Roots as the Anchor for Distributional Semantics in Arabic and Beyond

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Questions about Roots in Semitic and in General

- Do all words decompose into roots plus other morphemes?

- Do roots have meanings?

- Do roots have syntactic categories?

Conclusions

- Roots by themselves have no meaning
- The "patterns" of Semitic are instantiations of morphemes with syntactic category, e.g., noun and verb
- The patterns name functions from roots to places in a distributed meaning representation

How we'll get there: everyone was right

- This characterization of roots instantiates Saussure's vision of how "signs" work.
- This view of how roots contribute to word meaning is consistent with
  - Quine's meaning holism
  - The meaning representations – embeddings – in Large Language Models
- The separation of categoryless roots from patterns with syntactic categories both is the inspiration for the Distributed Morphology separation of roots and little n, v, and a heads and derives support from DM work crosslinguistically.
- This view of roots supports Borer's contention that roots be identified via their phonological form (and so are not abstract in the syntax)

And, quickly

- Data from brain and behavior support consequences of this view
  - No categorical division between polysemy and homophony
  - Early processing effects of category entropy for roots
  - Early processing effects of marked category functions from roots to meaning

**Quine
Semantic Holism**

Philosophy 208: *The Language Revolution*
Russell Marcus
Hamilton College, Fall 2011
Class 17

Quine and Holism

Holism and the Web of Belief

"The totality of our so-called knowledge or beliefs, from the most casual matters of geography and history to the profoundest laws of atomic physics or even of pure mathematics and logic, is a man-made fabric which impinges on experience only along the edges. Or, to change the figure, total science is like a field of force whose boundary conditions are experience...The total field is so underdetermined by its boundary conditions, experience, that there is much latitude of choice as to what statements to reëvaluate in the light of any single contrary experience. No particular experiences are linked with any particular statements in the interior of the field, expect indirectly though considerations of equilibrium affecting the field as a whole."

The Myth of the Museum

meanings skepticism

- In the meanings realist's museum, the meanings are objects, whether mental objects or abstract, third-realm objects.

- When we translate from one language to another, we switch labels on a meaning, which is independent of any language, and which maintains its determinate properties.

- For example, we can switch labels from 'kichwa chake kikubwa' to 'his head is big', both of which express the determinate proposition that his head is big.

- "Uncritical semantics is the myth of a museum in which the exhibits are meanings and the words are labels. To switch languages is to change the labels" (OR, 27).

Saussure and the Sign

mement unis et s'appellent l'un l'autre. Que nous cherchions le sens du mot latin *arbor* ou le mot par lequel le latin désigne le concept « arbre », il est clair que seuls les rapprochements consacrés par la langue nous apparaissent conformes à la réa-
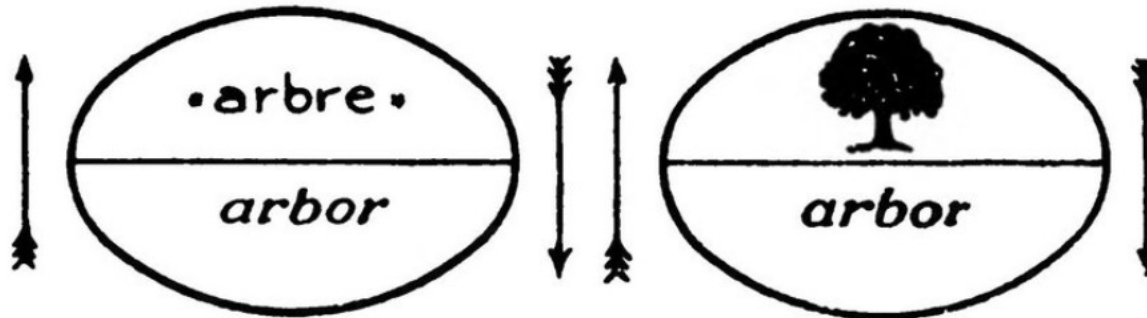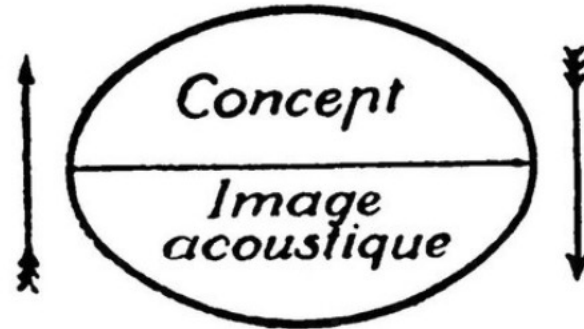
Signs in a 2-dimensional reduction of a multidimensional space. Could be phonological space or conceptual space. Sound and meaning are determined by each sign's contrast to all the other signs in the space.

swaziland
maldives
bhutan
nepal
bangladesh
borders
spouse
locations
spouse
households
carries
lone
span
autumn
noon
friday
source
suggestion
calling
seeks

swaziland
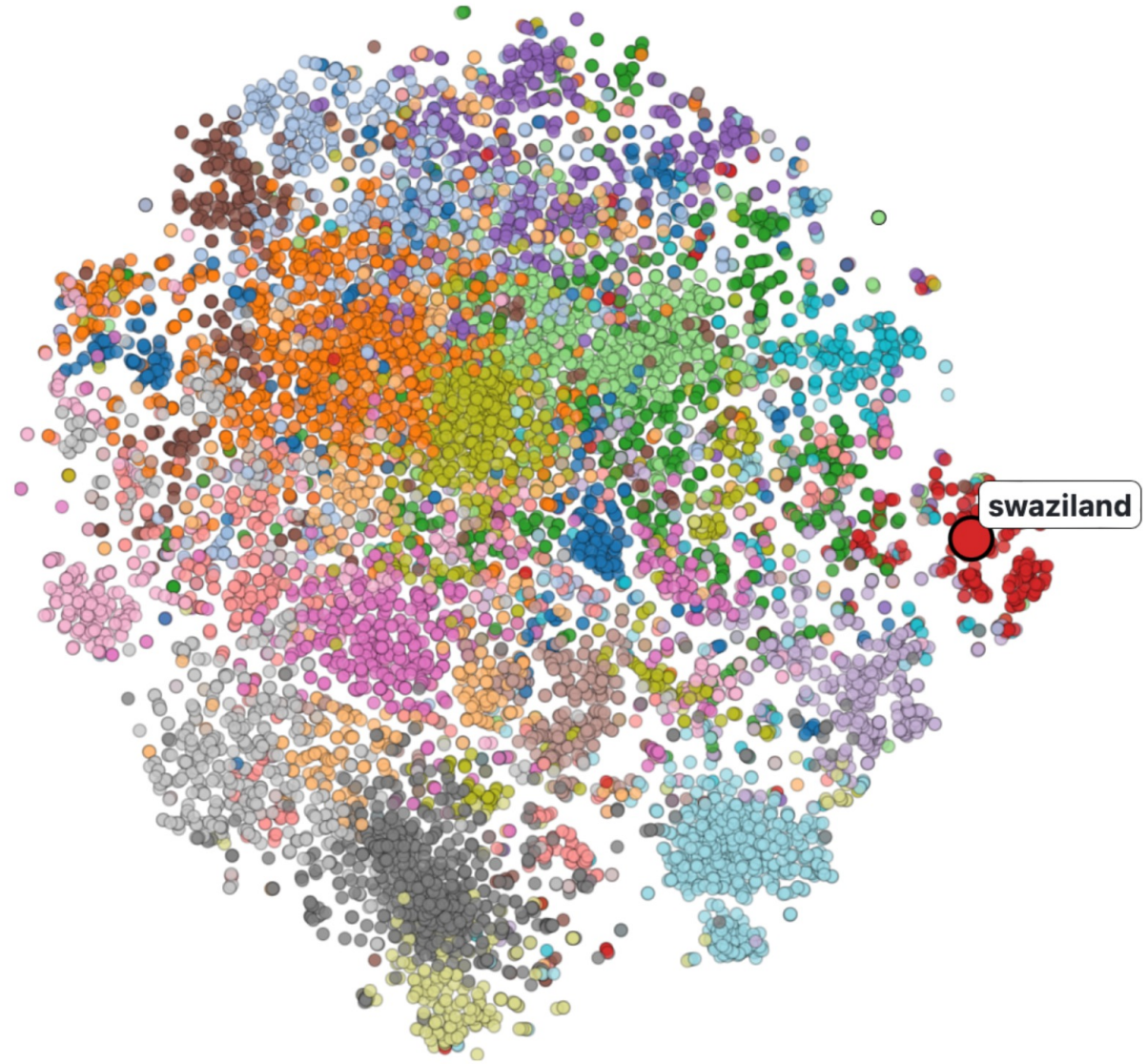
2 LLMs and clusters in meaning space that correspond to sentiment classes (the good vs. the bad and the ugly)

Twitter CBOW Model

Twitter Skip-Gram Model
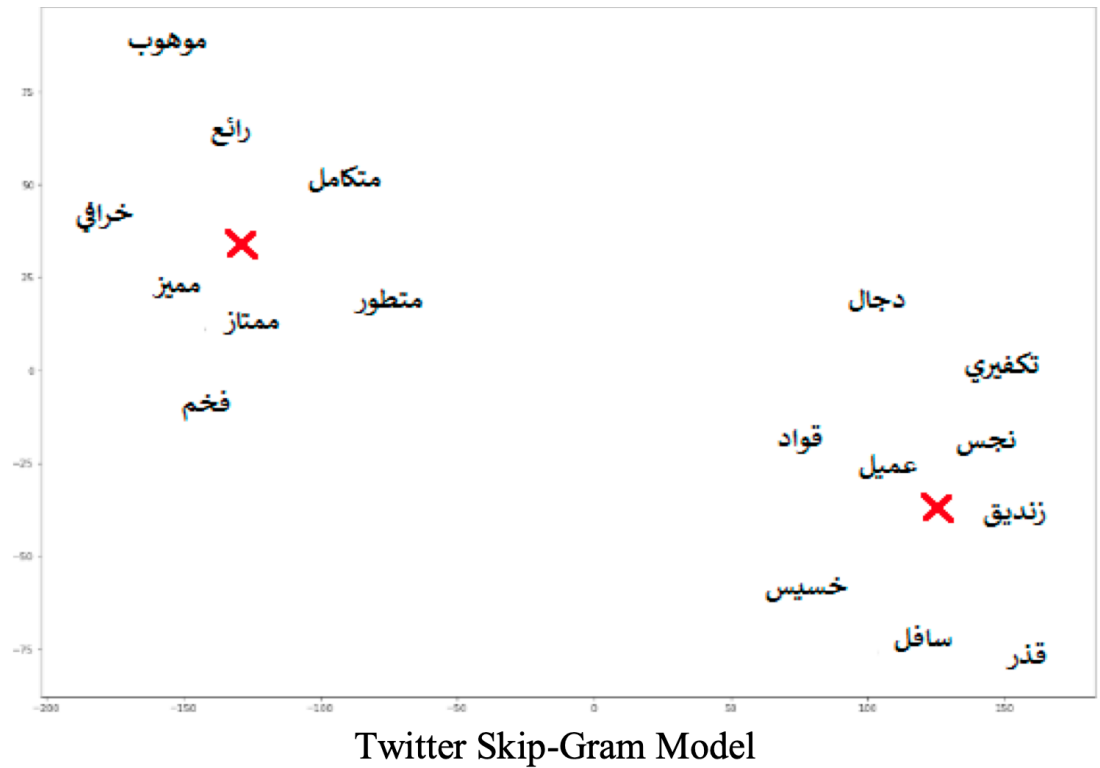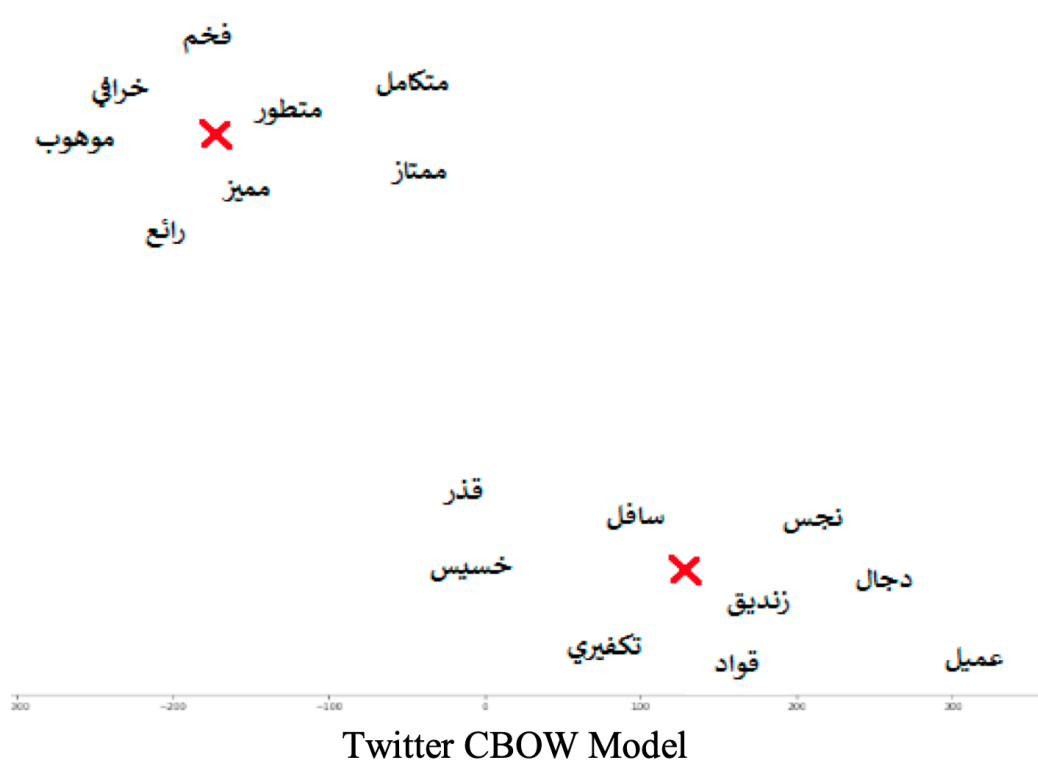
Root and pattern morphology

- kātib   writer
- kitāba   the act of writing
- kitāb   some writing, book
- kutub   books
- kutubī   bookdealer
- kutayyib   booklet
- maktūb   letter
- maktab   school, office
- maktaba   library, literature

Al Kaabi, M., & Ntelitheos, D. (2019). Rethinking templates: A syntactic analysis of verbal morphology in Emirati Arabic. *Glossa: a journal of general linguistics*, 4(1).

| Form	MSA	EA
	Template	Template
I	faʕal	fəʕal
II	faʕʕal	faʕʕal
III	faaʕal	faaʕal
IV	ʔafʕal	—
V	tafaʕʕal	tfaʕʕal
VI	tafaaʕal	tfaaʕal
VII	(ʔi)nfaʕal	nfəʕal
VIII	(ʔi)ftaʕal	ftəʕal
IX	(ʔi)fʕall	fʕall
X	(ʔi)stafʕal	stafʕal
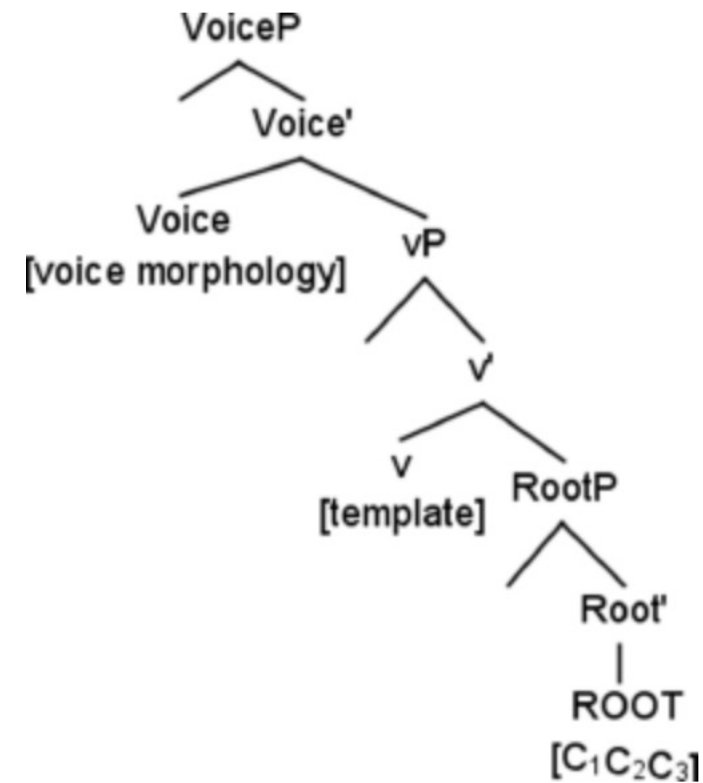
Different combinations of the voice and v morphemes yield the different forms

	Little v¹ [Ø]	Little v [Causative]	Little v [Applicative]	Little v [Inchoative]
Voice [Ø]	CVCVC FORM I	CVCCVC FORM II	CVVCVC FORM III	CCVCC FORM IX
Voice [Passive]	nCVCVC FORM VII	–	–	–
Voice [Middle/Reflexive]	CtVCVC FORM VIII	tCVCCVC FORM V	tCVVCVC FORM VI	–

Borer, Marantz generalize Semitic to all languages
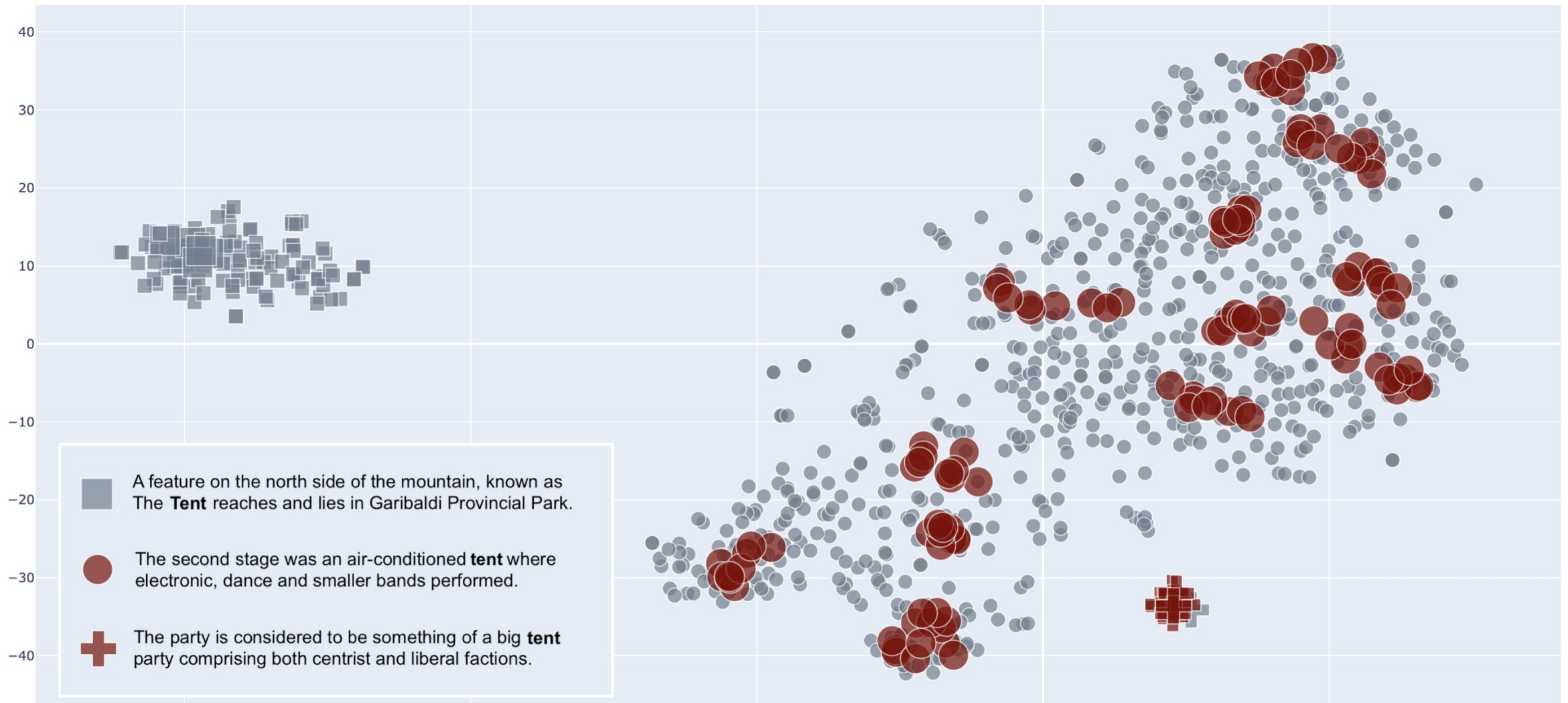
Cat, the noun decomposes into:

```
        n
       / \
      /   \
     n    √CAT
```
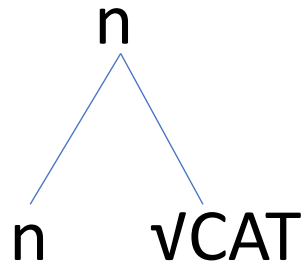
See my "Cat as a phrasal idiom" paper, et alia.

With Borer, we identify roots by their phonological/orthographic forms

- Which prohibits a popular analysis of the distinction between polysemy – related meanings of a single "lexical entry" – and homophony – two unrelated meanings, each associated with a separate lexical entry where the two entries share a phonological form.
  - Prohibited analysis:
    - Bat (baseball) vs bat (flying animal) = two homophonous lexical entries
    - Table (put a question at a meeting aside) vs. table (furniture) = two related senses of the same lexical item
  - New analysis:
    - Single root in all these cases.
    - Polysemy and homophony involve the distribution of root meanings in conceptual space.
    - Wilson & Marantz show that this new analysis covers behavioral correlates of polysemy vs homophony distinction (better than the prohibited account).

Wilson, Kyra, and Alec Marantz. "Contextual Embeddings Can Distinguish Homonymy from Polysemy in a Human-Like Way." *Proceedings of the 5th International Conference on Natural Language and Speech Processing (ICNLSP 2022)*. 2022.

A feature on the north side of the mountain, known as The **Tent** reaches and lies in Garibaldi Provincial Park.

The second stage was an air-conditioned **tent** where electronic, dance and smaller bands performed.

The party is considered to be something of a big **tent** party comprising both centrist and liberal factions.

Clustering analysis of senses vs. meanings yields right correlation with behavior
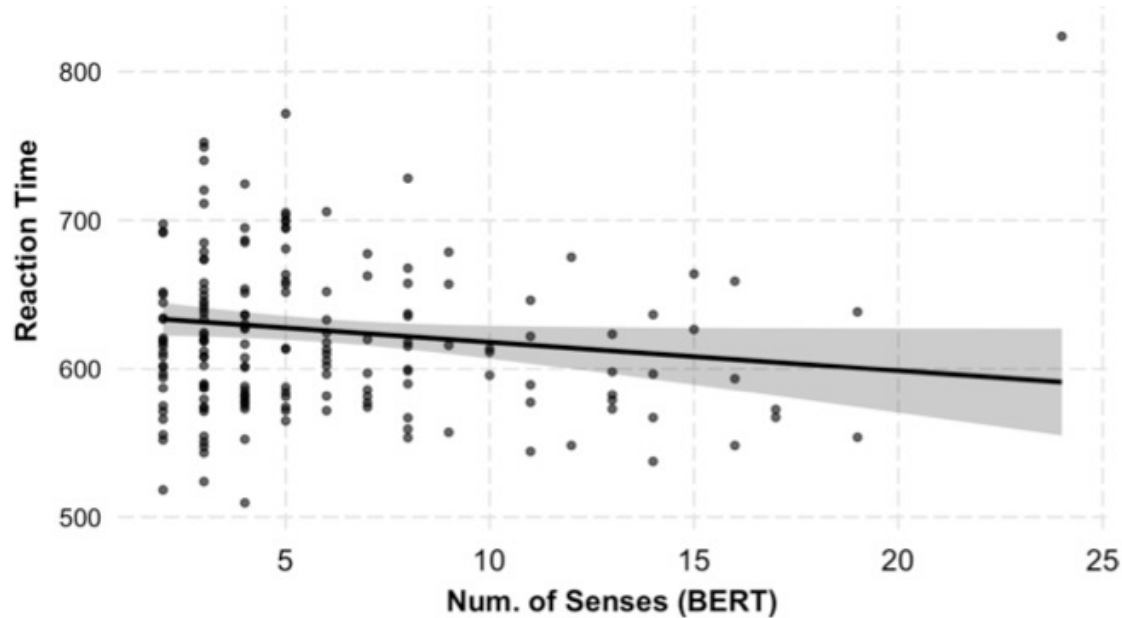
Figure 4: Regression line showing inverse relationship between number of senses and reaction time.
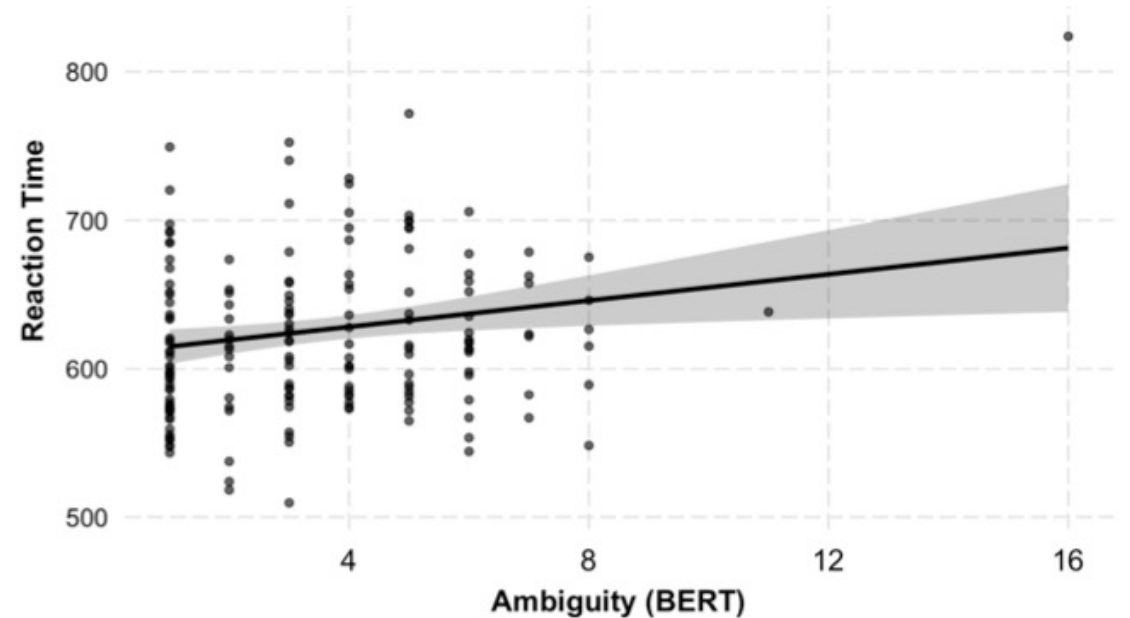
Figure 5: Regression line showing direct relationship between ambiguity and reaction time.

Let's map roots onto the brain

- Roots on the model of "signs"
  - They're points in multidimensional phonology space
    - Where "phonology" space includes both acoustic/articulatory related "real" phonology space and orthographic space
  - That are mapped, via syntactic category, to points in multidimensional, a-modal conceptual space ("a-modal" meaning not specific to spoken, written, or sign language)

- Roots don't have meanings. "Phases" consisting of a root and a category morpheme have a distributed space of meaning in conceptual space.

Muilti-dimensional phonological space in the brain = superior temporal lobe and the "auditory word form area"
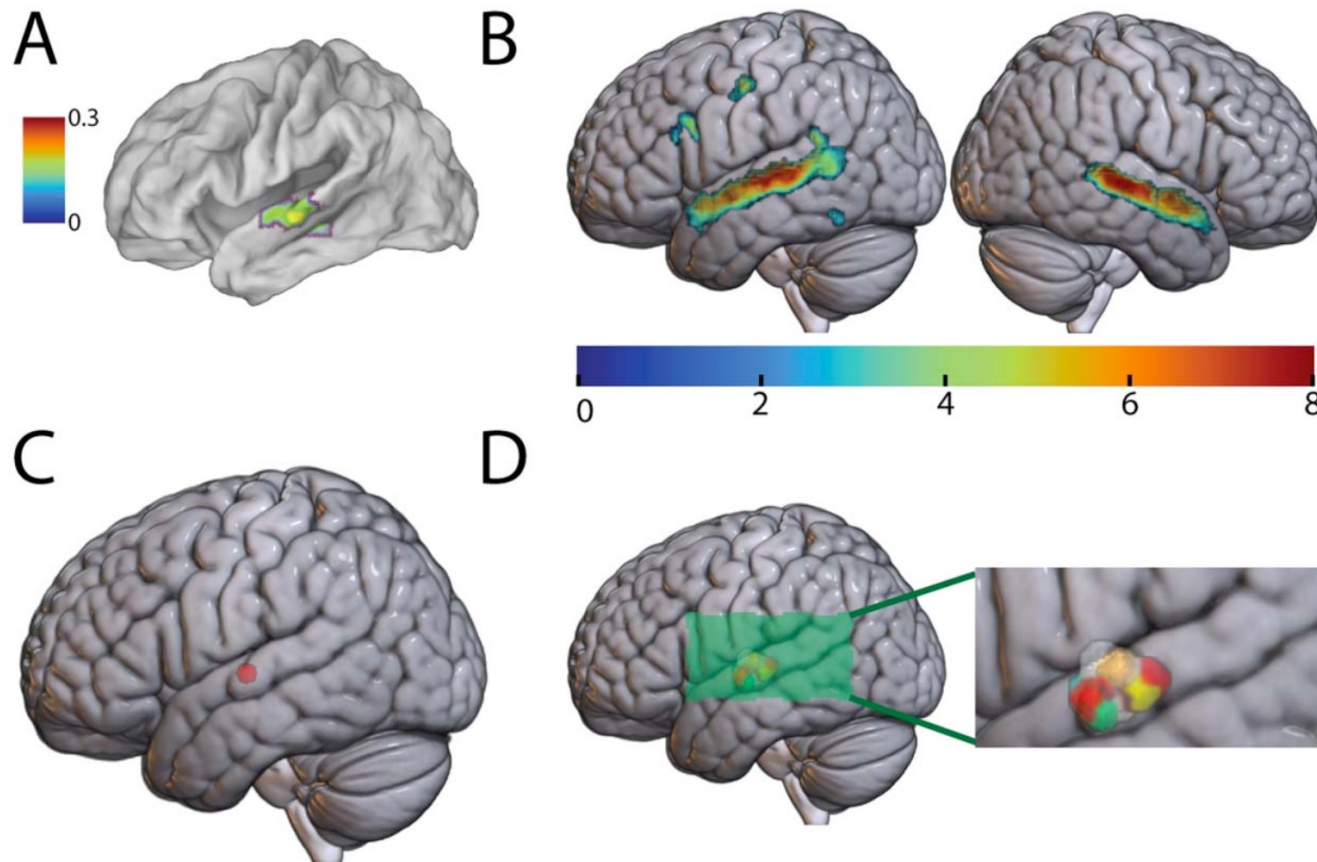
Damera, Srikanth R., et al. "Evidence for a Spoken Word Lexicon in the Auditory Ventral Stream." *Neurobiology of Language* 4.3 (2023): 420-434.

Recognizing Arabic roots in the auditory word form area

- Gwilliams, L., & Marantz, A. (2015). Non-linear processing of a linear speech stream: The influence of morphological structure on the recognition of spoken Arabic words. *Brain and language*, *147*, 1-13.

While listening to words, "phoneme surprisal" is a brain response sensitive to the probability of the phoneme being processed given the previous phonemes

- Is phoneme surprisal sensitive to ROOT surprisal or Whole Word surprisal?

KATABA

root morpheme
ktb

Vowels and CV shape associated with verbalizing morpheme
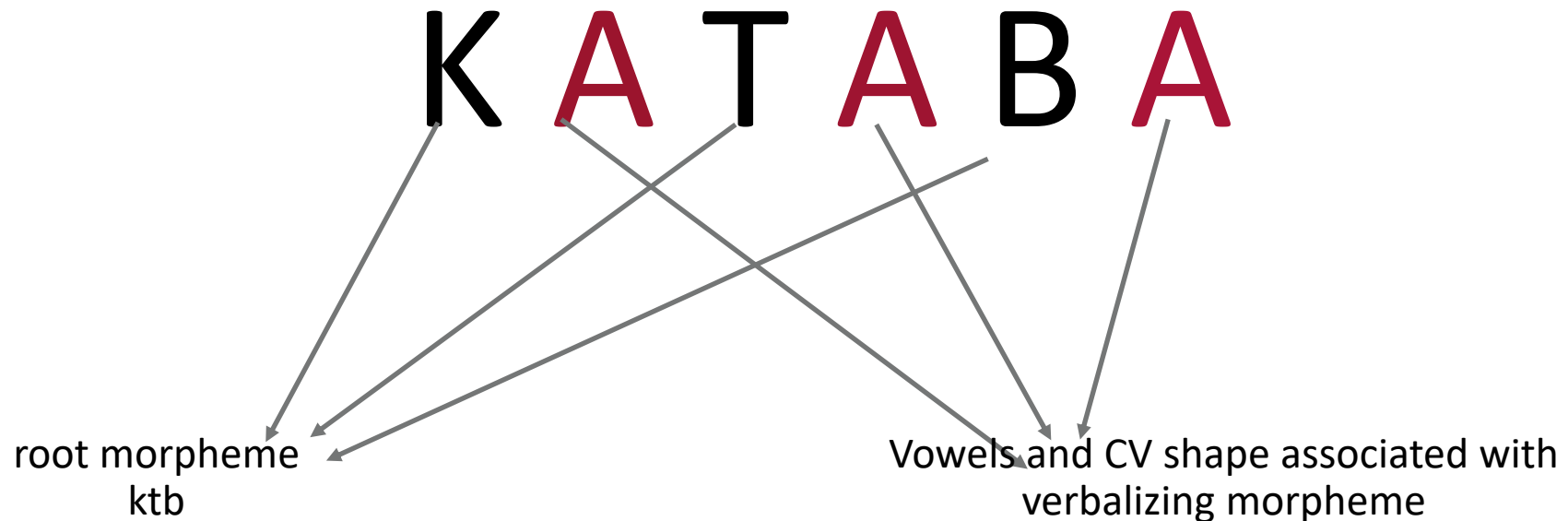
Using prediction to probe the representations relevant for word recognition

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- Does the relevant cohort of morphs for recognizing Arabic words the set of words consistent with the input or the set of roots consistent with the input?
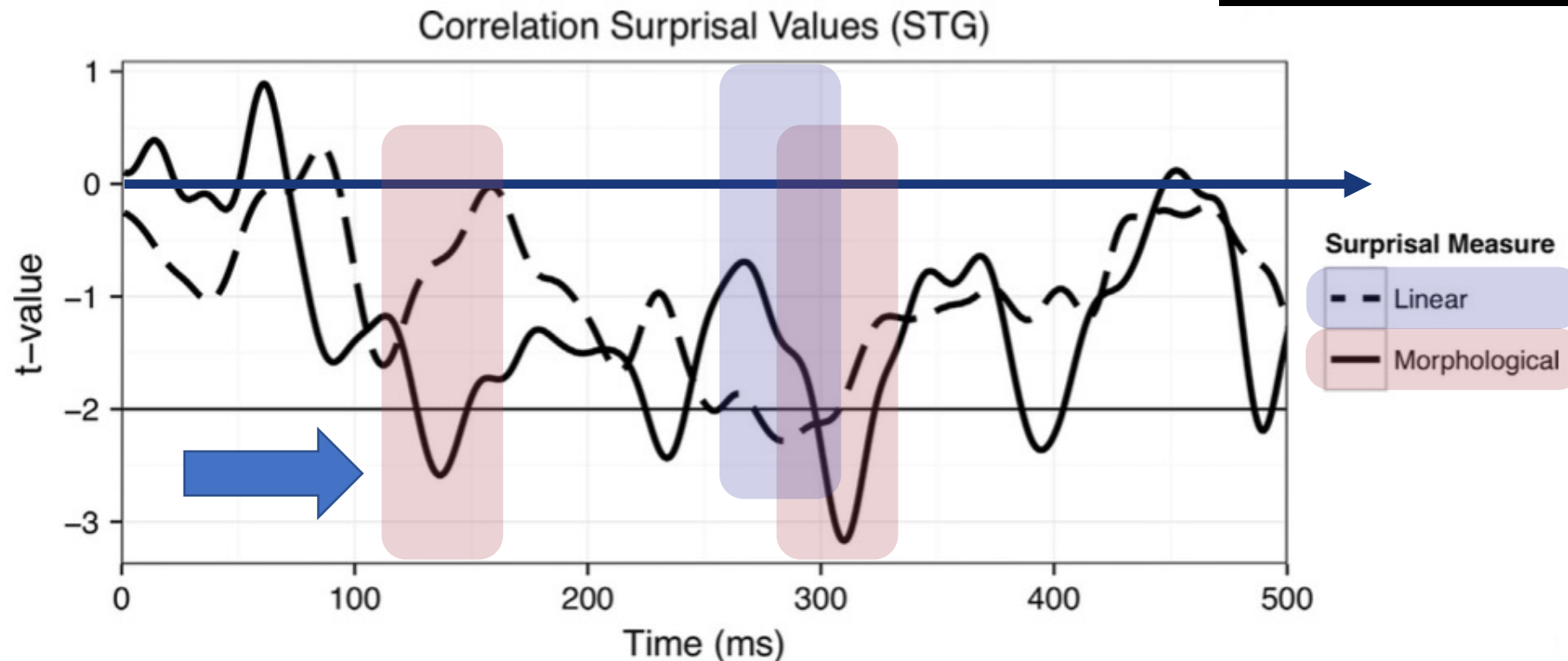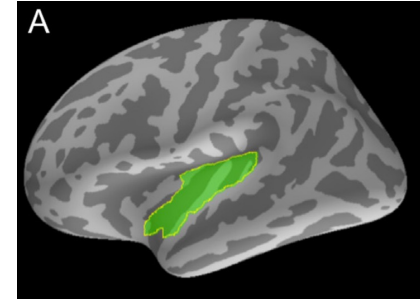
K A T A B A   p(B | KATA)

K T B   p(B | KT)

Materials chosen to decorrelate linear and morphological surprisal
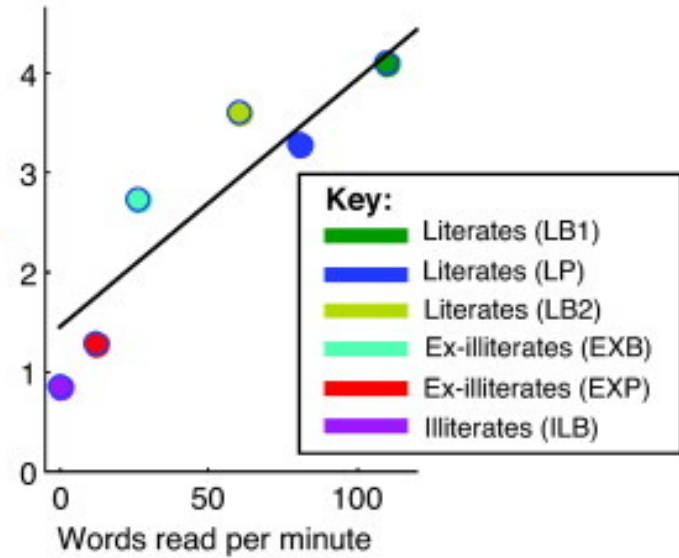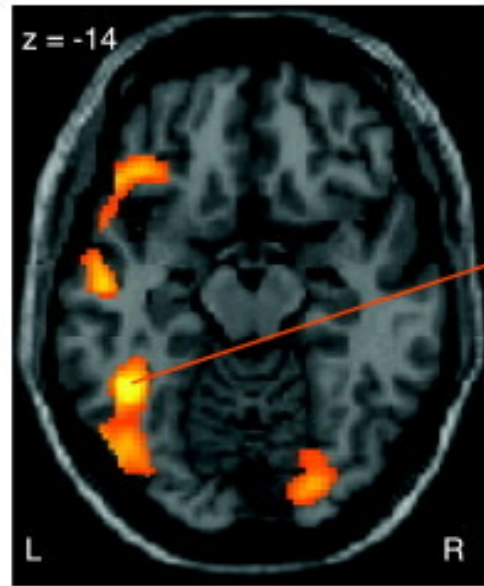
- 280 words with a CVCVCV structure
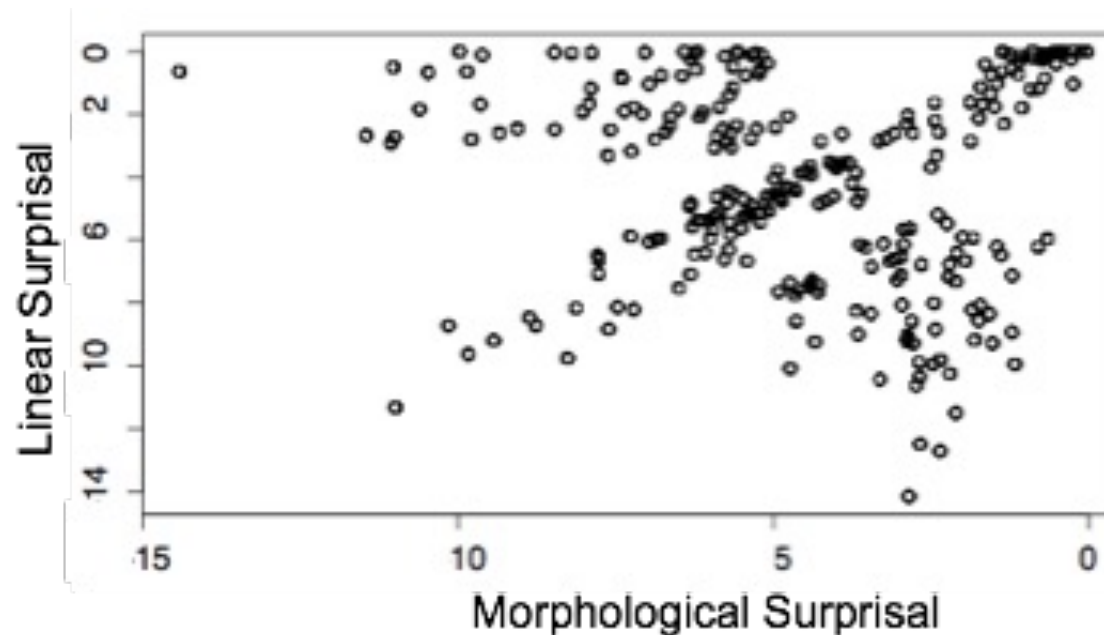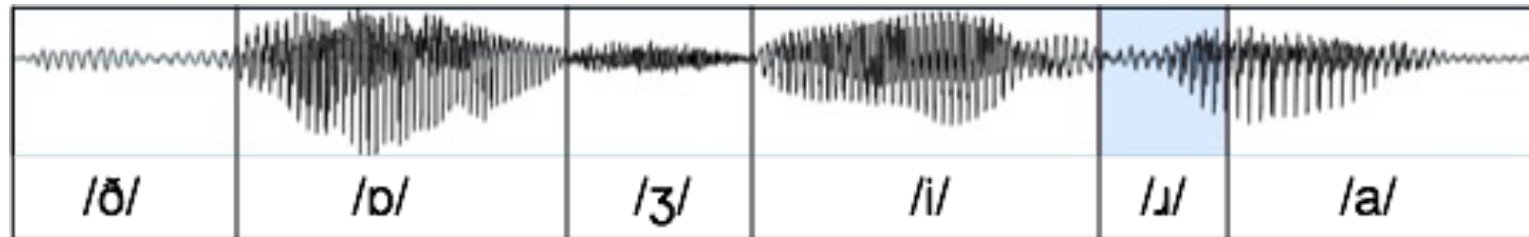
Phoneme surprisal based on the Root predicts the brain response in STC at around 120ms post phoneme onset

Visual Word Form Area – first identified via a cross-linguistic analysis of dyslexia

- Results from illiterates are particularly compelling

- Dehaene, S., & Cohen, L. (2011). The unique role of the visual word form area in reading. *Trends in cognitive sciences*, *15*(6), 254-262.
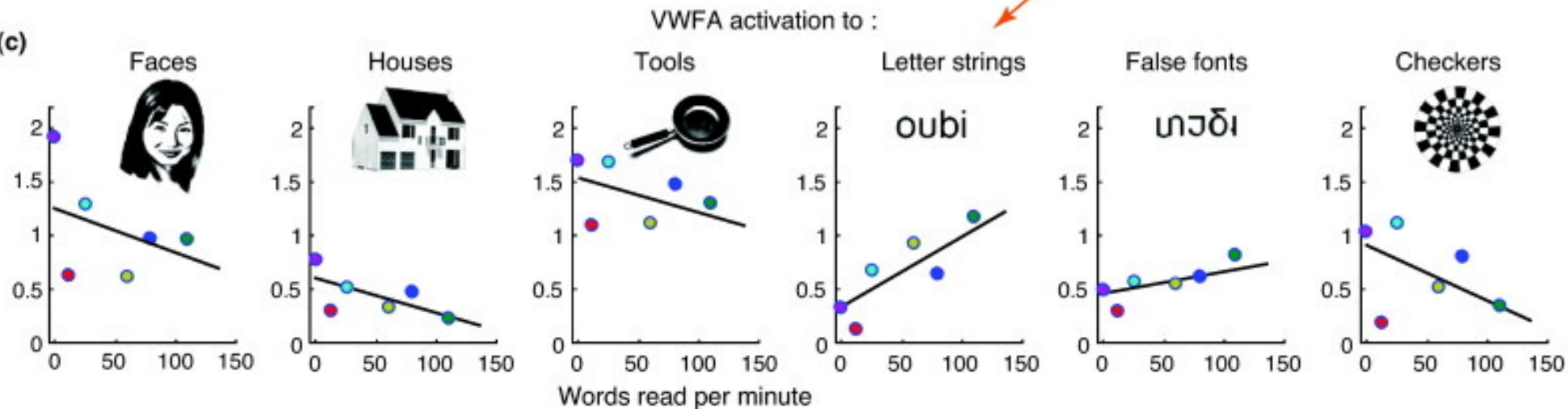
(a) Written sentences

z = -14

L   R

Words read per minute

Key:
Literates (LB1)
Literates (LP)
Literates (LB2)
Ex-illiterates (EXB)
Ex-illiterates (EXP)
Illiterates (ILB)

(b) Letter strings

z = -14

L   R

VWFA activation to :

(c)

Faces   Houses   Tools   Letter strings   False fonts   Checkers

oubi   ᴜᴎᴊᴆᴉ

Words read per minute

TRENDS in Cognitive Sciences

My Lab: The Visual Word Form Area is particularly sensitive to aspects of morphological structure

- For example, the transition probability between a root and a suffix
- The frequencies of suffixes
- Root frequency (but not complex word frequency, when the two variables are pitted against each other)

Effects of the syntactic category on the mapping from roots to meaning

- Experiment: Wilson & Marantz forthcoming

- VISUAL single word lexical decision experiment on monosyllabic English words that can be used as nouns or verbs

  - E.g., the clash, to clash – stimulus = "clash"

- Variable of interest: Noun/Verb entropy = how different from 50%-50% is the relative noun vs. verb use of the word?

- Hypothesis:

  - The brain should be sensitive to N/V entropy at the stage in which roots are mapped by syntactic class to meaning space

- Stage? Early root identification should take place via the activation of the root's representation in orthographic (and phonological) space, i.e., in Visual (and Auditory) Word Form areas, around 170ms after stimulus onset (timing from previous work).

- Between 170ms and 250ms, in these areas and the anterior temporal lobe, N/V entropy should modulate activity associated with mapping to the conceptual space in the middle and superior temporal lobes, with "conceptual" activation peaking 350-400ms post stimulus onset
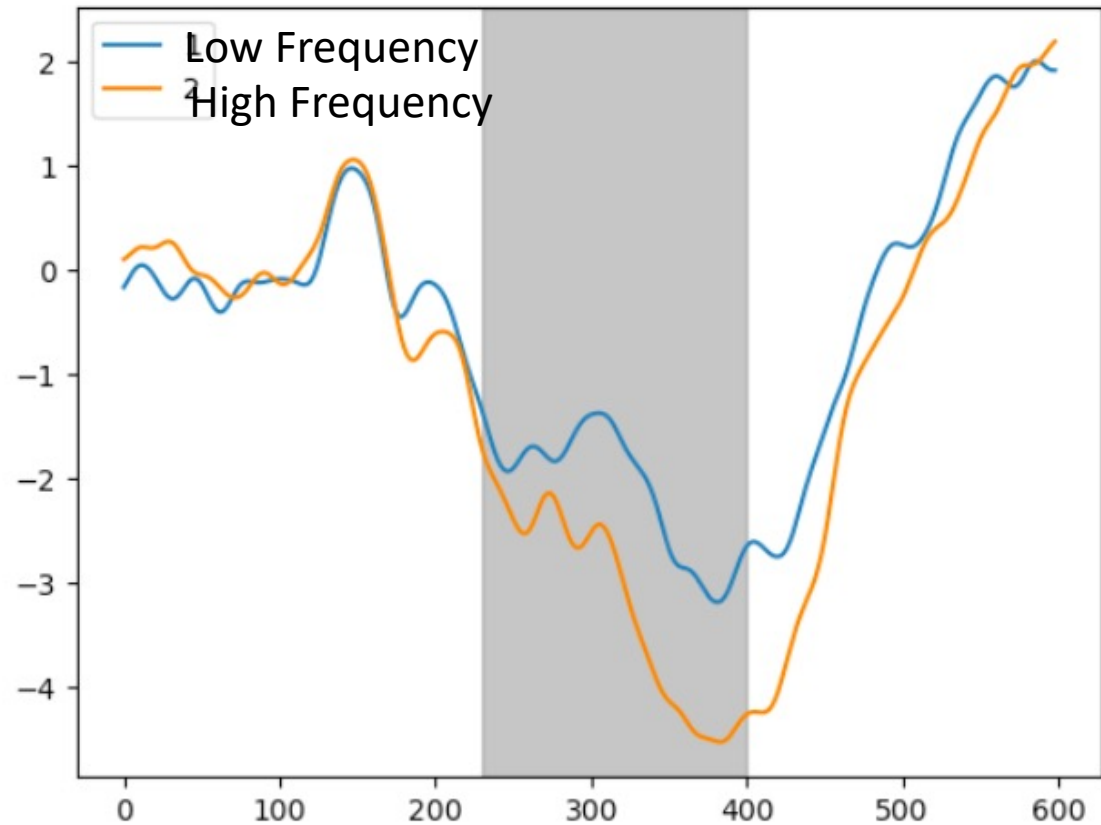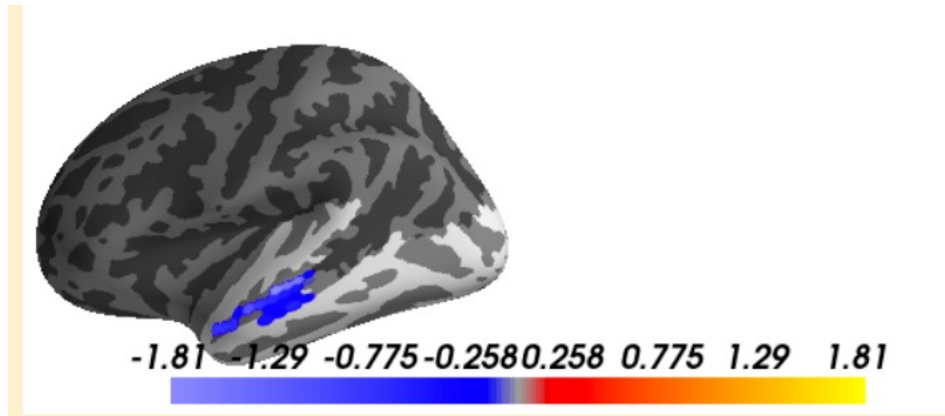
Activation in the anterior (superior) temporal lobe modulated by N/V entropy
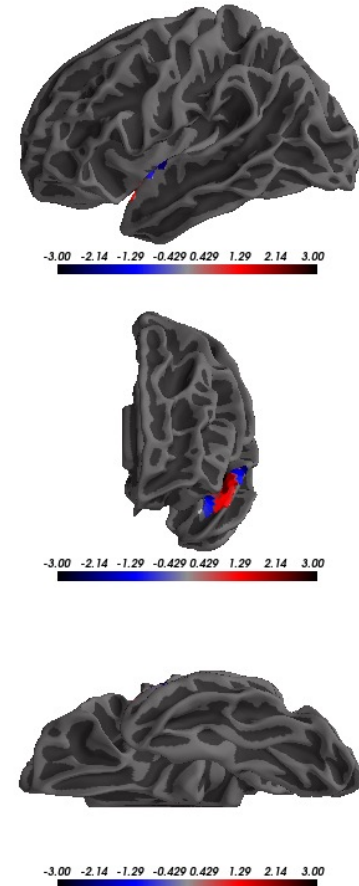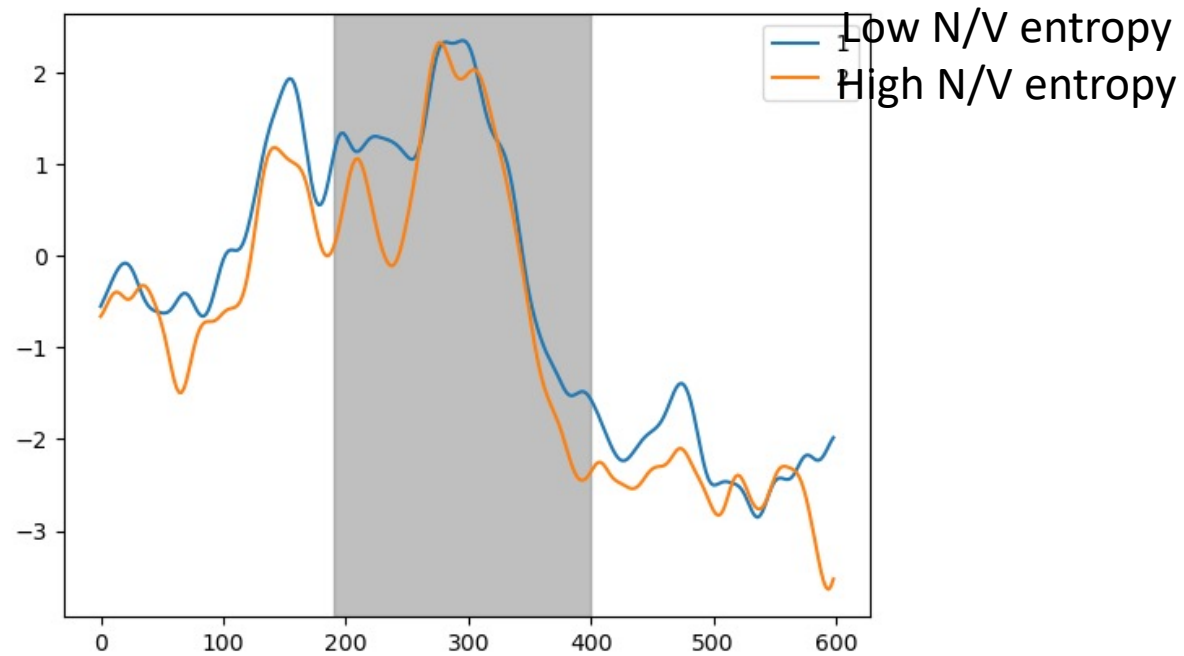
Activation in the Visual Word Form Area modulated by N/V entropy
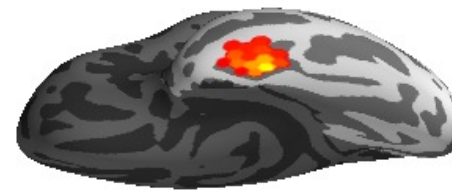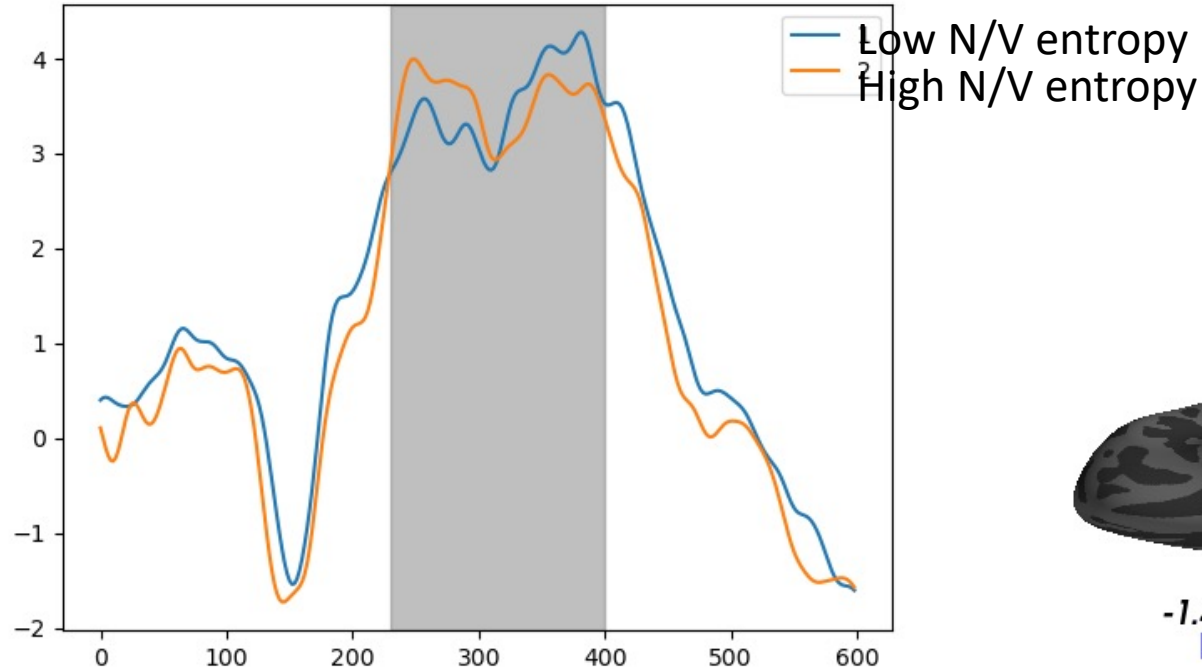
Activation after mapping to conceptual meaning: N400/M350 effect (here correlation with word frequency)

Arabic – Azar in prep.

- Here the different patterns are root-nominalizing affixes.

- The two patterns differ in their functions from roots to meaning space, one more likely to map to objects, the other more likely to map to places.

- However, each has "atypical" uses, where it maps roots to the other conceptual region

Word Pattern (affix)	Object word	Place word
Characteristics	*+Root*	*+Root*
	+Pattern	*+Pattern*
	+Word	*+Word*
maCCaCa	مـمـسحة maMSaHa mop	مـحـمـصة maHMaSa roastery
maCCaC	مبرد maBRaD Nail-file	مطبخ maTBaX kitchen

**Table ii.** *Semantic typicality manipulation design.*

Cells in green: typical meaning-to-affix relation. Cells

in red: atypical meaning-to-affix relation

Hypothesis: typicality, as a property related to the mapping from roots to conceptual space, should modulate activity in the post-170, pre-350 time window, and in the "form areas" and/or anterior temporal lobe

As predicted, but a little earlier than expected

Novel early semantic effects of typicality

A main effect of typicality at 153-176 ms (p=.024) at the ventral processing stream
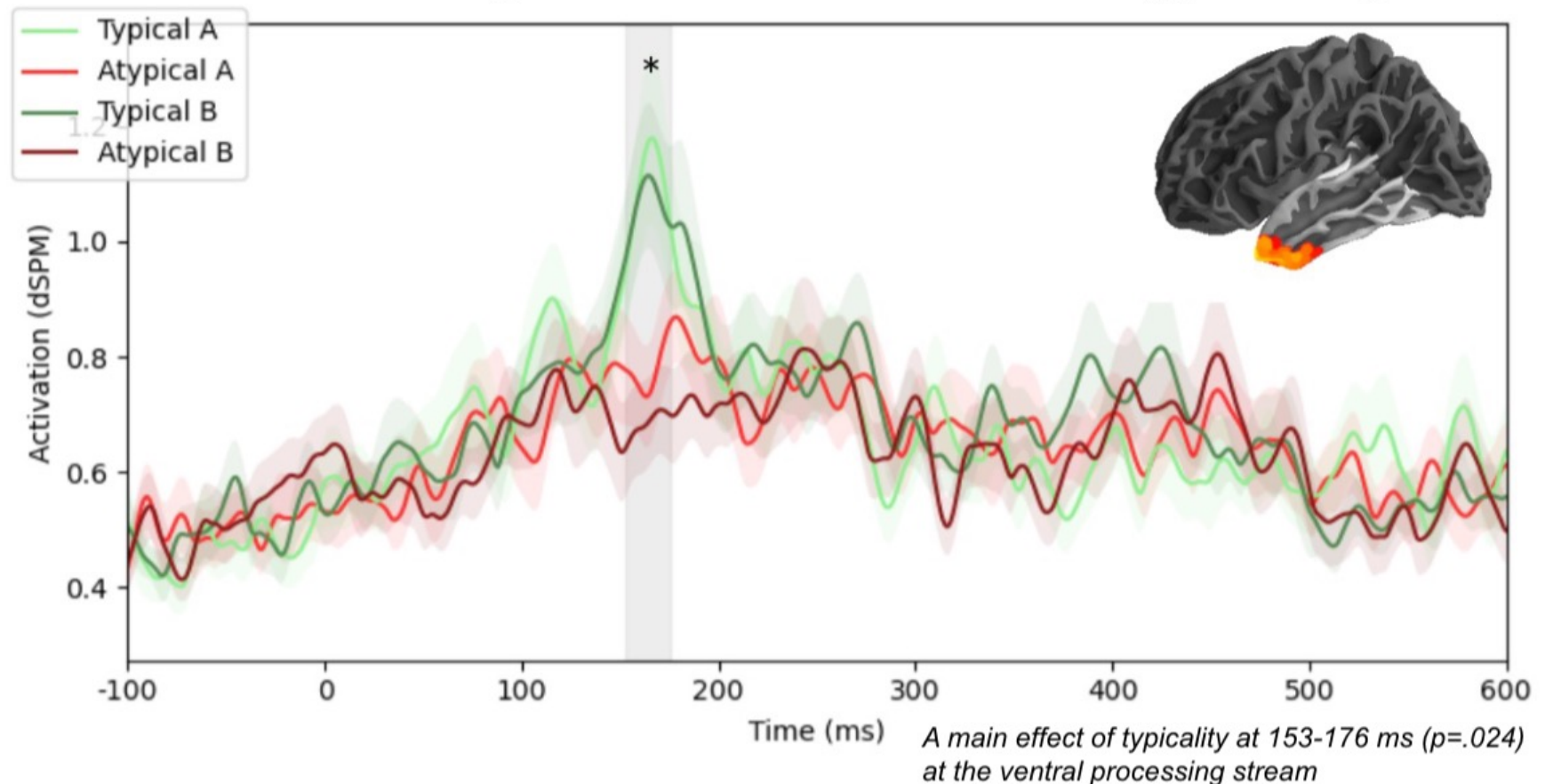
Conclusion

- Consonantal roots in Arabic correspond to the phonological/orthographic form of Saussurian signs – units in phonological/orthographic space that are mapped by grammatical category to conceptual space.

- The patterns of Arabic are the phonological/orthographic realization of syntactic category heads and are involved in the mapping to conceptual space.

- This analysis is consistent with analytic (theoretical) linguistic theory as well as with results from following the processing of words in the brain.

- It may provide a new angle on understanding the semantic fluidity along with some semantic consistency of Semitic roots across patterns.