My Questions

1. How do different parts of speech contrast with each other in the brain? Does this apply to broader categories such as modifiers vs modified words?
2. Can we identify specific ROIs that correlate with part of speech preferences?
3. Can we train a model to predict part of speech based on brain activity?



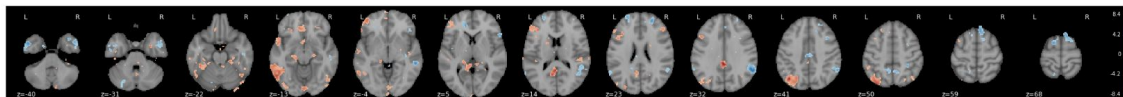
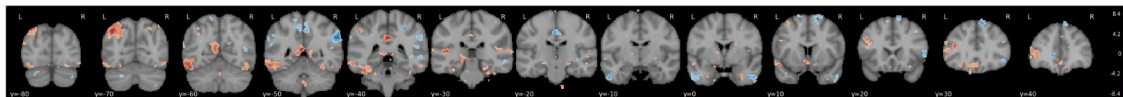
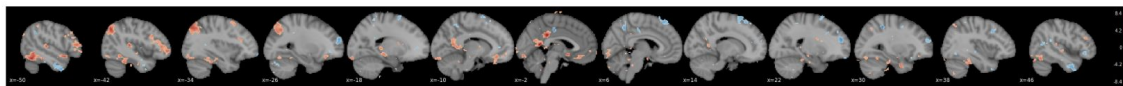
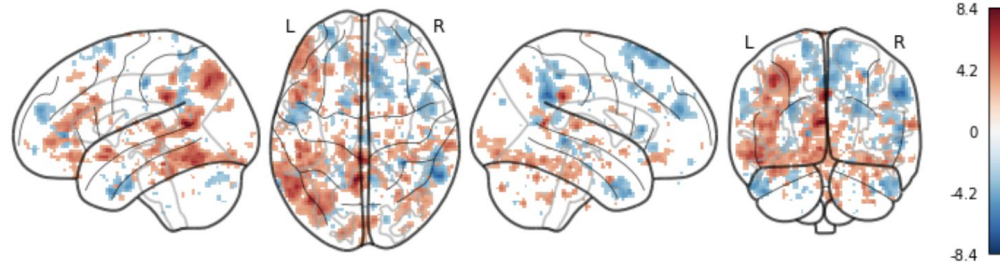
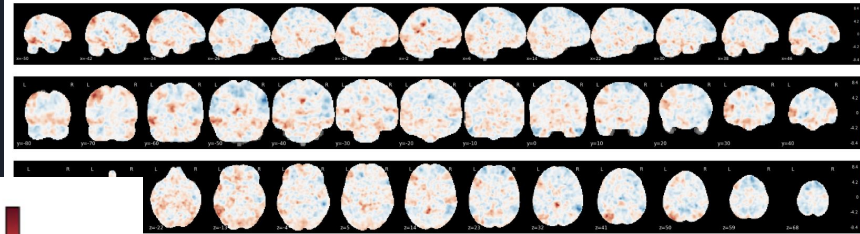
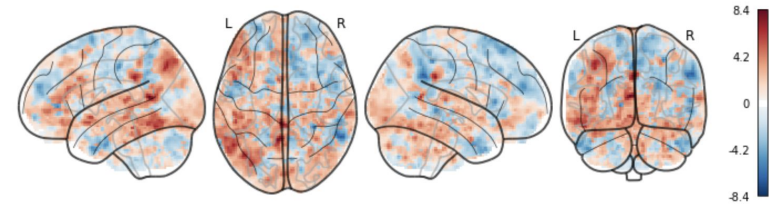
# Question 1

## Methods:

1. Using spaCy to tag transcripts with Part of Speech
  - a. Removing words that cannot fit transcript timing splits (contractions)
2. Run first level model across all subjects
3. Create individual contrasts for parts of speech
4. Threshold and plot

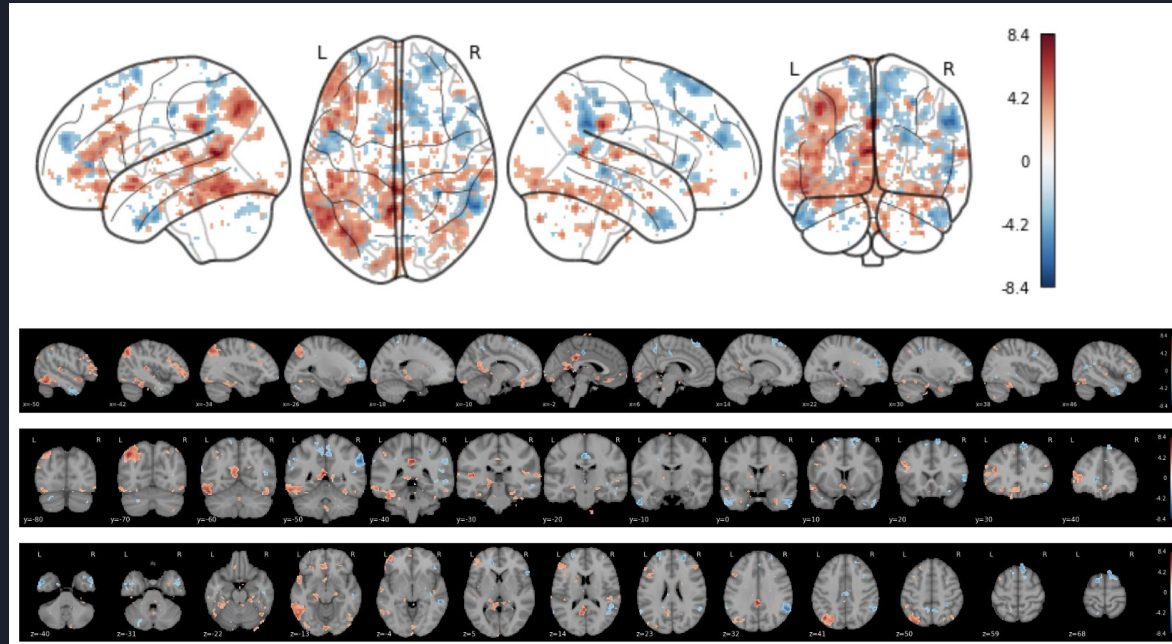
# Nouns versus Verbs

Effect of threshold:  $unc = .01$



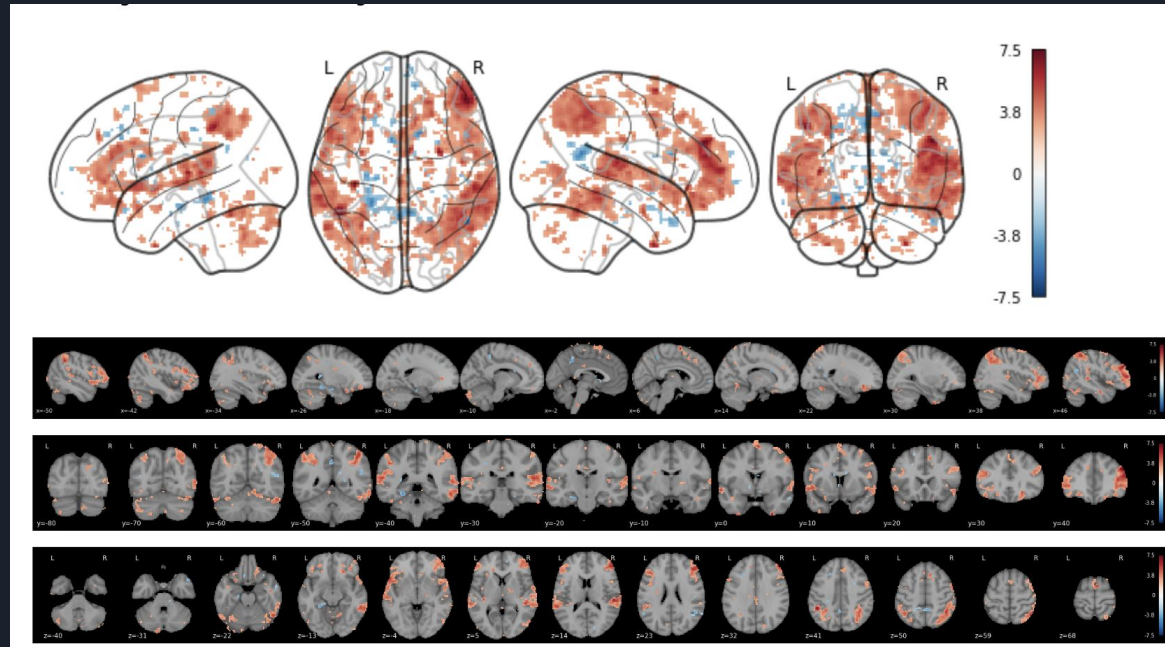
# Nouns versus Verbs

- Verb activation:
  - More activity in the right hemisphere
  - Bilateral temporal poles
  - Cerebellum
- Noun activation:
  - Bilateral posterior inferior temporal gyrus
  - Left superior temporal gyrus, particularly near the angular gyrus



# Adjectives versus Adverbs

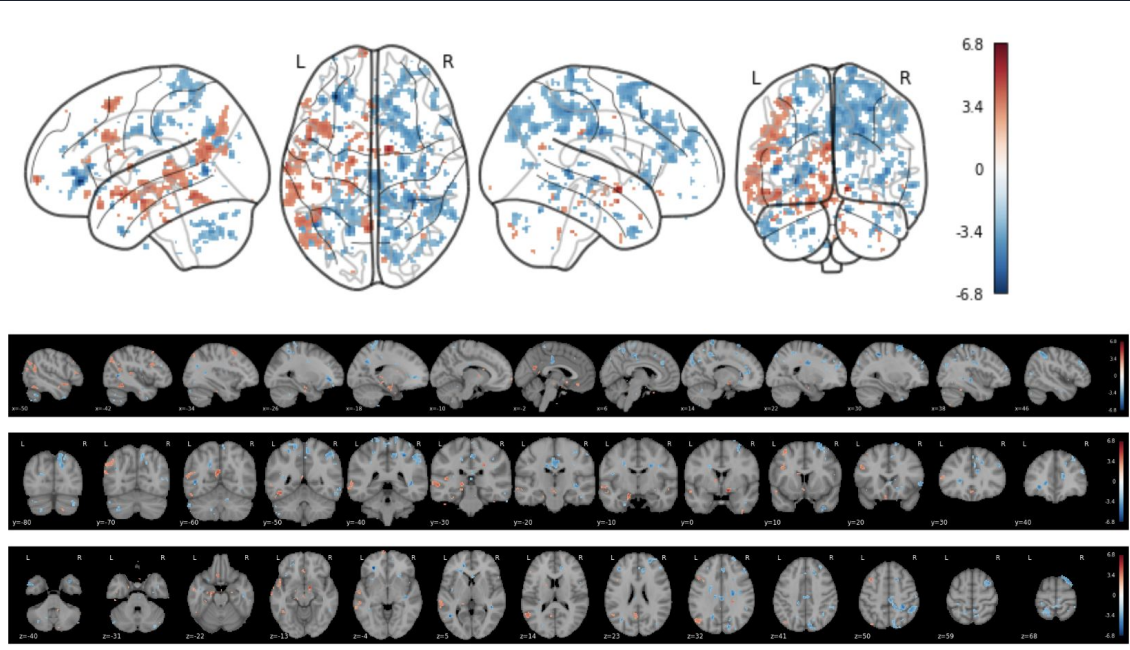
- Adjective activation:
  - Greater overall, bilaterally, for adjectives compared to adverbs
  - Bilateral frontal cortex
  - Broca's Area
- Adverb activation:
  - N/A





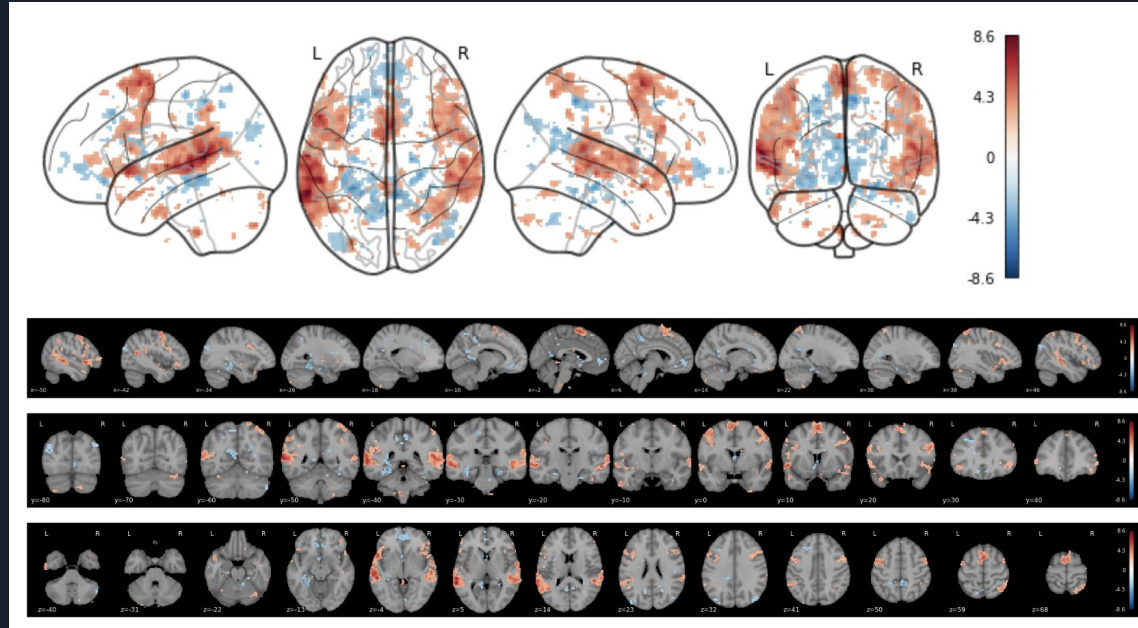
# Nouns versus Adjectives

- Noun activation:
  - Centered on left temporal lobe
- Adjective activation:
  - Greater overall activation, particularly in the right hemisphere
  - Some activity in the cerebellum



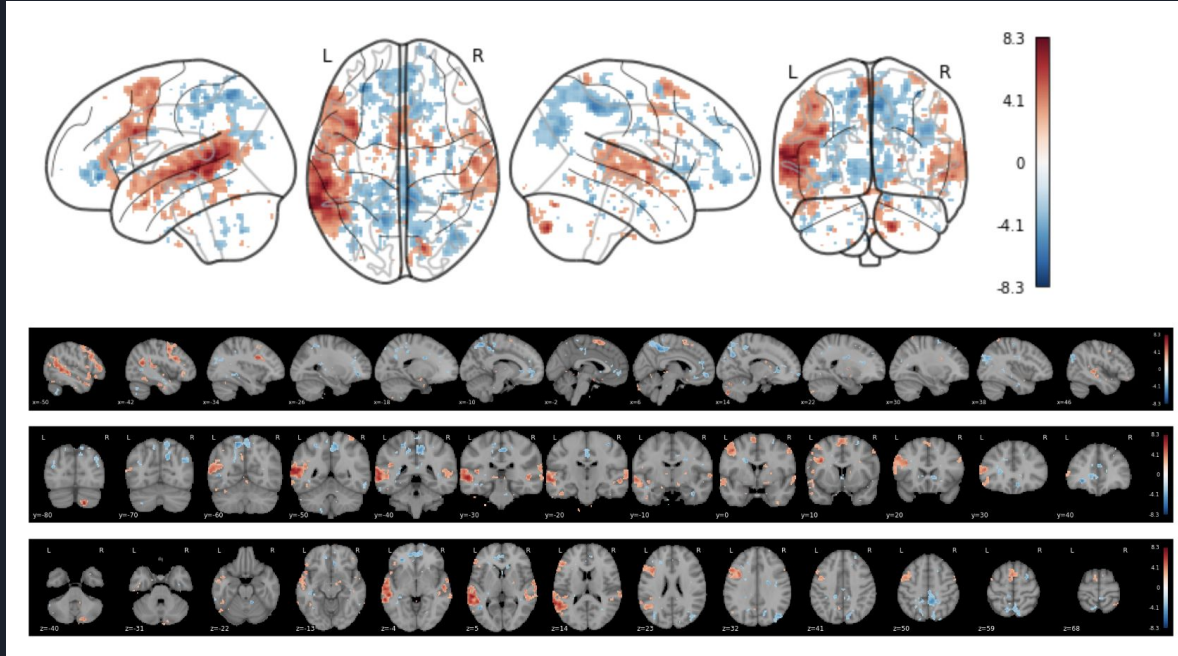
# Verbs versus Adverbs

- Verb activation:
  - Bilateral activation of the superior temporal gyrus (Wernicke's area and Angular Gyrus)
  - Cerebellum
  - Broca's Area
- Adverb activation:
  - Scattered, but some activity in frontal regions



# Nouns and Verbs versus Adjectives and Adverbs

- Modified activation:
  - Left superior temporal gyrus, with the right as well to a latter extent
- Modifier activation:
  - Posterior parietal activation





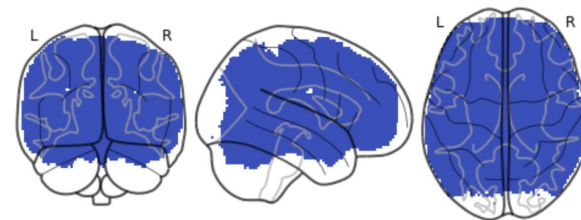
## Question 2

Methods:

1. Same spaCy and first-level model steps
2. RSA analysis (modified vs modifiers)
3. Threshold attempts

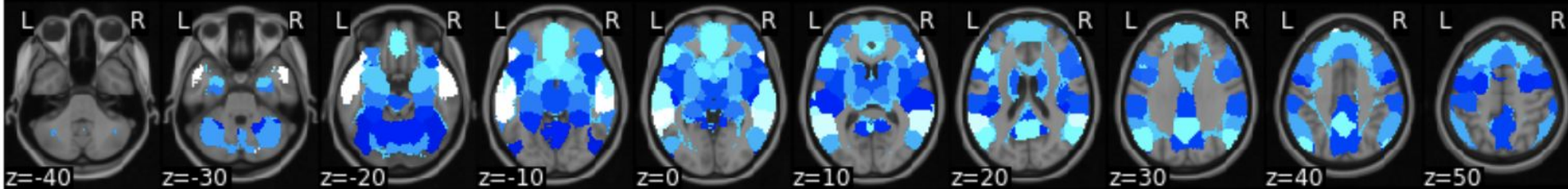
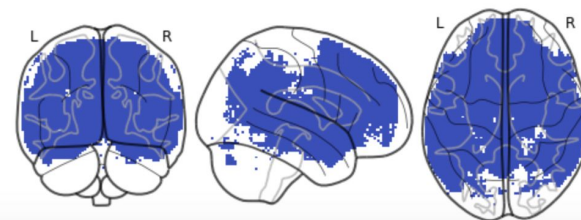
# What Went Wrong?

- Too many areas of activation: extremely small threshold doesn't fix the problem
- RSA isn't the best method to look at my question
- Blue RSA results are ambiguous



```
[37]: thresholded = threshold(rsa_lang_r, rsa_lang_p, thr=.0002)
      plot_glass_brain(thresholded.to_nifti(), cmap='coolwarm')
```

```
t[37]: <nilearn.plotting.displays.OrthoProjector at 0x7f82253dff50>
```





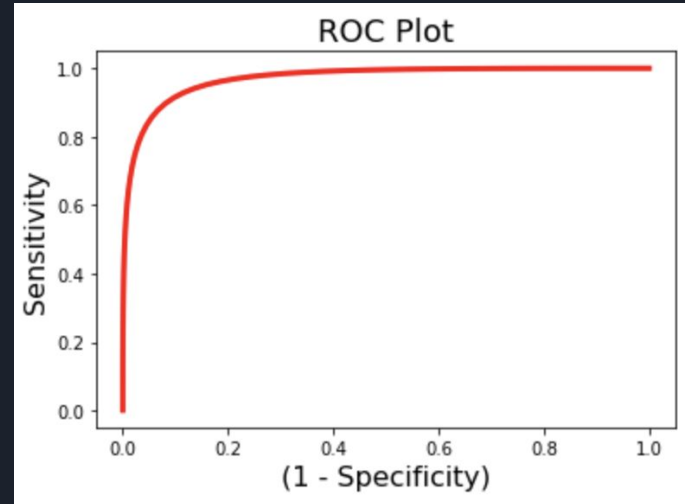
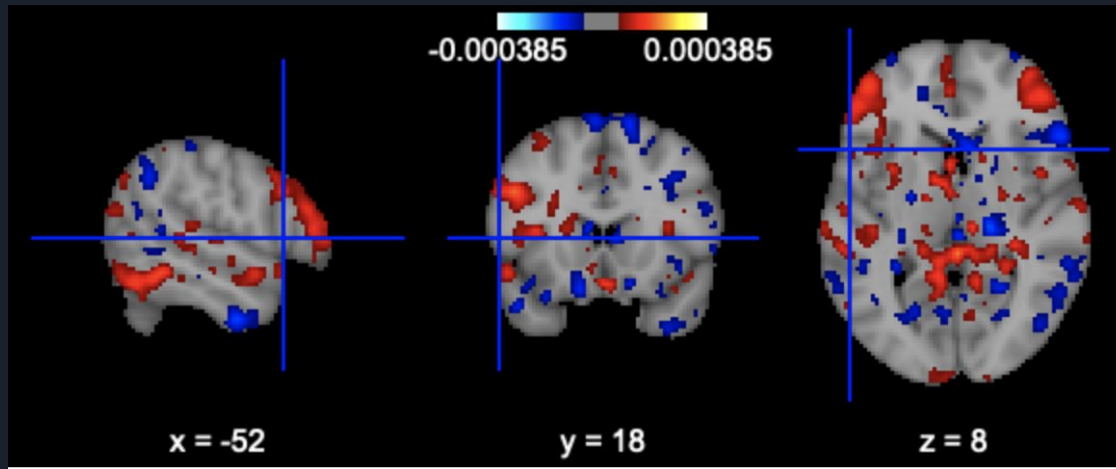
## Question 3 (A last minute analysis!)

Methods:

1. Same spaCy and first-level model steps
2. Conditions averaged across runs for a subject
3. 80% of data is used to train to predict the other 20%

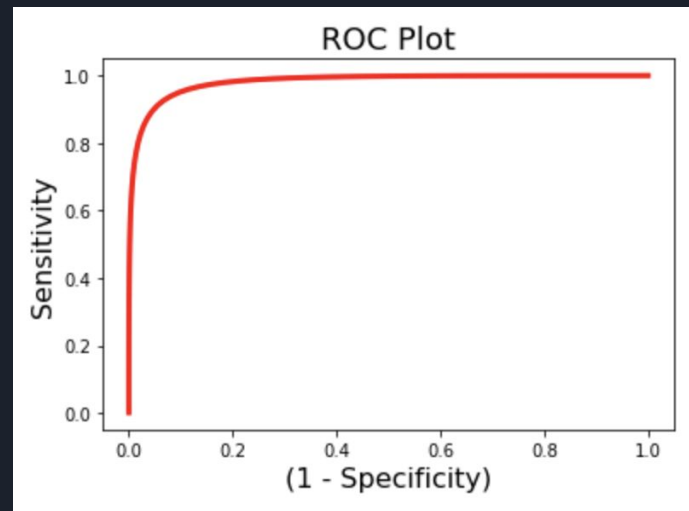
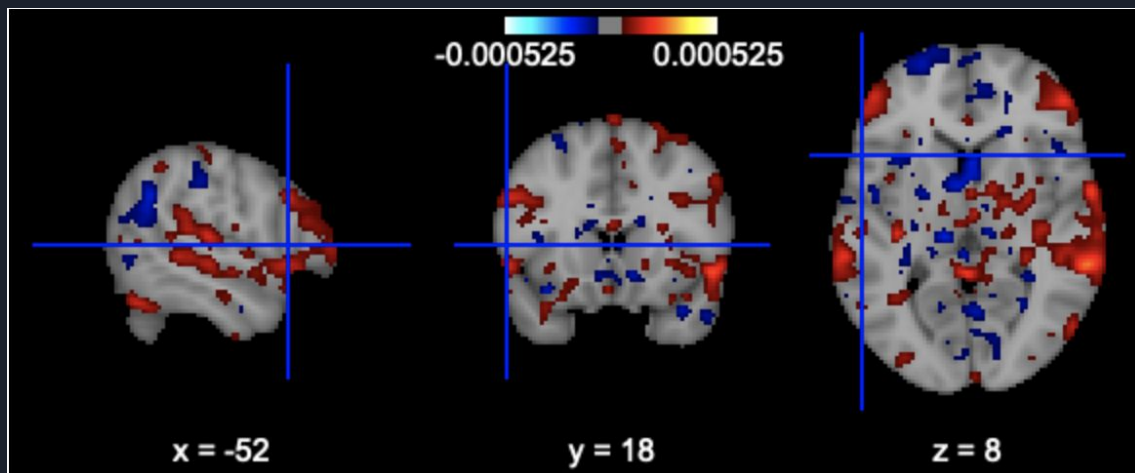
# Predicting Nouns versus Verbs

Model predicts with 82% accuracy!



# Predicting Adjectives versus Adverbs

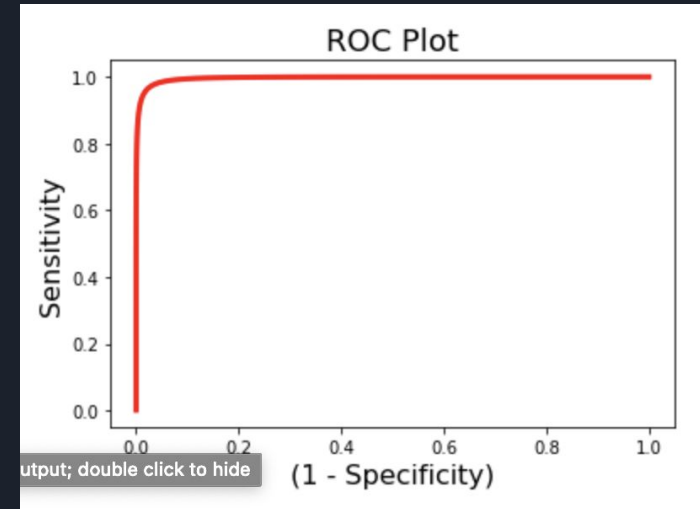
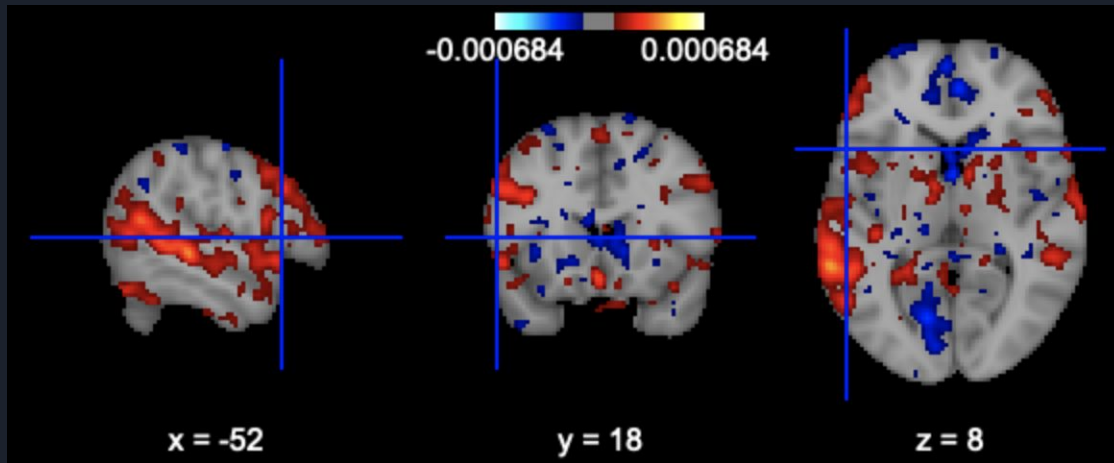
Model predicts with 80% accuracy!





# Predicting Modified versus Modifier

Model predicts with 84% accuracy!





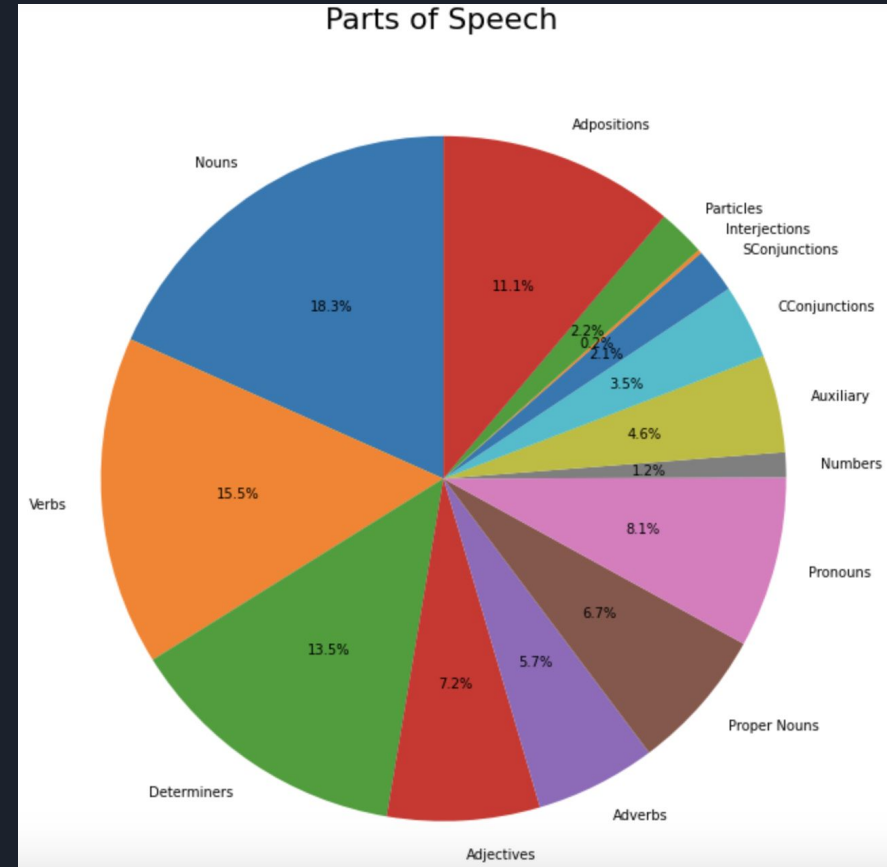
# Discussion

Main points of interest:

- The cerebellum: verbs and adjectives
  - Previous research tends to show activation primarily in the right cerebellar hemisphere in language tasks
  - My results showed bilateral activation
- Left superior temporal gyrus: 'modified' words
- Right hemisphere activity?
  - Sometimes shown to be recruited for more complex language comprehension
- Nouns and verbs
  - Scattered results of previous research

# Part of Speech Counts

- Nouns, verbs, and determiners contribute the largest number of words
- Overall count is not balanced across three segments of transcript
  - In paired sample t-test, all differences between transcript are significant





# Limitations

- This study wasn't designed as part of speech analysis—stimuli are unbalanced
- Categories of 'modified' and 'modifier' is imperfect, especially in regards to adverbs
- No consideration of the original study's manipulated variable of trait paranoia



# Conclusion (and future directions)

Part of speech affects brain activation, even in naturalistic language tasks!

Future experiments might:

- Use the trained model from question 3 on other data (and other types of tasks)
- Examine more minute part of speech differences



# References

- Berlingeri, M., Crepaldi, D., Roberti, R., Scialfa, G., Luzzatti, C., & Paulesu, E. (2008). Nouns and verbs in the brain: Grammatical class and task specific effects as revealed by fMRI. *Cognitive Neuropsychology*, 25(4), 528-558, doi:10.1080/02643290701674943.
- Crepaldi, D., Berlingeri, M., Cattinelli, I., Borghese, N. A., Luzzatti, C., & Paulesu, E. (2013). Clustering the lexicon in the brain: a meta-analysis of the neurofunctional evidence on noun and verb processing. *Frontiers in Human Neuroscience*, 7, 303, doi:10.3389/fnhum.2013.00303.
- Davis, M. H., Meunier, F., & Marslen-Wilson, W. D. (2004). Neural responses to morphological, syntactic, and semantic properties of single words: an fMRI study. *Brain and Language*, 89(3), 439-449, doi:10.1016/S0093-934X(03)00471-1.
- Finn, E. S., Corlett, P. R., Chen, G., Bandettini, P. A., & Constable, R. T. (2018). Trait paranoia shapes inter-subject synchrony in brain activity during an ambiguous social narrative. *Nature Communications*, 9(1), 1-13, doi:10.1038/s41467-018-04387-2.
- Lee, S. S., & Dapretto, M. (2006). Metaphorical vs. literal word meanings: fMRI evidence against a selective role of the right hemisphere. *NeuroImage*, 29(2), 536-544, doi:10.1016/j.neuroimage.2005.08.003.
- Moseley, R. L., & Pulvermüller, F. (2014). Nouns, verbs, objects, actions, and abstractions: Local fMRI activity indexes semantics, not lexical categories. *Brain and Language*, 132, 28-42, doi:10.1016/j.bandl.2014.03.001.
- Murdoch, B. E. (2010). The cerebellum and language: historical perspective and review. *Cortex*, 46(7), 858-868, doi:10.1016/j.cortex.2009.07.018.
- Sahin, N. T., Pinker, S., & Halgren, E. (2006). Abstract grammatical processing of nouns and verbs in Broca's area: evidence from fMRI. *Cortex*, 42(4), 540-562, doi:10.1016/S0010-9452(08)70394-0.
- Tyler, L. K., Randall, B., & Stamatakis, E. A. (2008). Cortical differentiation for nouns and verbs depends on grammatical markers. *Journal of Cognitive Neuroscience*, 20(8), 1381-1389, doi:10.1162/jocn.2008.20095.