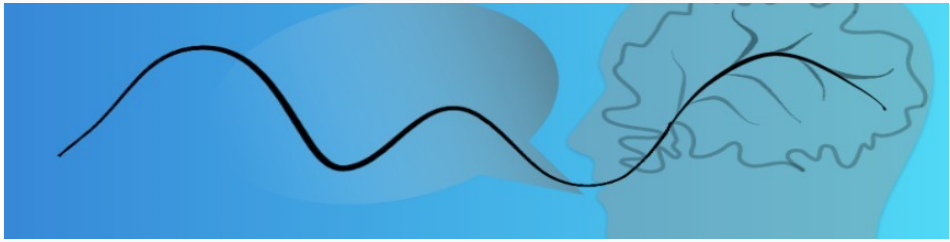

Syntactic Planning, Informational Risk, and the Information Threshold

Joel C. Wallenberg[1]

(with collaborators: Rachael Bailes, Anton K. Ingason[3] and Christine Cuskley[2])

[1] University of York, UK
[2] Newcastle University, UK
[3] University of Iceland, Iceland

"Constraints on the Adaptiveness of Information in Language" (CAIL)

- `https://cail-project.github.io/`
- Collaboration with Christine Cuskley and Rachael Bailes
- ESRC Secondary Data Analysis Initiative (SDAI), grant #ES/T005955/1

Today's Talk

Information Uniformity and Language

What It's For: Noise Resistance

- Theoretical excursus: language and ruin

What It Does: Syntactic Planning

- Diachronic Study 1: Information Theoretic Constant Rate Effects: OV to VO
- Diachronic Study 2: Adding Adjunct Fronting with V2
- Theoretical Implications

Further Work: English topicalization is disappearing

Conclusions and Lots More To Do

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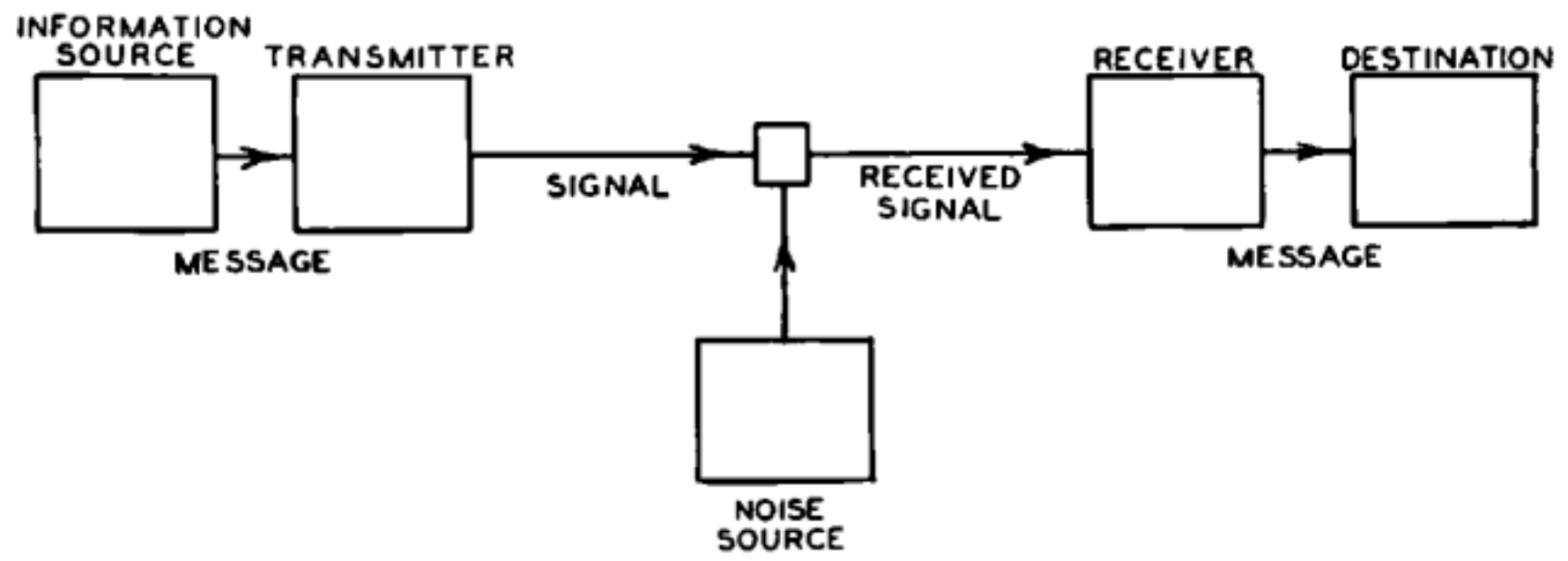

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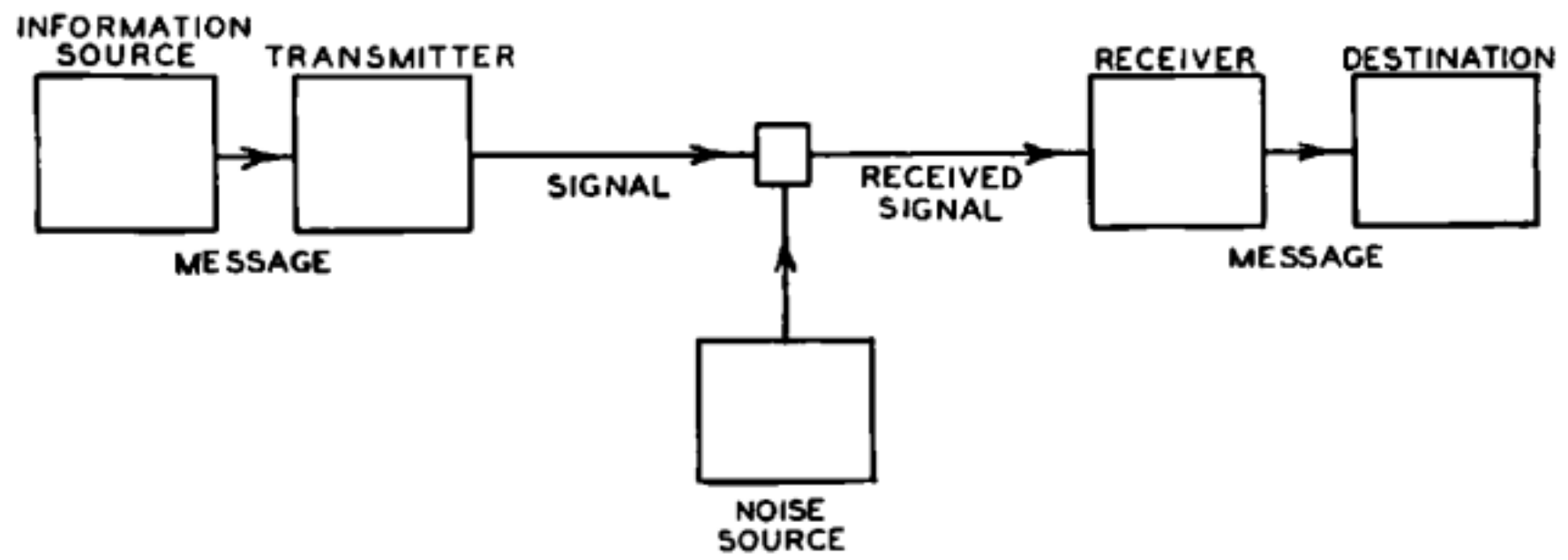
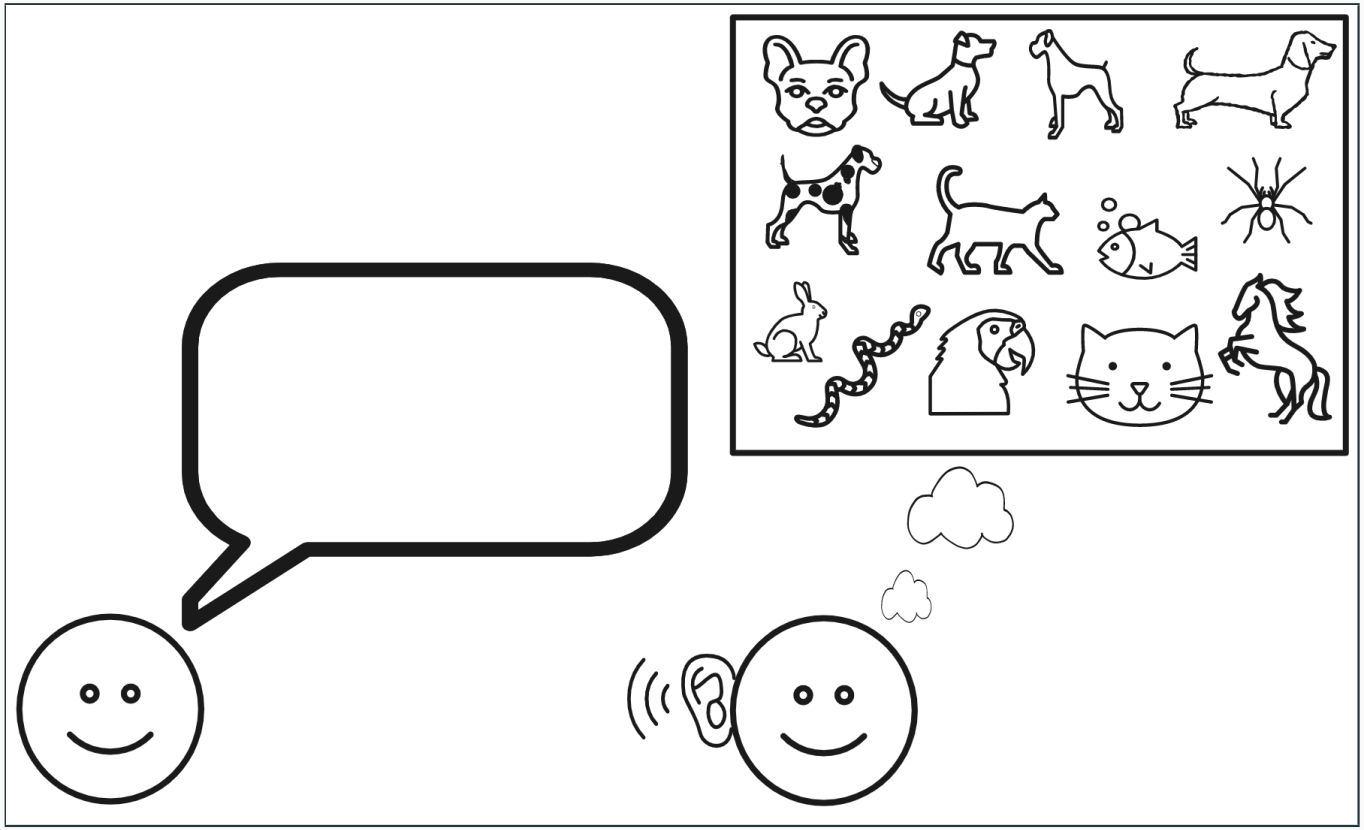


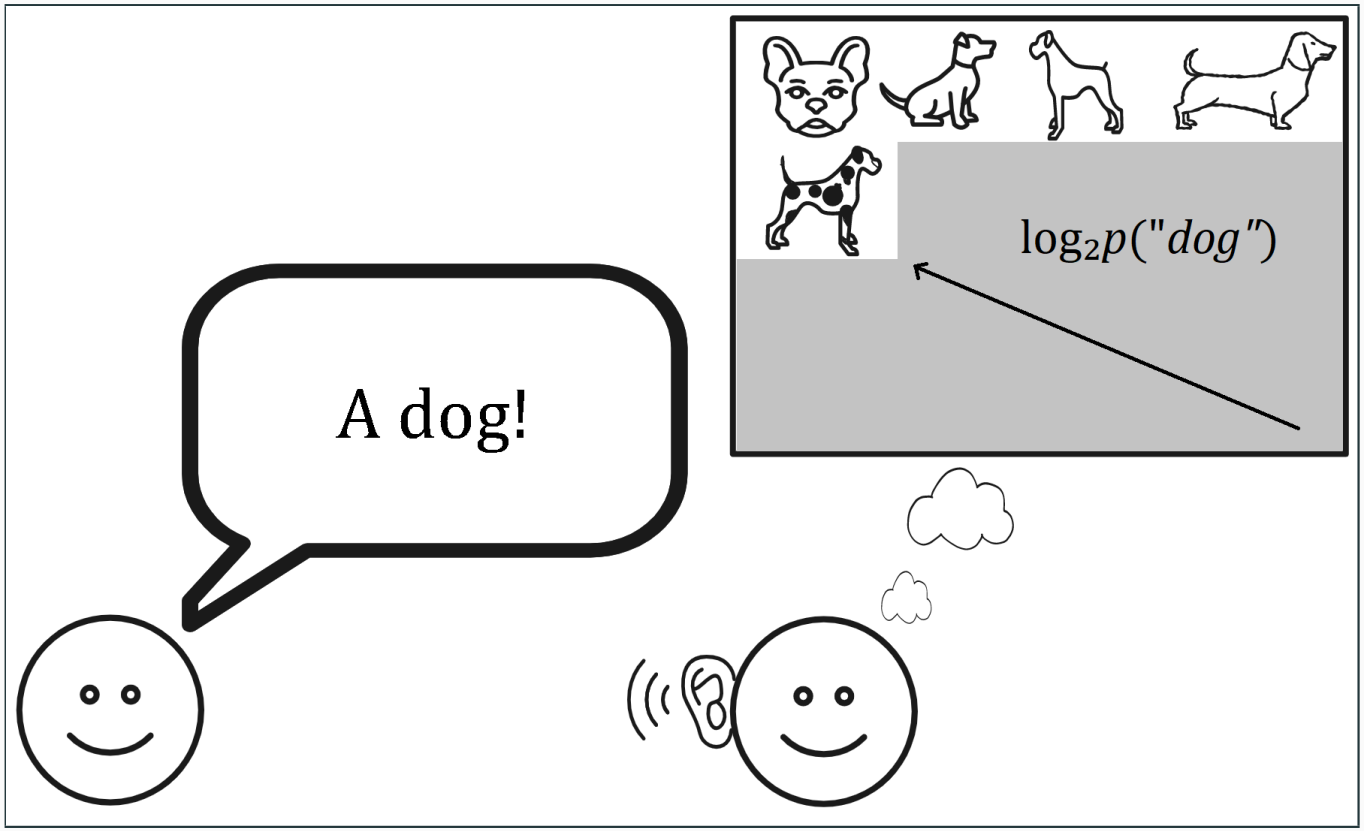
- **Key Insight:** The amount of information a sender can theoretically communicate about an event is the uncertainty ("entropy") the receiver has about the event beforehand, which may be reduced by a signal (Hartley, 1928; Shannon, 1948).

Information content of words



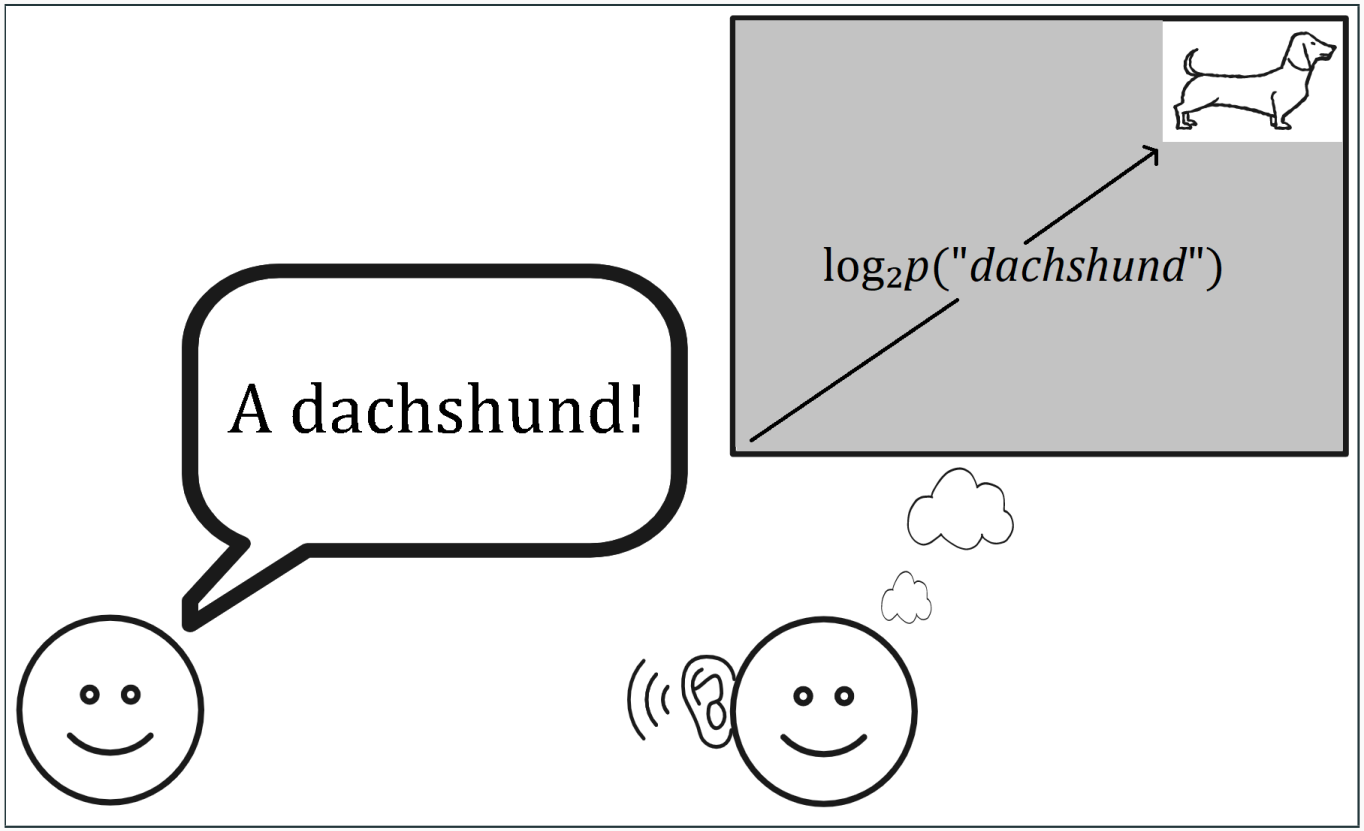
Receiver begins with a **set of expected outcomes** that could result from the message they receive. This set of expected outcomes is the amount of **uncertainty** they have about the message.

Information content of words



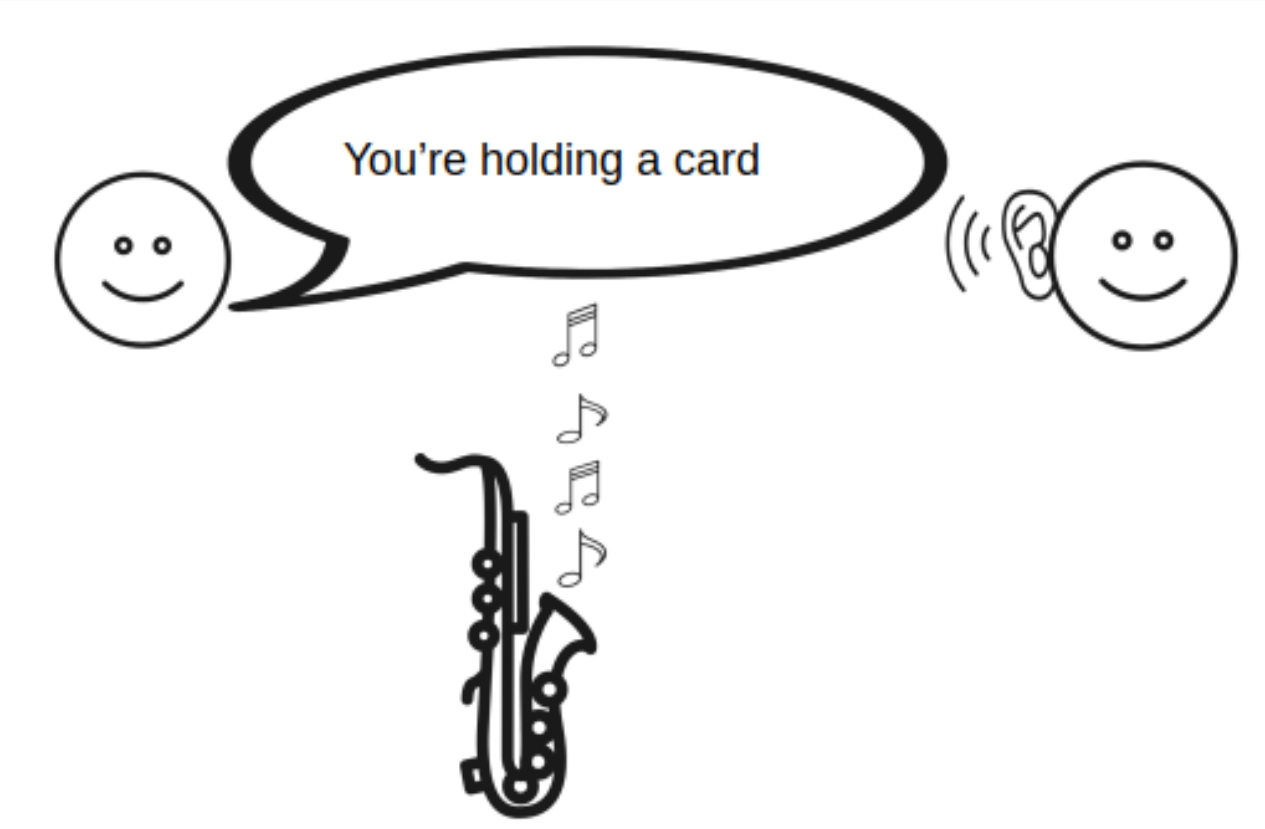
Sender uses a word that **reduces the receiver's uncertainty** by some amount proportional to the word's frequency. Here, the word is relatively frequent.

Information content of words



The more infrequent the word, the more uncertainty is reduced.

Redundancy mitigates against noise



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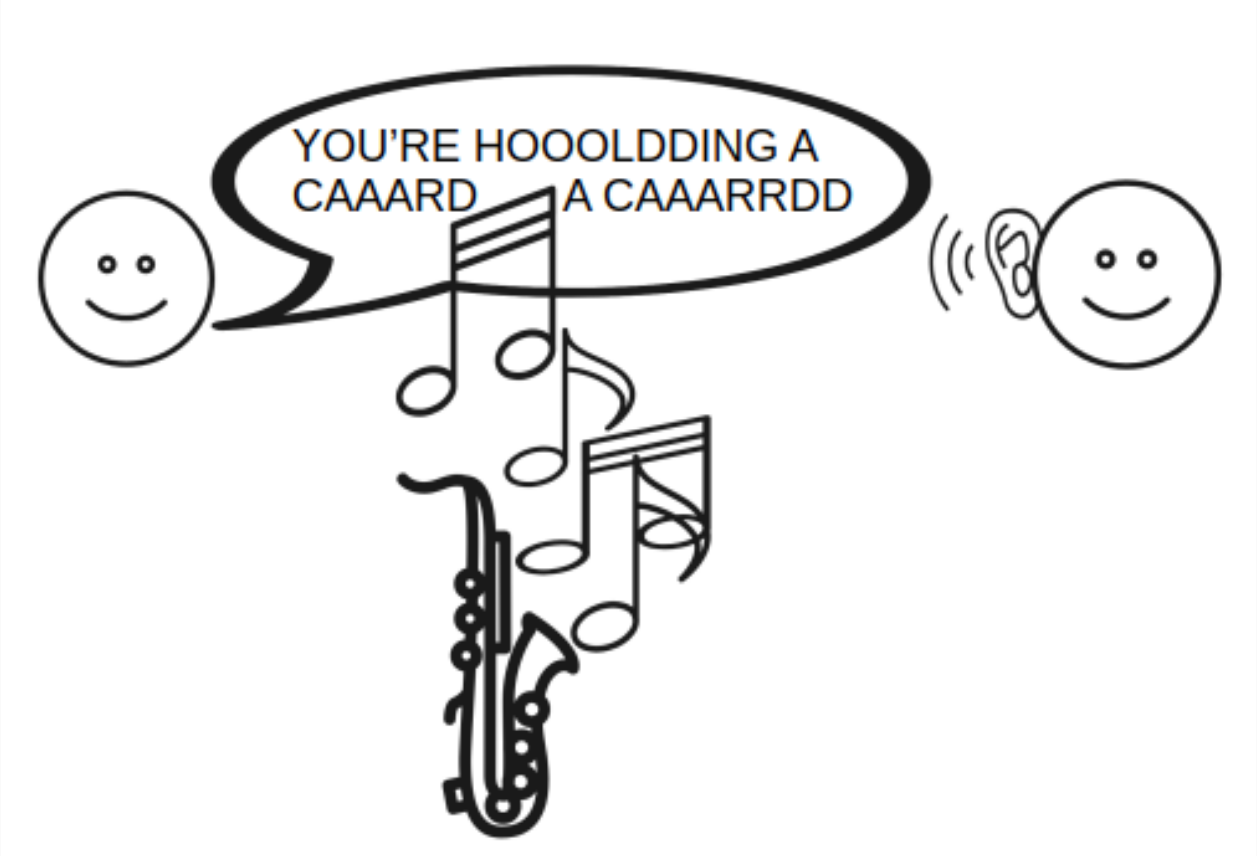

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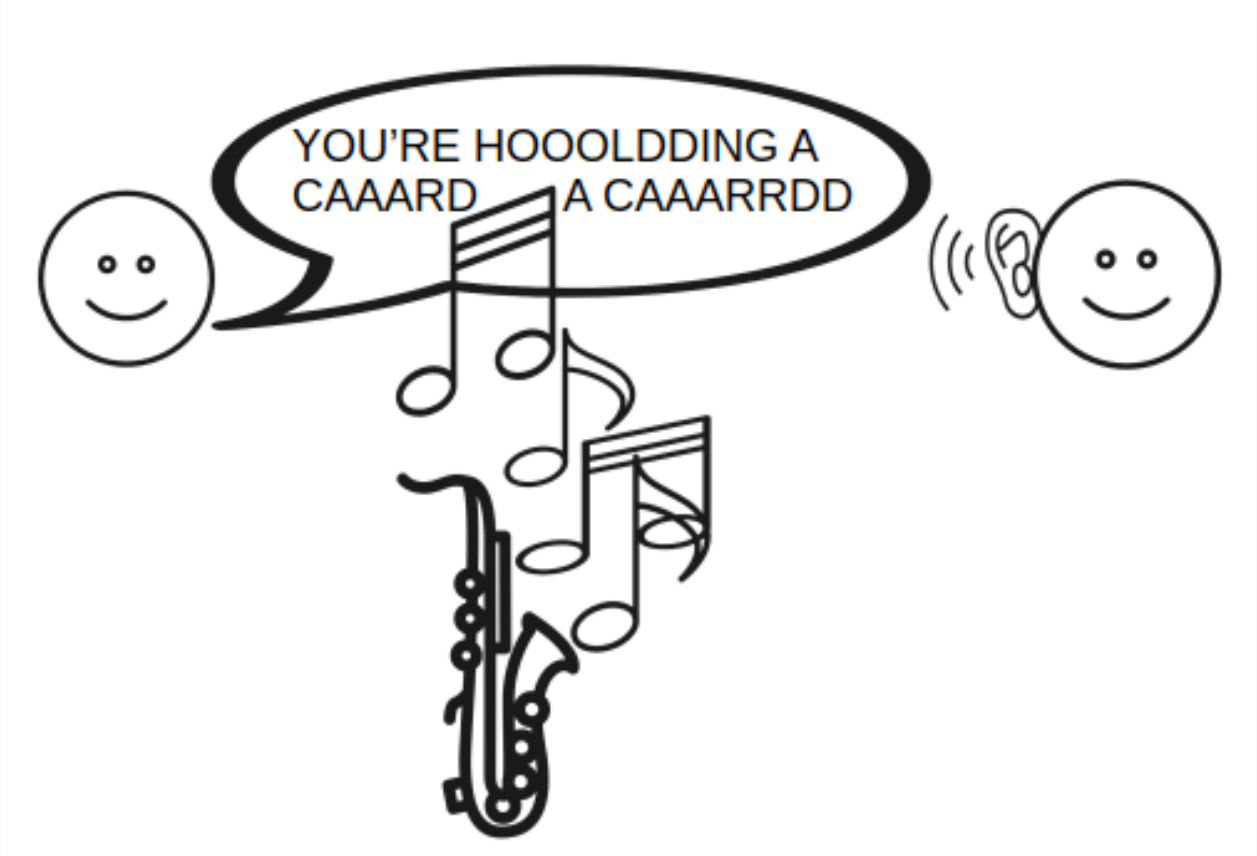

(Shannon, 1948; Fenk & Fenk, 1980; Fenk-Oczlon, 2001; Aylett & Turk, 2004; Levy & Jaeger, 2007; Frank & Jaeger, 2008; Jaeger, 2010; Turk, 2010; Chingacham et al., 2023)

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- Signalling error reduced arbitrarily given sufficient redundancy (Shannon, 1948).
- Does reordering confer noise resistance?

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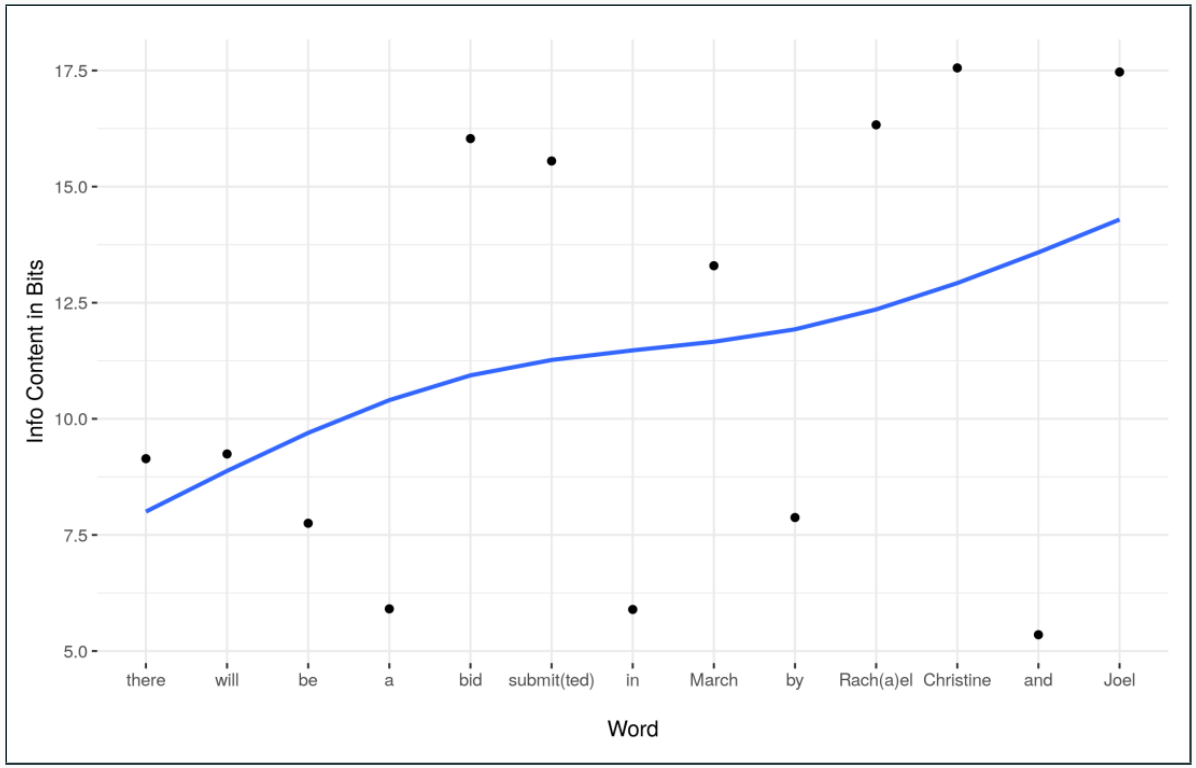
Information distributions of sentences

Deriving the information content of each word means we can derive a **distribution of information content values** for a given sentence.



Uniformity of information distributions

These distributions can vary in terms of how the information is spread or clustered. The **order of elements** in a sentence derives **more uniform** or **more asymmetric** distributions of information (Cuskley, Bailes, & Wallenberg, 2021).

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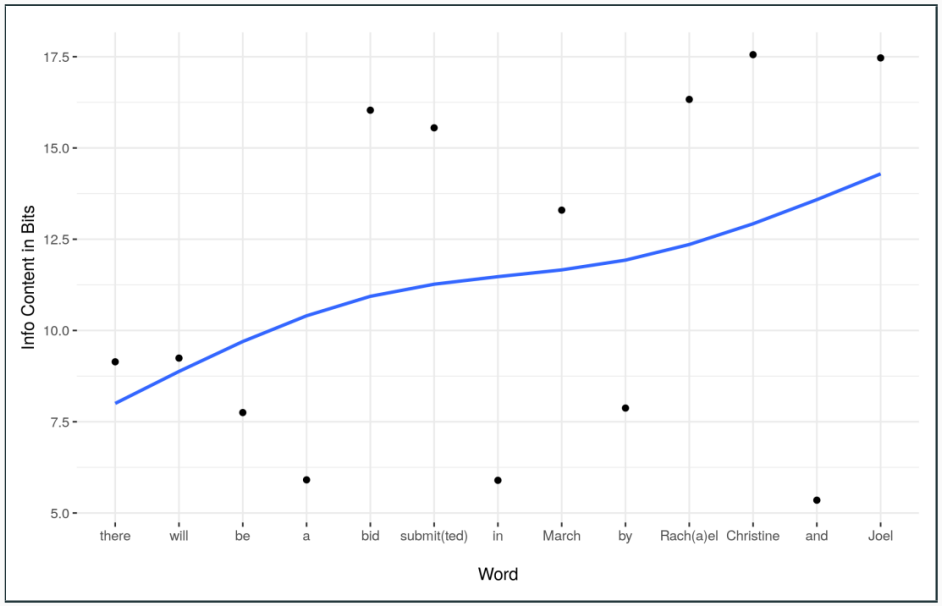

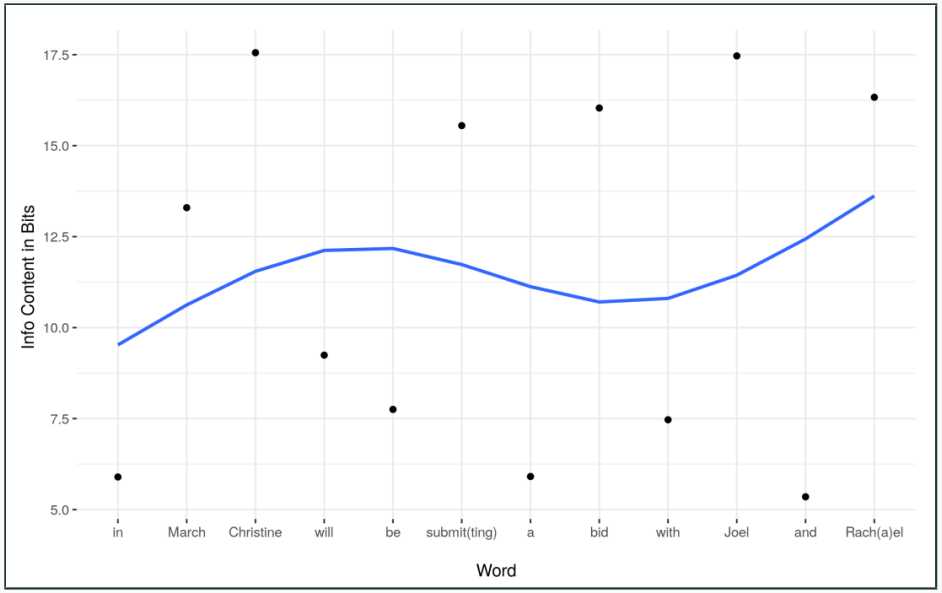

We can measure how uniform an information distribution is with Deviation of the Rolling Mean (DORM) (Cuskley et al., 2021).

DORM: Deviation of the Rolling Mean

en	eg	skal	sjá	yður	aftur
6.79	6.15	10.1	9.25	6.15	10.4

DORM: Deviation of the Rolling Mean

en		eg	skal	sjá	yður	aftur
6.79		**6.15**	10.1	9.25	6.15	10.4
	6.47					

DORM: Deviation of the Rolling Mean

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6.79		**6.15**		**10.1**	9.25	6.15	10.4
	6.47		**8.12**				

DORM: Deviation of the Rolling Mean

en			eg			skal			sjá	yður	aftur
6.79			6.15			**10.1**			**9.25**	6.15	10.4
	6.47			8.12			**9.67**				

DORM: Deviation of the Rolling Mean

en		eg		skal		sjá		yður	aftur
6.79		6.15		10.1		**9.25**		**6.15**	10.4
	6.47		8.12		9.67		**7.70**		

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	6.47		8.12		9.67		7.70		8.29	

Sample variance of rolling means = 1.33 bits^2

low DORM $\rightarrow$ more uniform

high DORM $\rightarrow$ more lopsided

UIDO: Uniform information density optimisation

- An algorithm that finds the most uniform/dispersed/smooth distribution of a given set of values (Cuskley et al., 2021).
- Not absolute lowest DORM possible; but robust enough and computationally tractable.
- Useful **calibration** for utterance DORMs & establishing a baseline.

UIDO: Uniform information density optimization

- For a given array of values (e.g. information values of words in a sentence):
  - The array of information content values is ordered greatest to least.
  - Starting with the second and penultimate value in the array and moving inward, every other number is swapped, mixing up the large and small values.
  - DORM is calculated for the resulting array.
  - If this is lower than the original DORM, the array is kept.
  - Otherwise, the algorithm proceeds with the original array.
- Useful calibration for interpreting utterance DORMs & establishing a baseline, as well as current study use.

Corpus-Based Simulation

- The Penn-York Computer-annotated Corpus of a Large amount of English (PYCCLE; Ecay, 2015).
- 628,083 sentences exactly 10 words in length.
- DORMs for 4 versions: maximally uniform/dispersed, original, random, maximally asymmetric.

Uniformity of distributions

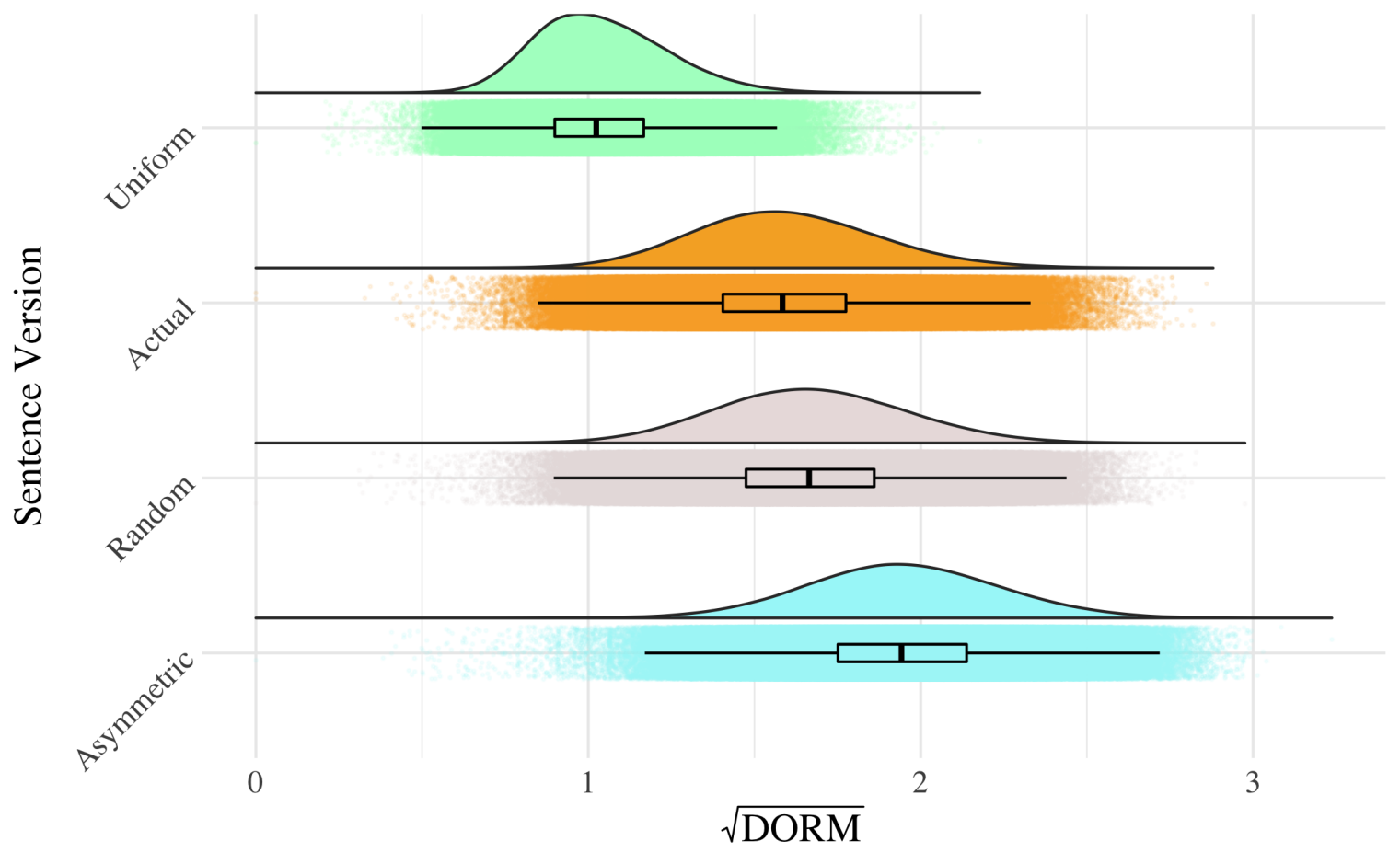

Figure 1: Distributions of the square root of DORM values for 628,083 sentences prior to noise simulation.

Single-unit and clustered noise

- Single-unit noise: three random single units "knocked out" per distribution per trial.

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    - More similar to naturally occurring noise events that span multiple linguistic units.
- Knocked out item positions matched across all 4 versions of all sentences in each trial.

Information loss in conditions of noise

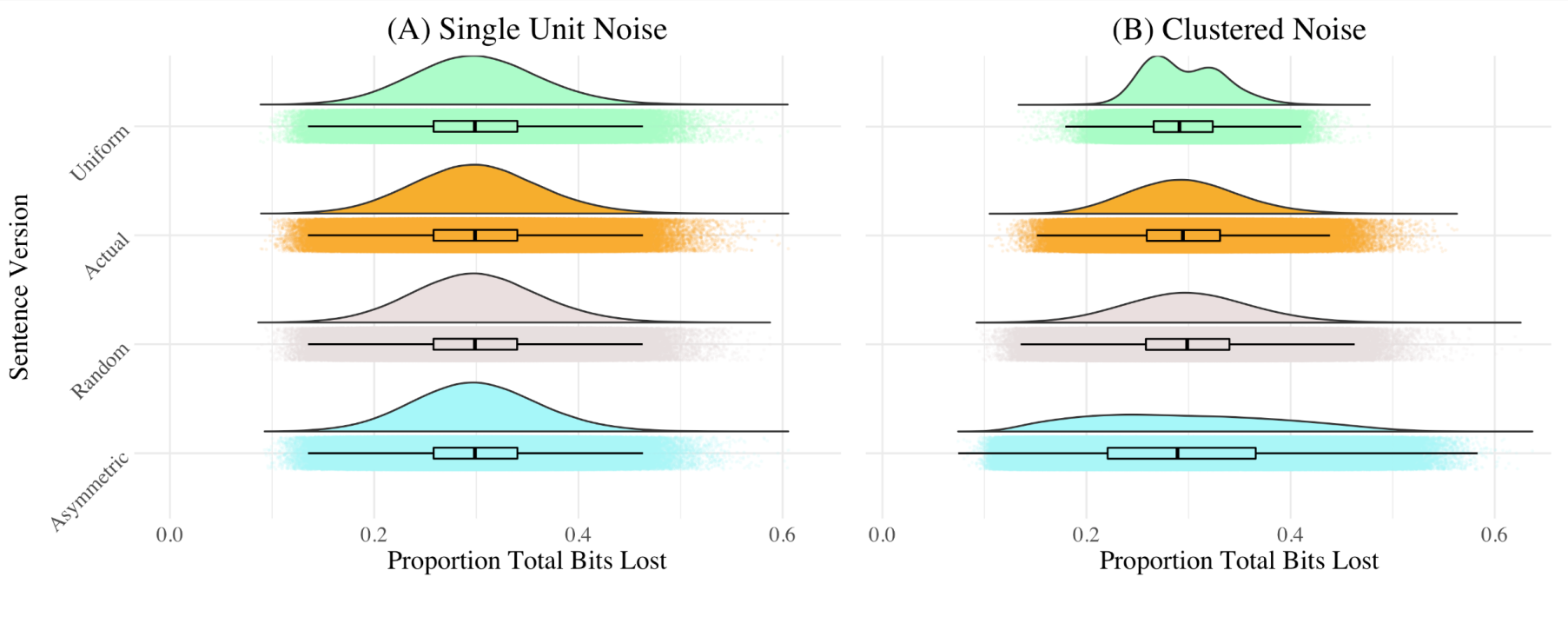

Figure 2: Distributions of the proportion of information lost in 628,083 trials in each condition under 3 single-word noises (A) and clustered noise (B)

Catastrophic Failures

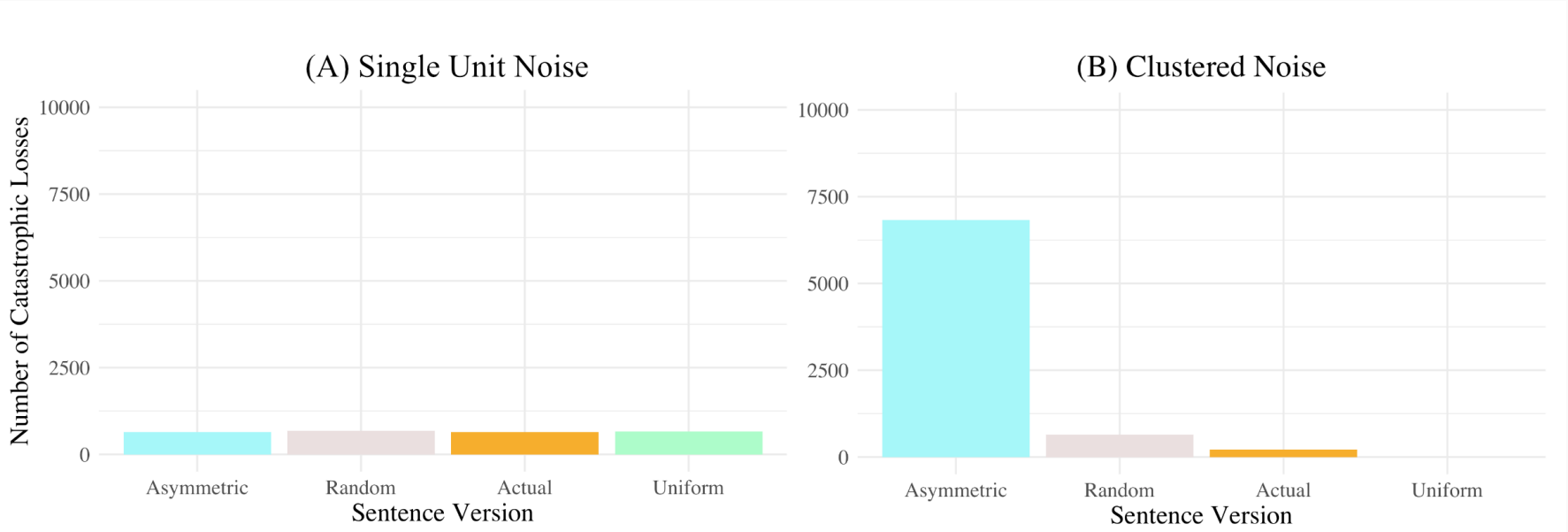

Figure 3: The number of sentences with "catastrophic" information failure in each condition (a noise event knocking out $\geq$ 50% of the total information content) under 3 single-word noises (a) and clustered noise (b)

Interim Conclusions: What It's For

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- ...particularly where continuous noise spans multiple categorical linguistic units.
- More uniform orders may decrease overall info loss, probably because of Zipfian vocabularies (but so do asymmetric).

Theoretical Excursus: Language and "Ruin"

- Signalling happens between every linguistic level, as does noise (Aylett & Turk, 2004).

  acoustic $\rightarrow$ **segmental/allophonic** $\rightarrow$ **phonemic** $\rightarrow$ **morphemic** $\rightarrow$ **morphosyntactic** $\rightarrow$ **propositional/utterance-function**

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  - "Uniform" had a single-sentence 100% VaR of 50%, or a 99.9% VaR of 42%.

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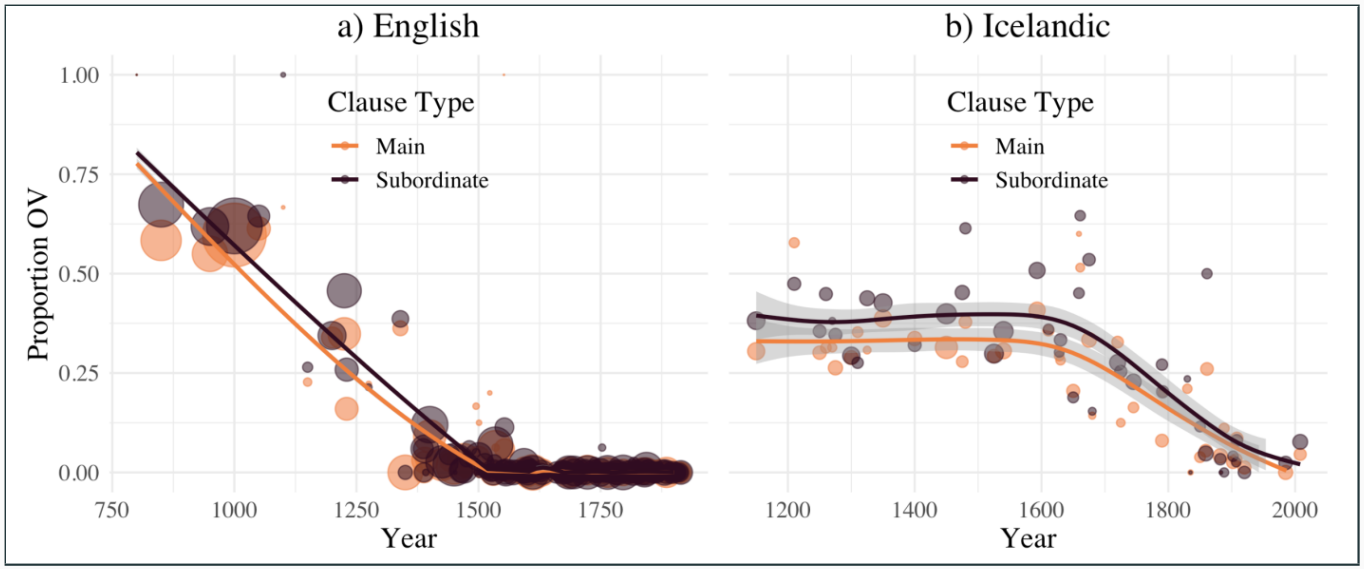

e.g. In the change from OV to VO in English & Icelandic, OV is consistently favoured in subordinate clauses throughout the steady decrease in its overall proportion (see also Pintzuk & Taylor 2006).

CRE in English and Icelandic OV to VO

- Based on this account of information uniformity, (Wallenberg, Bailes, Cuskley, & Ingason, 2021) predicted a previously undetected argument-type effect in the English and Icelandic OV to VO changes.

CRE in English and Icelandic OV to VO

- Based on this account of information uniformity, (Wallenberg et al., 2021) predicted a previously undetected argument-type effect in the English and Icelandic OV to VO changes.
- During the change, speakers had access to both constituent orders, making this an ideal case for testing whether language users choose more informationally uniform constructions.

OV-to-VO in English

Middle English:

(1) Mi feader & Mi moder for-þi þt ich nule þe
My father and my mother because that I not+would you
forsaken; habbe forsake me.
forsake have forsaken me
"Because I would not forsake you, my father and mother have forsaken me"

(*St. Juliana*, northern Herefordshire/southern Shropshire, date: c1225; ID CMJULIA-M1,106.172 from the *Penn Parsed Corpus of Middle English 2* PPCME2, 2000)

OV-to-VO in Icelandic

Historical Icelandic:

(2) a. . . . og sannleikurinn mun yður frelsa
and the truth will you free
". . . and the truth will free you."

(*Oddur Gottskálksson's New Testament*, date: 1540; ID 1540.NTJOHN.REL-BIB, 204.662 from *Icelandic Parsed Historical Corpus (IcePaHC, 2009)*)

b. . . . en eg skal sjá yður aftur.
but I shall see you-pl again
". . . but I shall see you again"

(*Oddur Gottskálksson's New Testament*, date: 1540; ID 1540.NTJOHN.REL-BIB, 223.1305 from IcePaHC)

English and Icelandic OV to VO

- Syntactic constituents (and their lexical content) occur at different frequencies, which means they have different information content values.

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Constituent Type	**Average Information Content** (PPCMBE; A. S. Kroch et al., 2016)
Pronominal DP	low ($\approx$ 11.7 bits)
Nominal DP	high ($>$ 13.7 bits)
Lexical Verb	mid ($\approx$ 13.5 bits)

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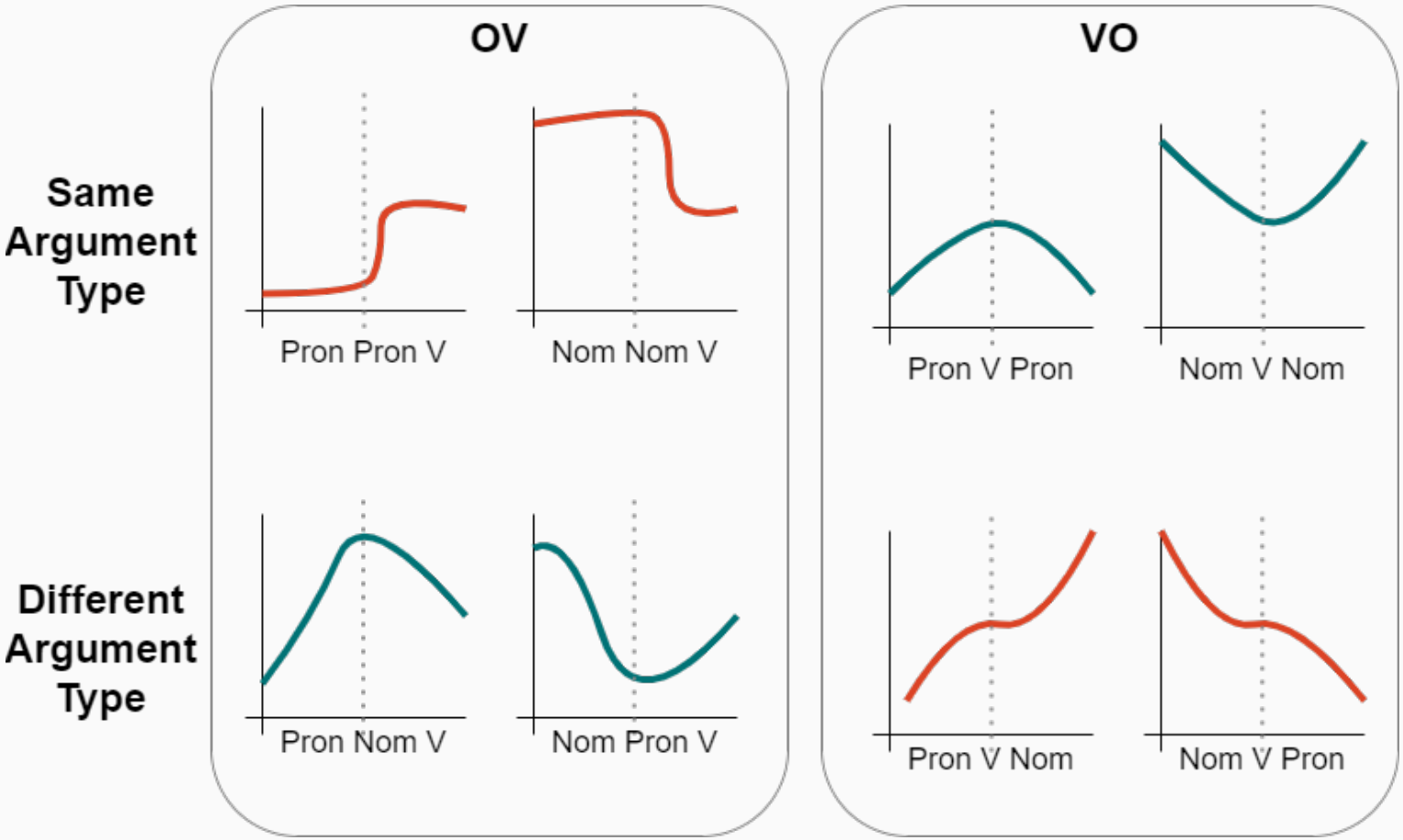
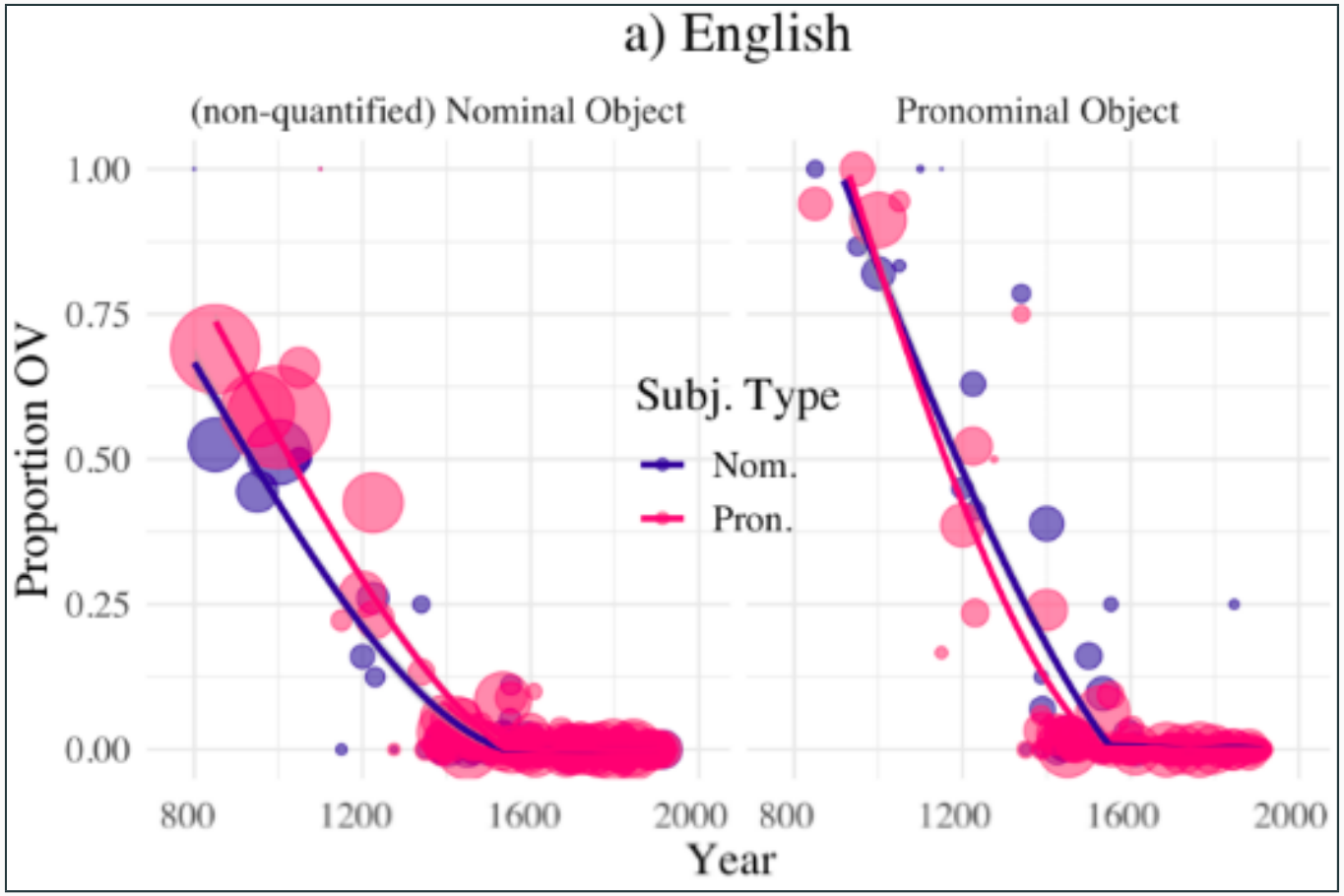
- We can therefore make predictions about the ordering of elements that speakers will prefer, when they have a choice - i.e., constituent orders that yield more uniform information distributions.

Predictions



- **OV is disfavoured** when Sbj and Obj are the **same type**
- **OV is favoured** when Sbj and Obj are **different types**

Results:
OV is favoured when Subject and Object are different types



YCOE and Penn Parsed Corpora of Historical English (Taylor, Warner, Pintzuk, & Beths, 2003; A. S. Kroch & Taylor, 2000; A. Kroch, Santorini, & Delfs, 2004; A. S. Kroch et al., 2016)

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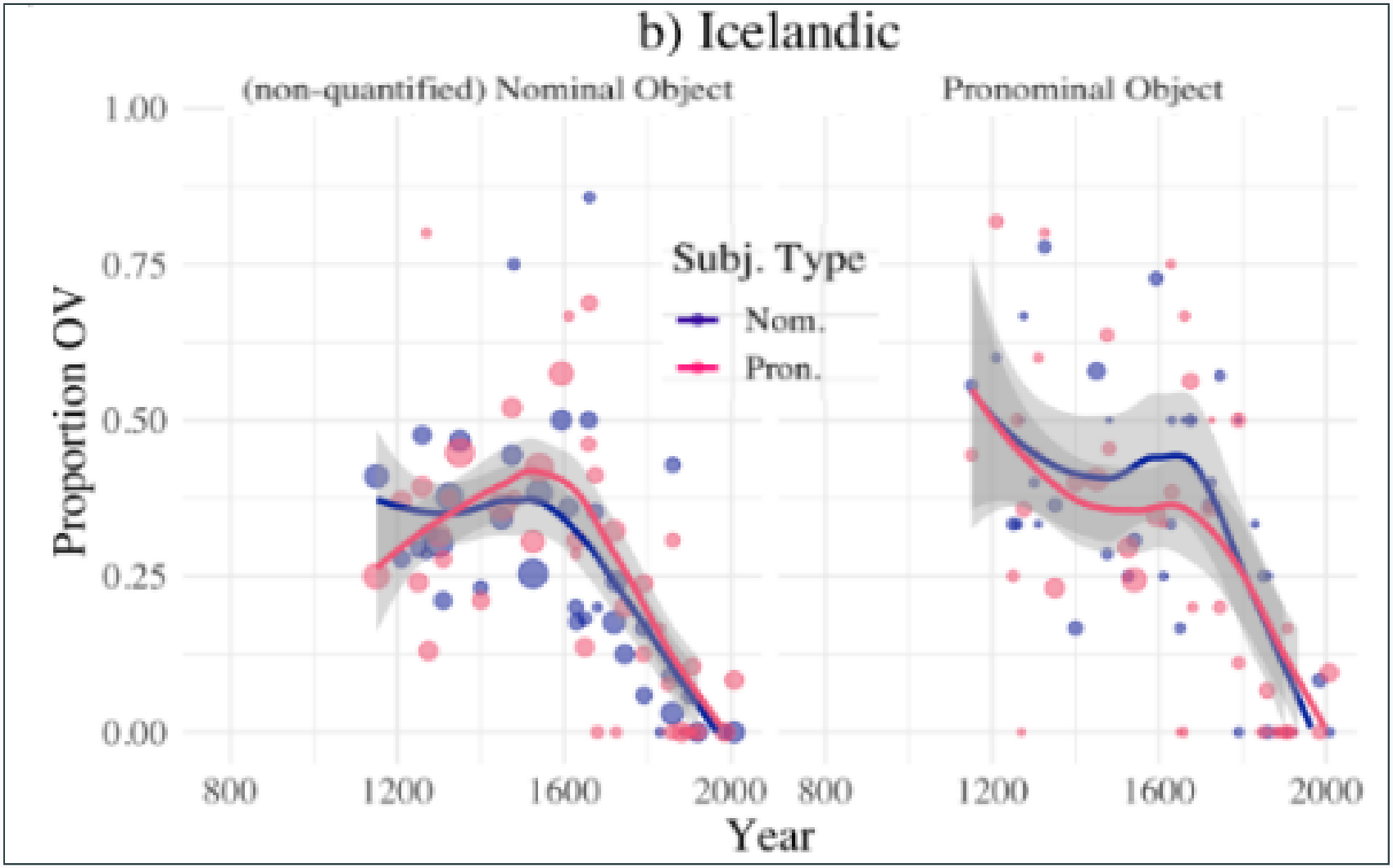
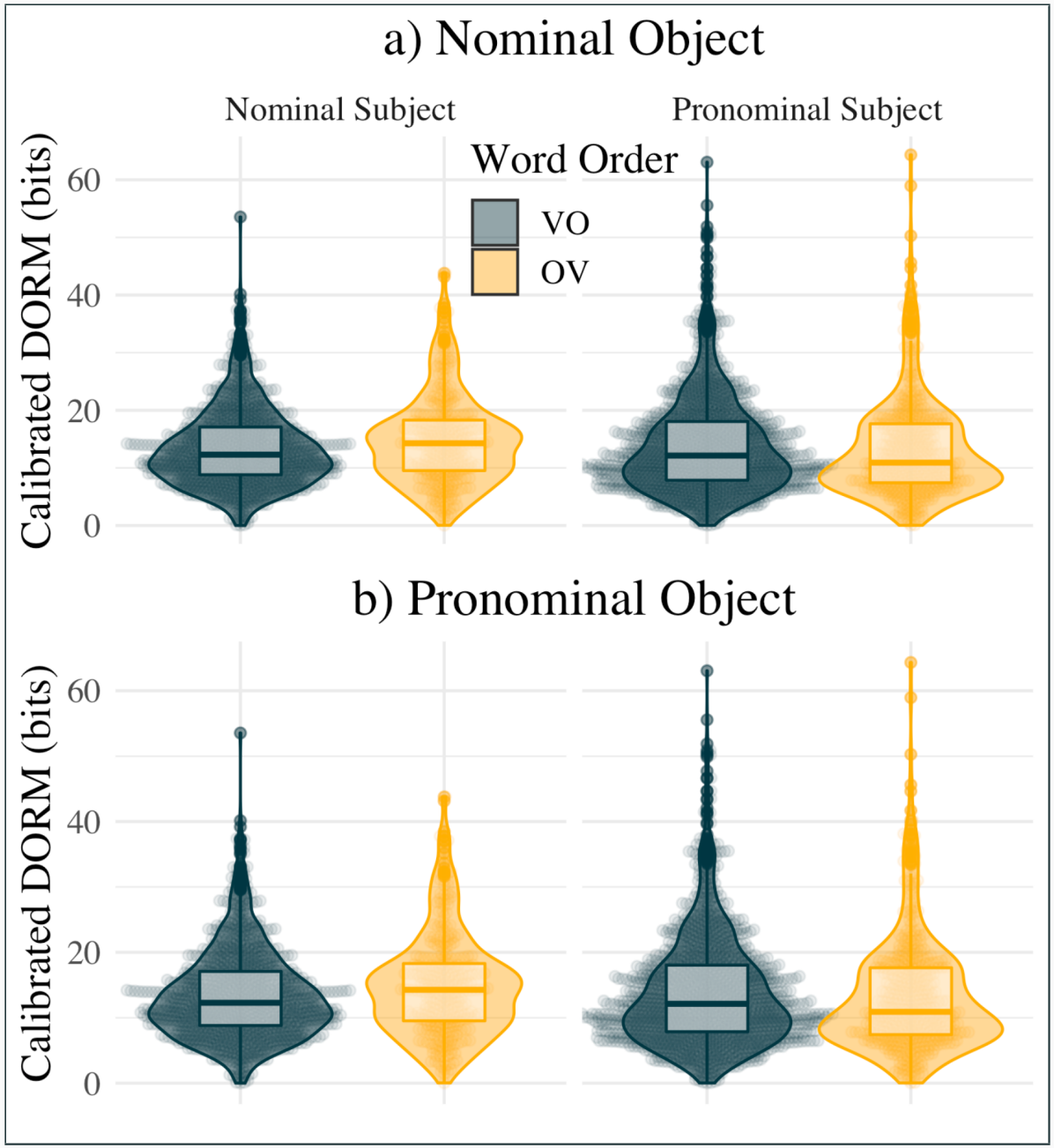
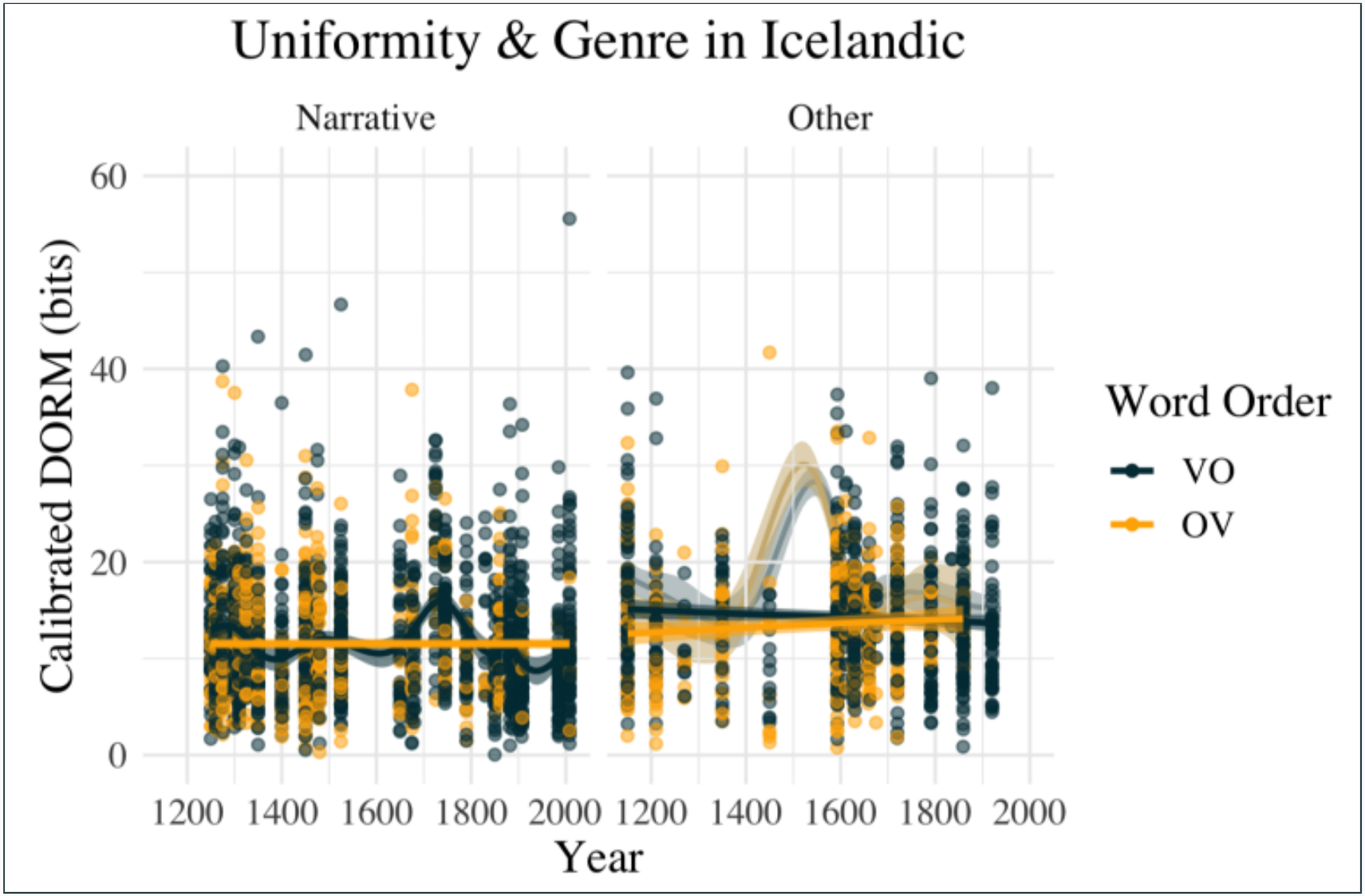


IcePaHC (Wallenberg, Ingason, Sigurðsson, & Rögnvaldsson, 2011)

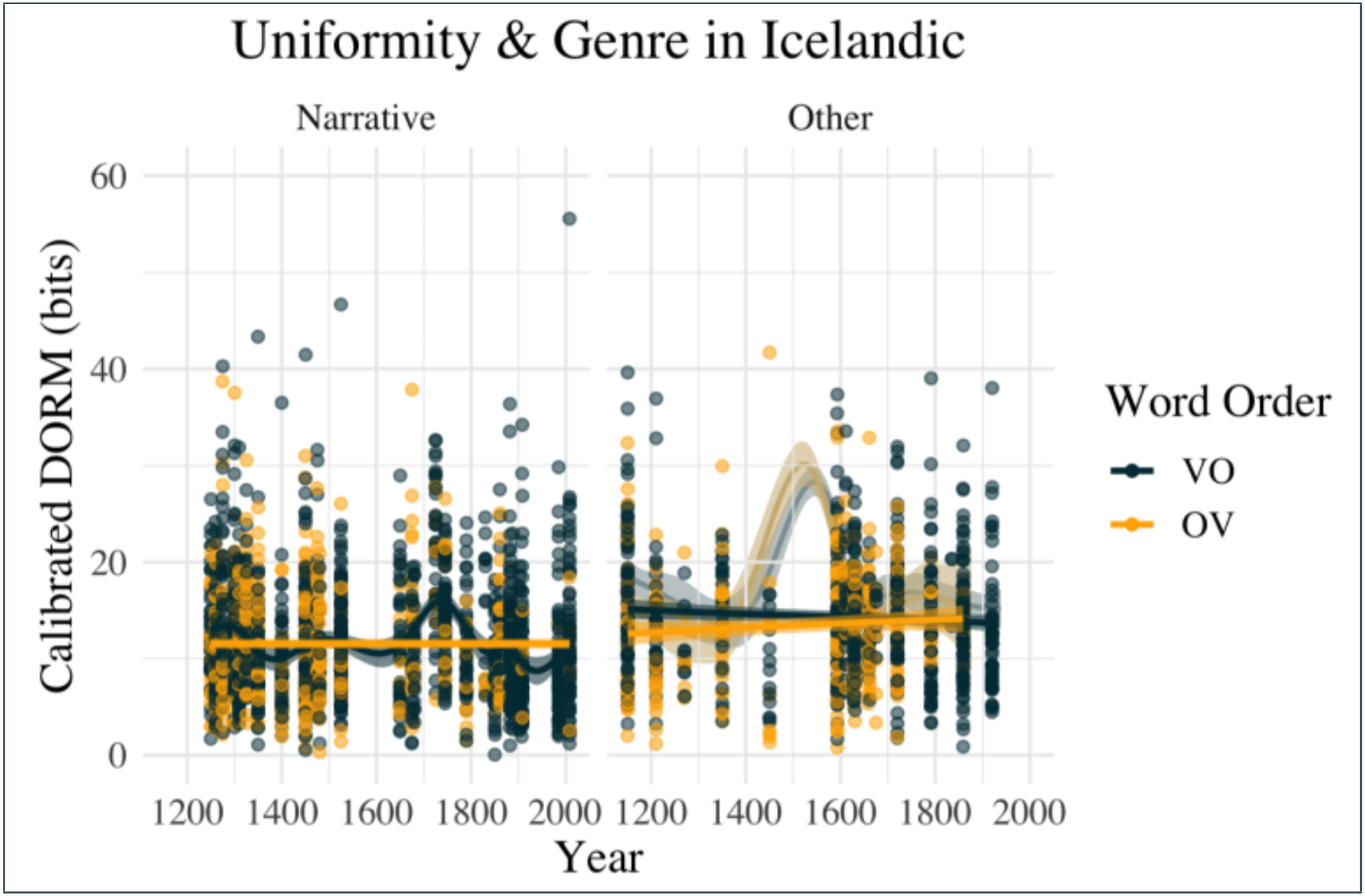
Results: DORMs by Obj, Sbj Type



Results: A threshold?
Information density remains constant



...but the outlier indicates a complex planning problem



Diachronic Study 2: Adding V2

- Wallenberg et al. (2021) showed that a pressure for information uniformity creates contextual effects in the OV-to-VO change.
- OV-to-VO progresses across the argument-type contexts at the same rate ("Constant Rate Effect" (A. S. Kroch, 1989) and subs).
- But we did not account for how Subject-Aux inversion under V2 interacts informationally with OV/VO.
- We now consider Icelandic main clauses with adjunct XPs...

Examples: adjunct fronting under V2

VO – no fronting

(3) Jón hefur keypt bók
Jón has bought a.book
í dag.
in today
'Jón has bought a book today.'

OV – no fronting

(4) Þessi sami riddari vildi
This same knight wanted
eigi gaum gefa
not attention give
'This same knight didn't want to pay attention [to...].'
(1475.AEVINTYRI.NAR-REL,.933)

VO – adjunct fronting

(5) Í dag hefur Jón
in today has Jón
keypt bók.
bought a.book
'Today, Jón has bought a book.'

OV – adjunct fronting

(6) Aldrei hafði kóngsson
never has a prince
slíkan grip séð.
such a.thing seen
'Never has a prince seen such a thing'
(1450.VILHJALMUR.NAR-SAG,21.327)

Diachronic Study 2: Adding V2

- From earlier study, constituent order affects distribution uniformity.

Diachronic Study 2: Adding V2

- From earlier study, constituent order affects distribution uniformity.
- Remember: syntactic constituents occur at different frequencies, which means they have different information content values.

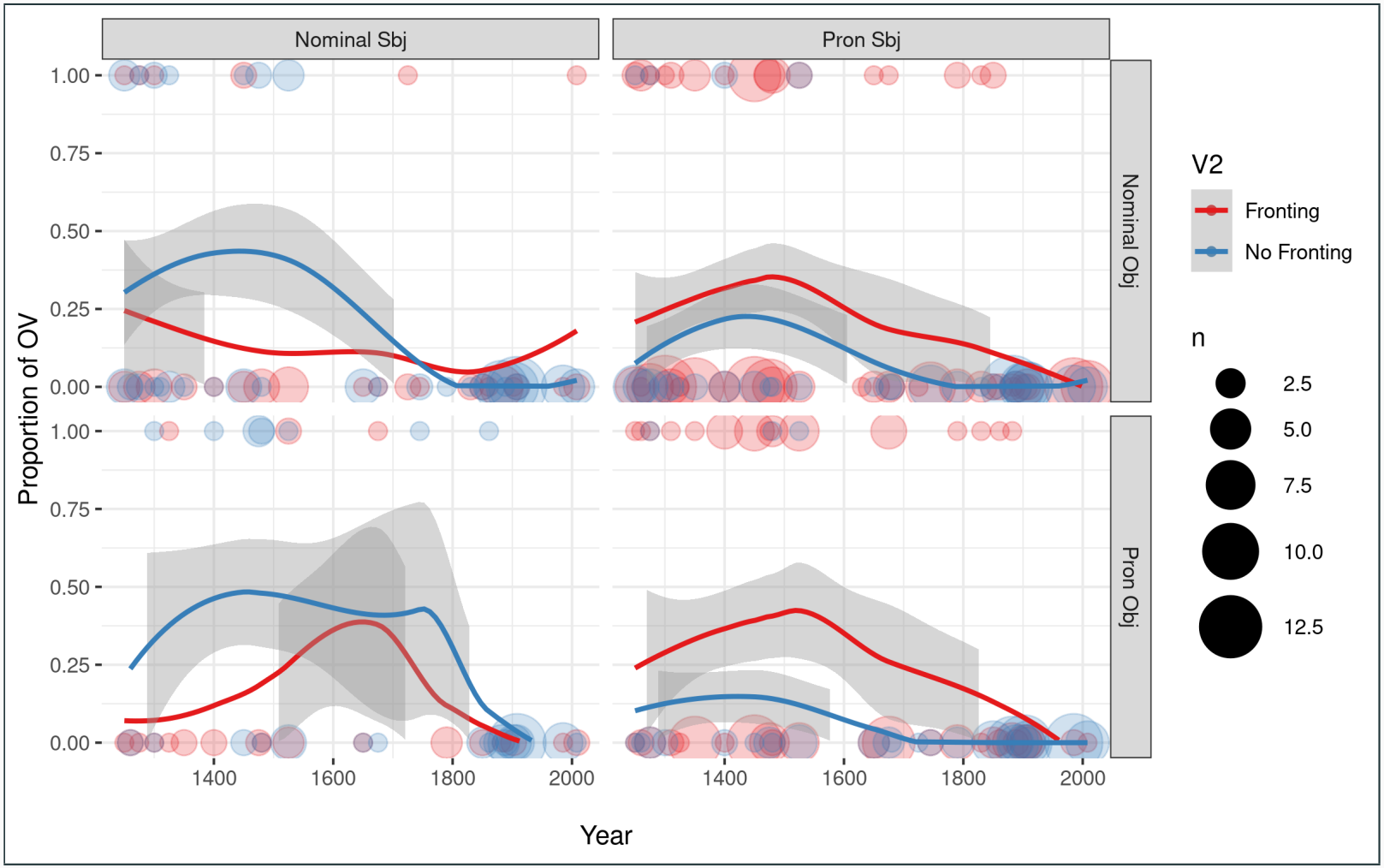
Constituent Type	**Average Information Content** (PPCMBE; A. S. Kroch et al., 2016)
Pronominal DP	low ($\approx$ 11.7 bits)
Aux	low-ish ($\approx$ 12.4 bits)
Lexical Verb	mid ($\approx$ 13.5 bits)
Nominal DP	high ($>$ 13.7 bits)

Finally, Adjunct XPs are comparable to (not least because in many cases they include) Nominal DPs, and are therefore treated here as high

Study 2: Adding V2

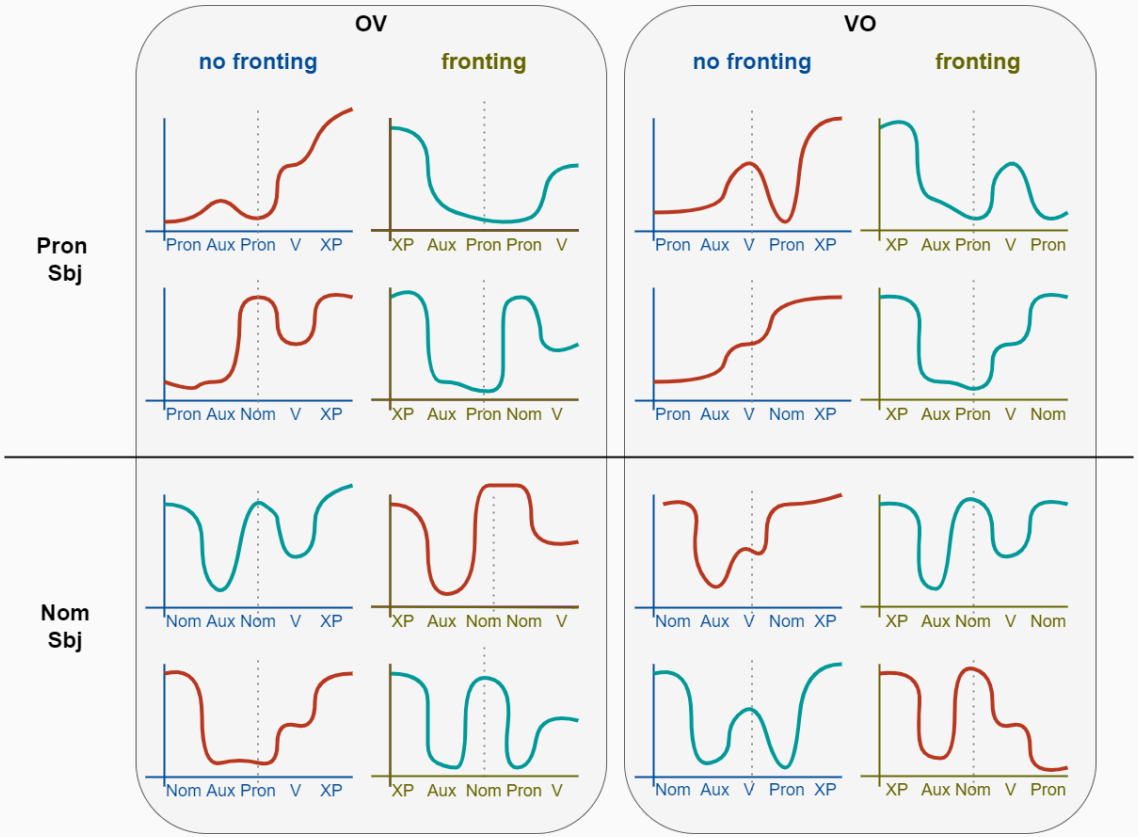
- We might also expect that V2 will also give rise to information theoretic effects that interact with OV/VO, as argument type did in previous study.
- So that's what we looked for...

Preliminary:
Is V2 a "context" for OV/VO (in the CRE sense)?



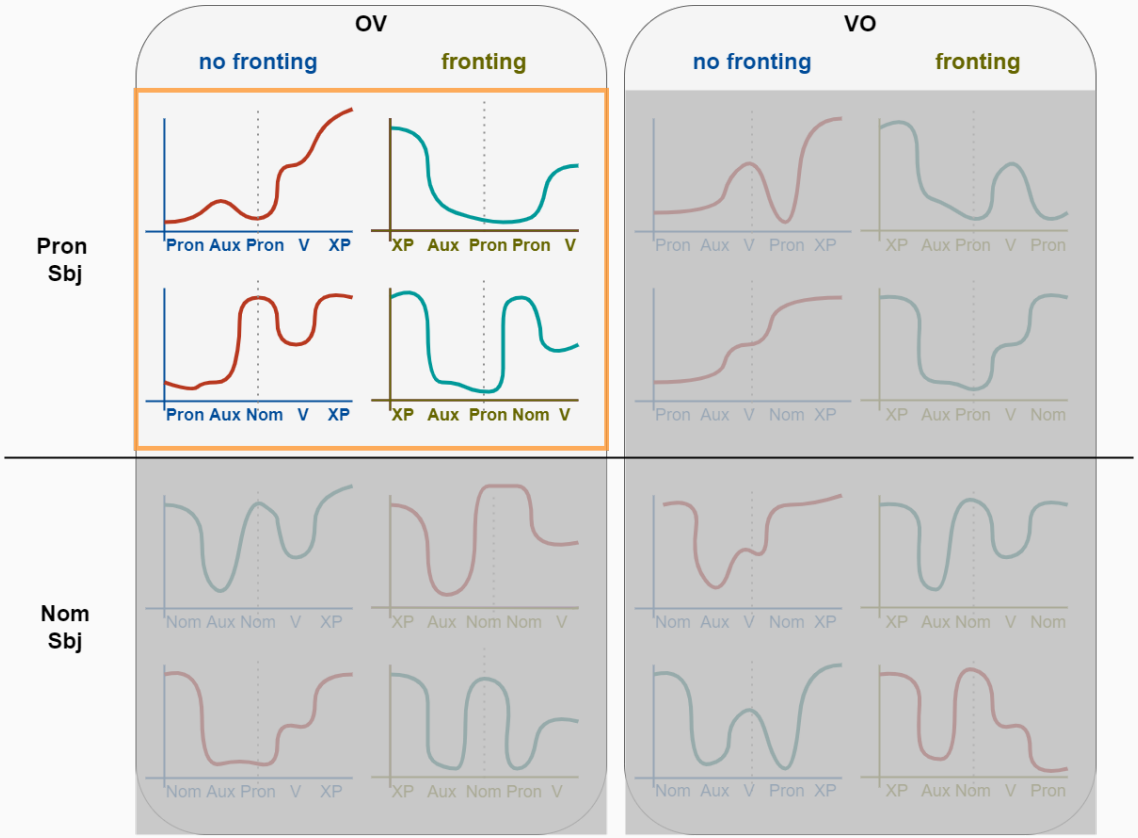
- Predictions not borne out if V2-fronting conditions choice of OV/VO.

Study 2 Predictions
Speakers deploy fronting when it yields more uniformity



If speakers *deployed* adjunct-fronting to maximise information uniformity (given other parameters), they would conform to this pattern

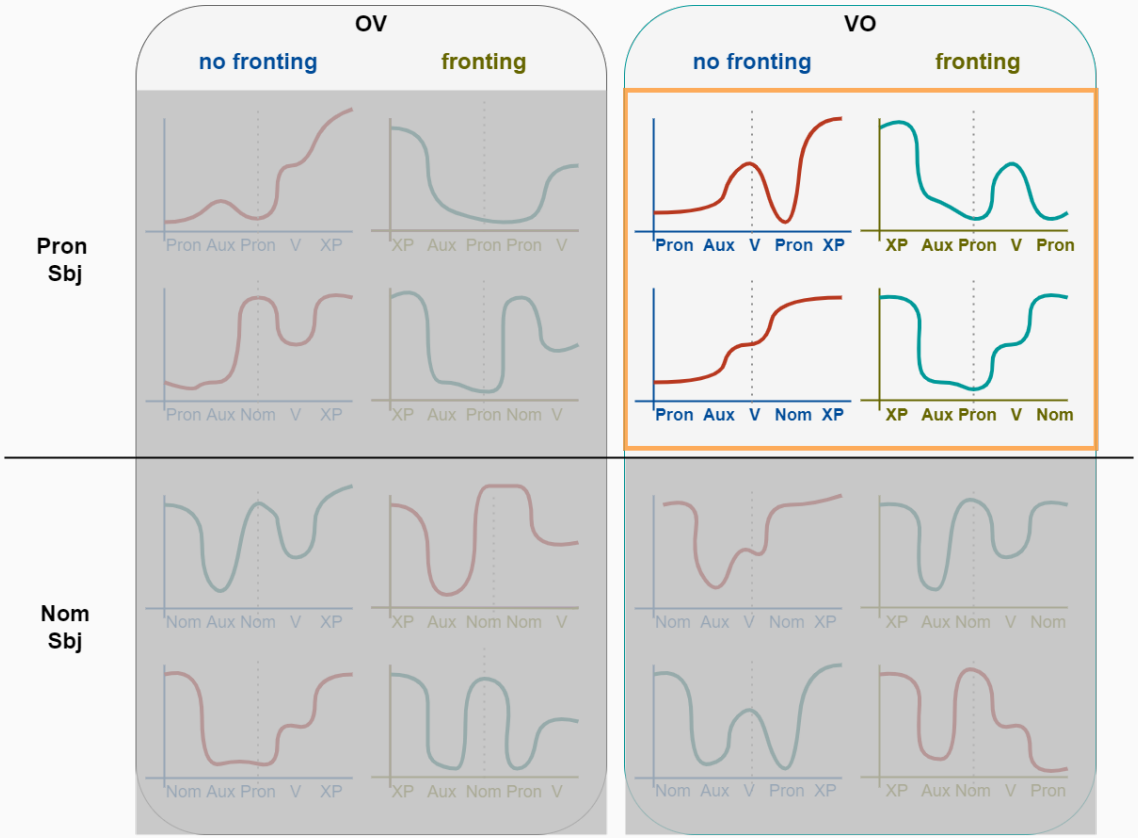
Study 2 Predictions
Given OV and Pron Sbj:



+ Pron Obj:
  - Fronting helps balance out the unavoidable 3-unit informational troughs (Pron-Aux-Pron & Aux-Pron-Pron)

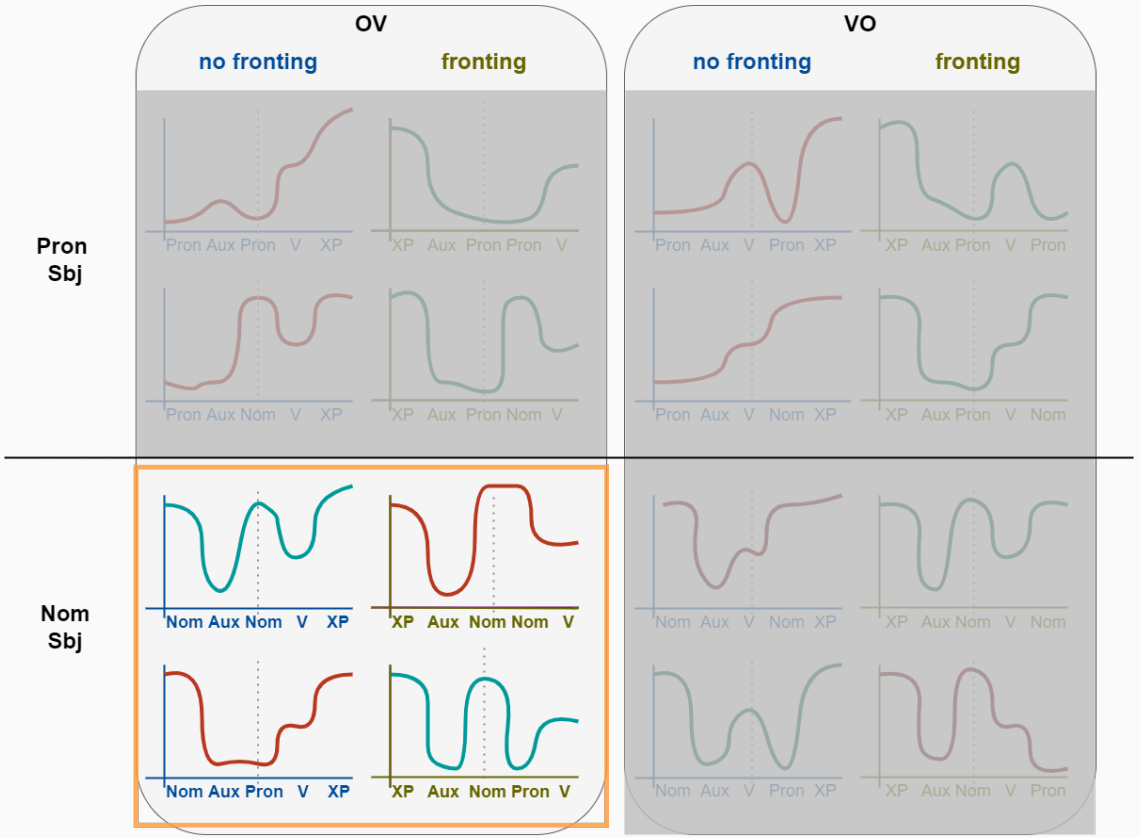
+ Nom Obj:
  - Fronting means avoidance of clustered information peak (Nom-V-XP)

Study 2 Predictions
Given VO and Pron Sbj:



+ Pron Obj:
  - Fronting may yield a bit more uniformity
+ Nom Obj
  - Pressure from 2-unit informational troughs and peaks (Pron-Aux & Nom-XP)
  - Maximally asymmetric distribution can be avoided by fronting

Study 2 Predictions
Given OV and Nom Sbj:

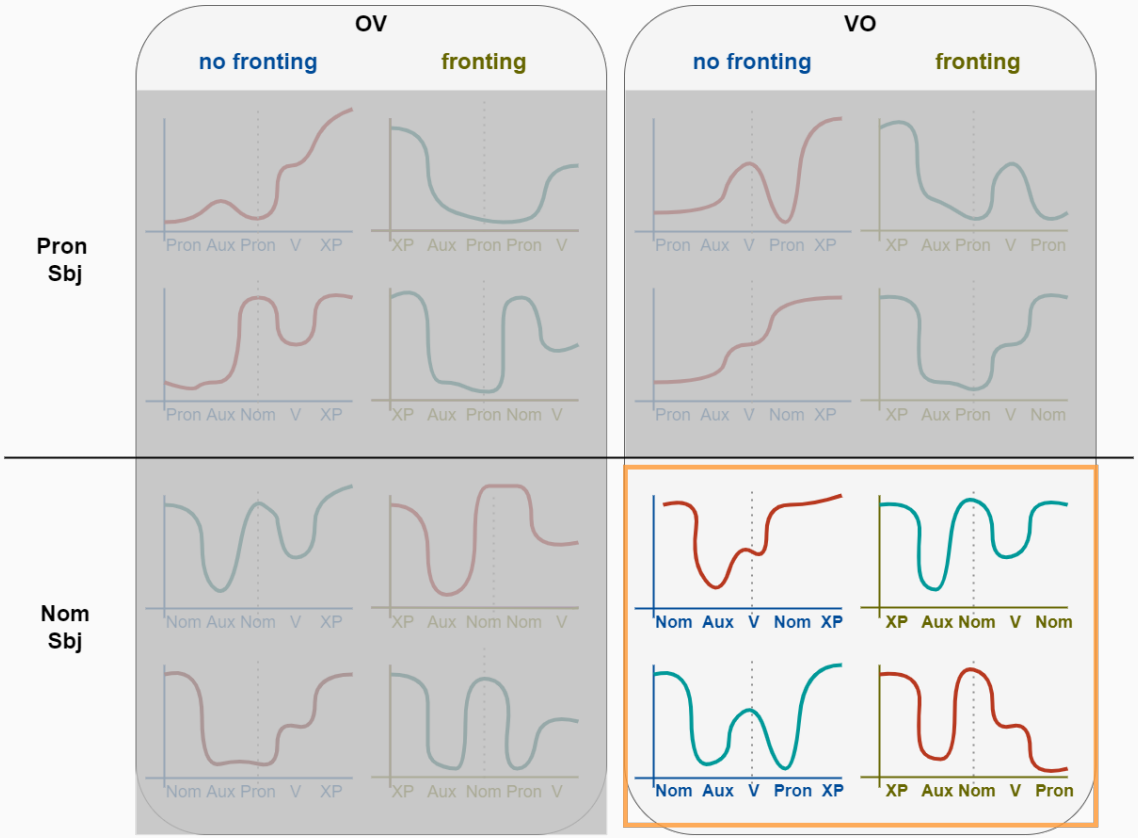


Distribution symmetries aren't so obviously different, so pressures probably aren't strong. But:

+ Nom Obj:
  - Fronting yields 2-unit informational peak (Nom-Nom), so *may* be disfavoured

+ Pron Obj:
  - Fronting *might* be more uniform (if not more symmetrical)

Study 2 Predictions
Given VO and Nom Sbj:



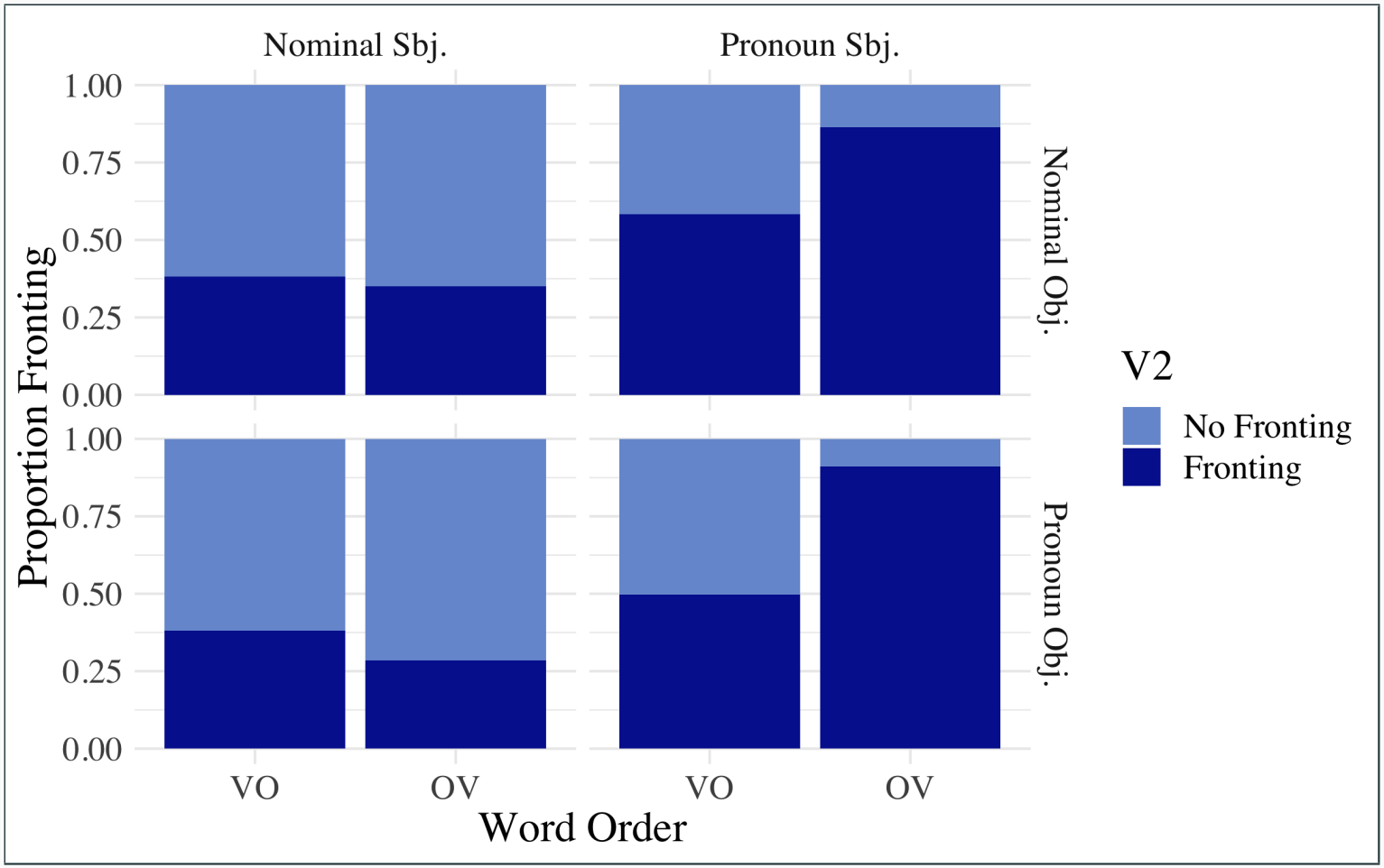
Distribution symmetries not obviously different, so pressures probably aren't strong. But:

+ Nom Obj:
  - Fronting *may* yield slightly more uniform distribution (by avoiding clustered peak of Nom+XP)

+ Pron Obj:
  - Non-fronting might be more symmetrical

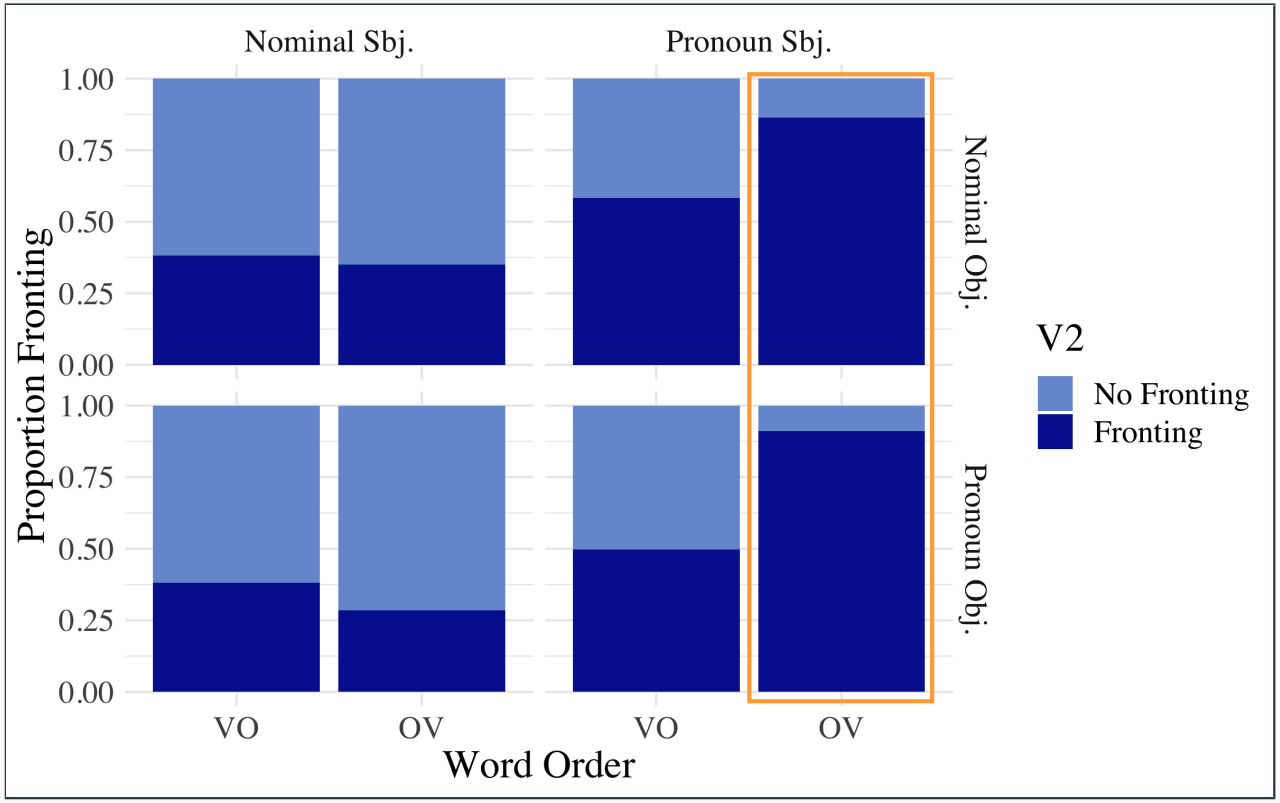
Study 2 Predictions
Speakers deploy fronting when it yields more uniformity

Study 2 Results



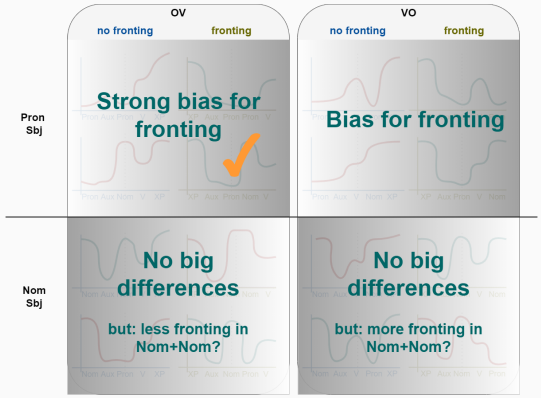
- Overall, fronting appears where we'd expect if speakers are trying to maximise the uniformity of information distributions with the order of constituents.

Study 2 Results: Given OV and Pron Sbj

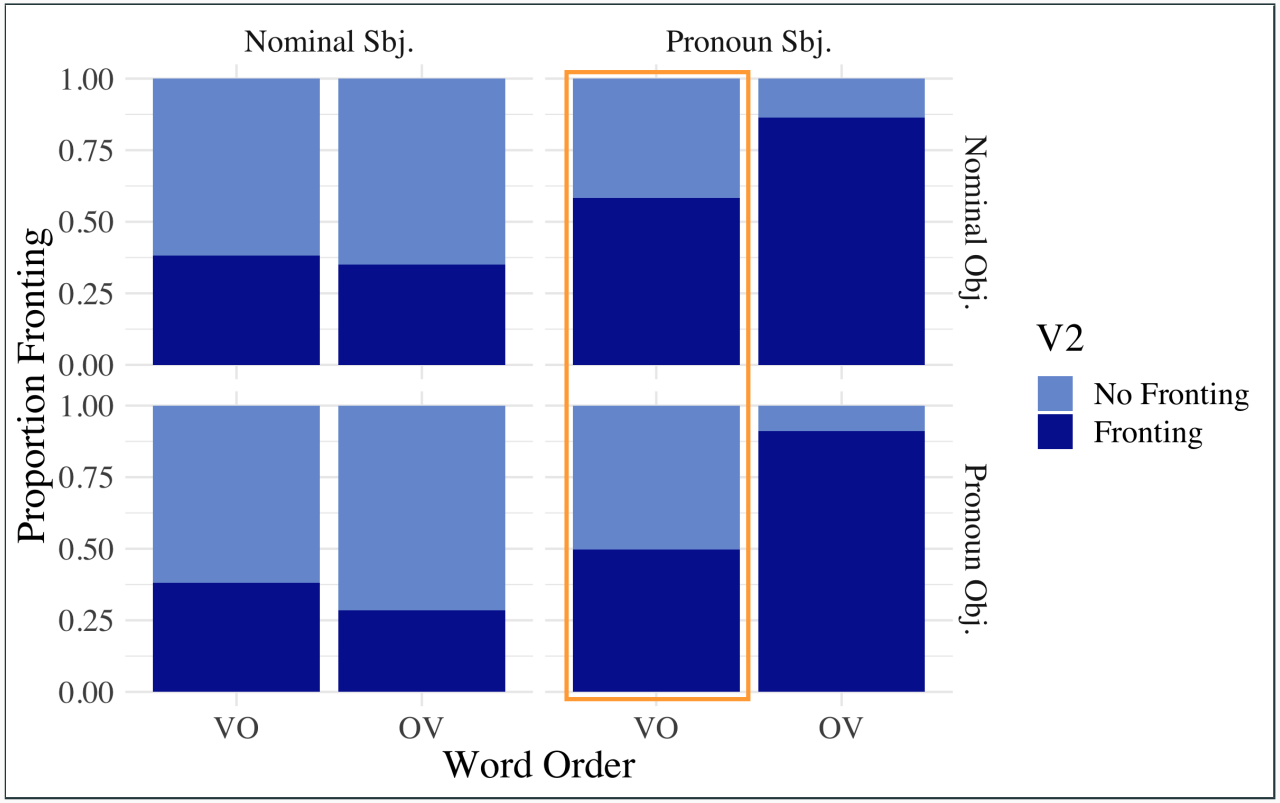


Two pressures for fronting

- Pron Sbj + Nom Obj: Avoid long peak (Nom-V-XP)
- Pron Sbj + Pron Obj: Avoid maximal asymmetry

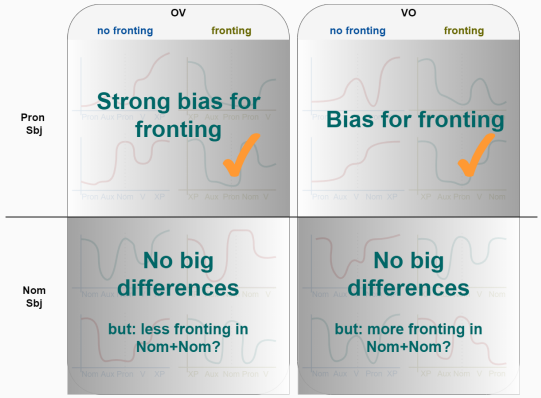


Study 2 Results: Given VO and Pron Sbj

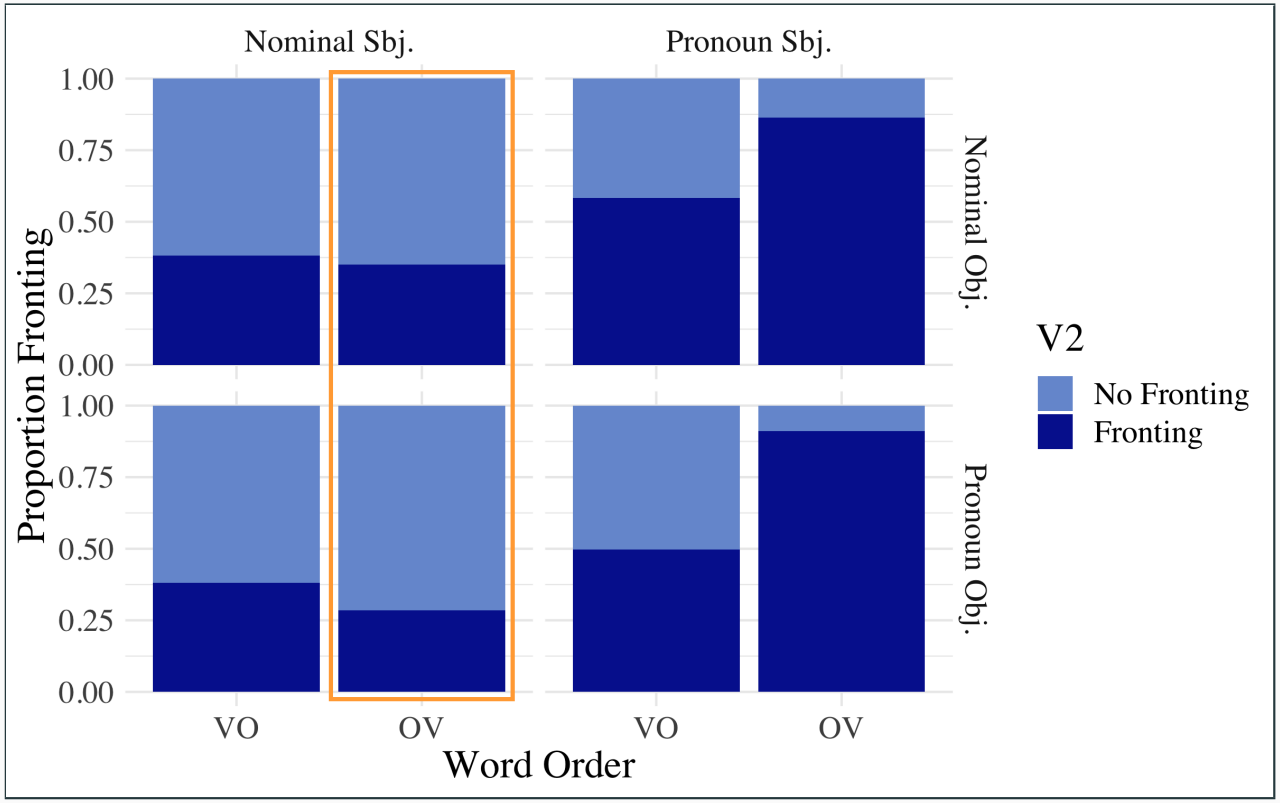


Bias for fronting

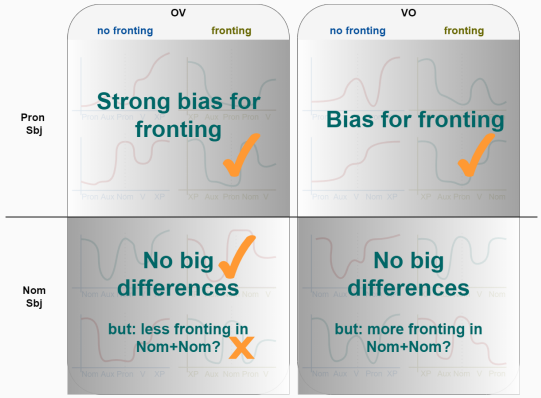
- Stronger (>50%) for Pron Sbj + Nom Obj
- Avoidance of maximal asymmetry



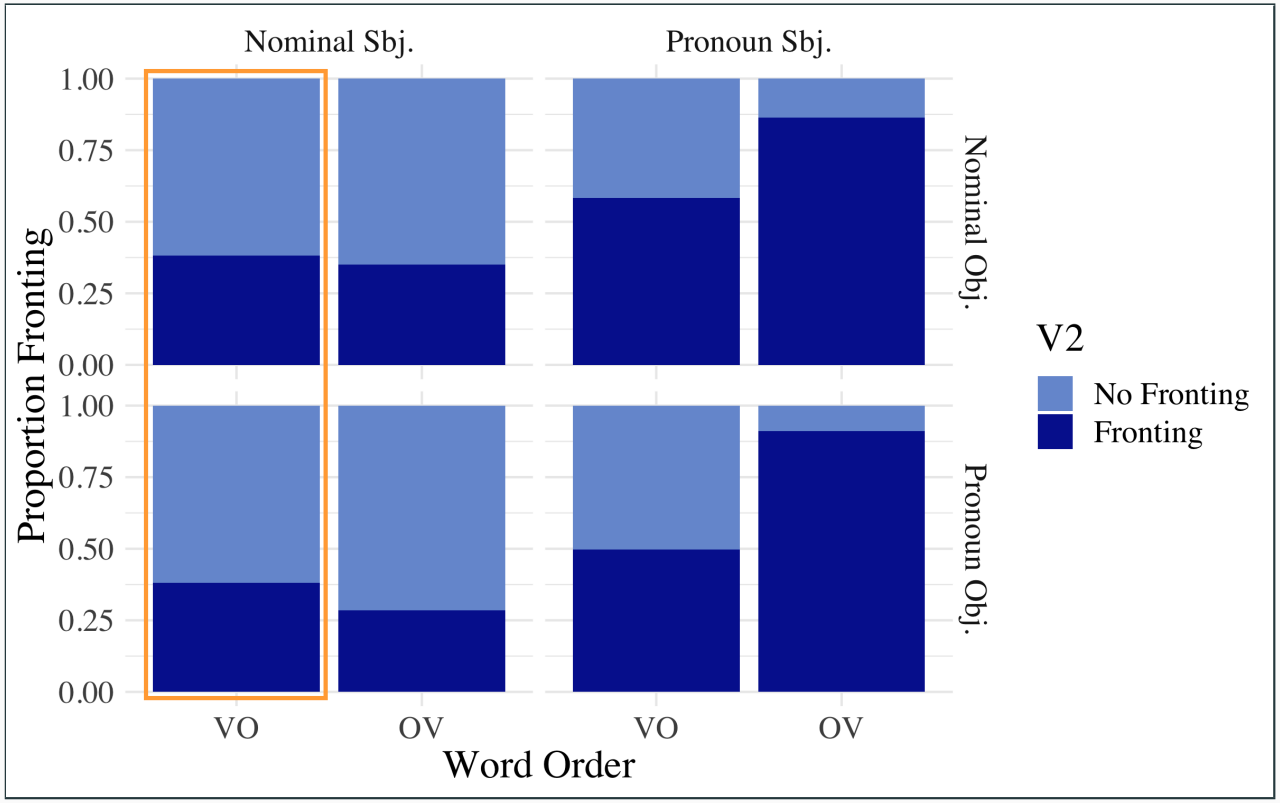
Study 2 Results: Given OV and Nom Sbj



- Less fronting than in VO overall
- No big difference between Pron/Nom Objs, but not the direction we'd expected (less fronting to avoid Nom+Nom)



Study 2 Results: Given VO and Nom Sbj



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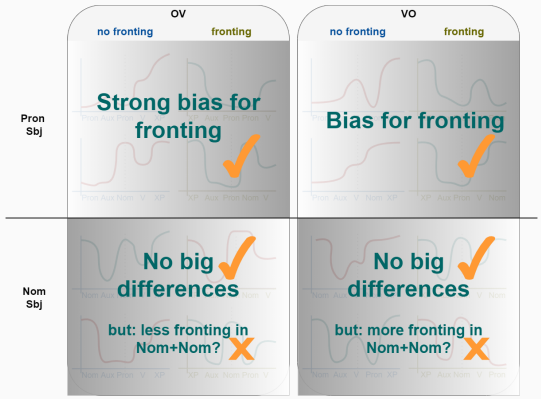

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- **The Kauhanen-Walkden Theorem** (aka Time Separation Theorem) (Kauhanen & Walkden, 2018): time separation is strictly bounded.
- Maximum/minimum uniformity is strictly bounded.

Information Uniformity and Language

What It's For: Noise Resistance

Theoretical excursus: language and ruin

What It Does: Syntactic Planning

Diachronic Study 1: Information Theoretic Constant Rate Effects: OV to VO

Diachronic Study 2: Adding Adjunct Fronting with V2

Theoretical Implications

Further Work: English topicalization is disappearing

Conclusions and Lots More To Do

Further Work: Non-V2 Object Topicalization

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(11) Joel she likes (but Bill she doesn't).

(12) Joel the cat likes.

(13) Joel Viola likes.

(14) Joel, Viola likes.

From PPCMBE, nominal objects ($\chi^2 = 260$, $p < 2 \times 10^{-16}$):

	Fronted	In Situ	Prop. Fronted
Pron Sbj	631	20,071	0.031
Nom Sbj	119	16,808	0.0071

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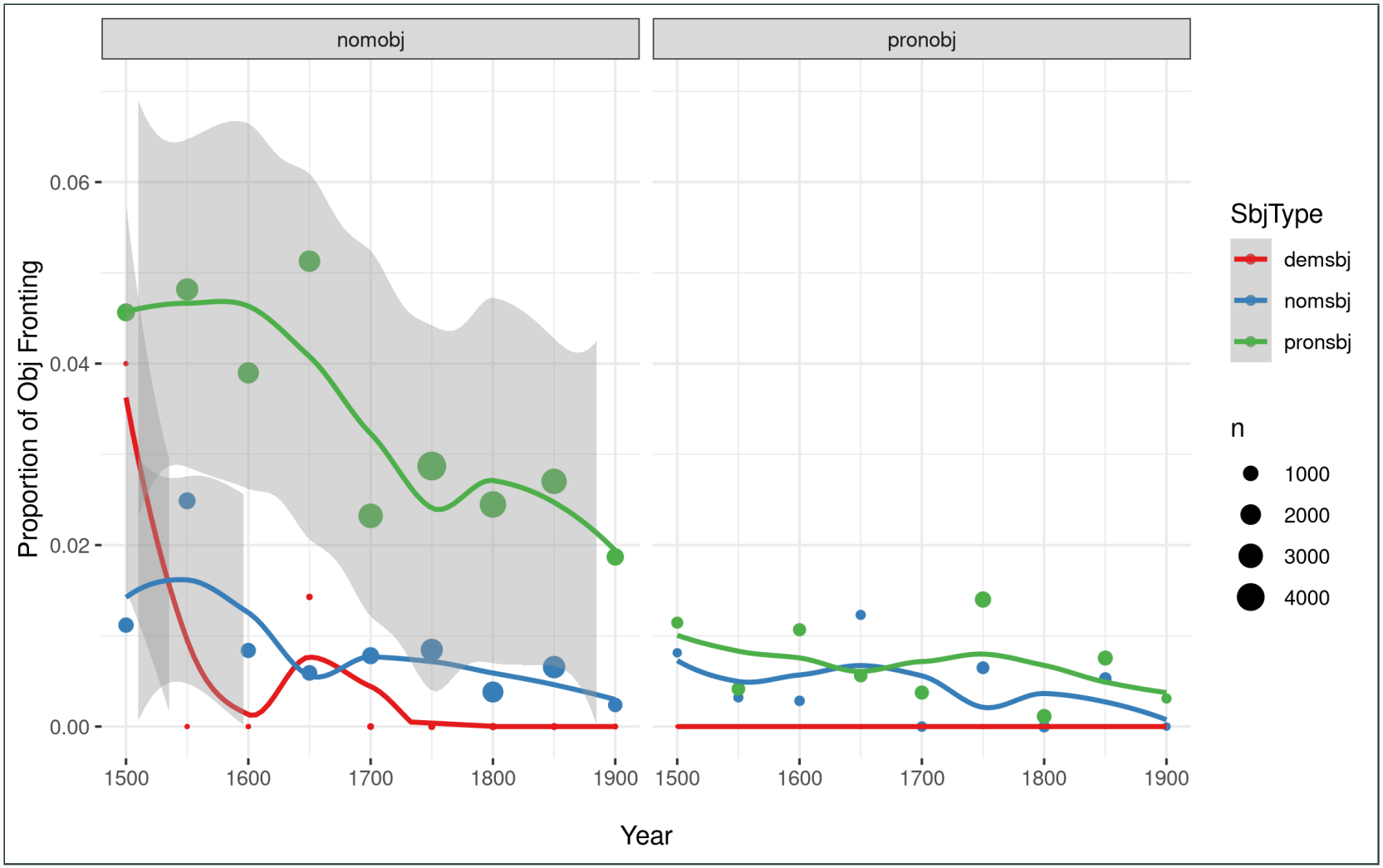
  - The two syntactic forms overlap in function (Prince, 1998), and therefore compete in use (A. S. Kroch, 1994).
  - The competition is mitigated by specialization, but along a continuous dimension, and so total specialization is impossible and slow change results (Wallenberg, 2016).

Further Work: Non-V2 Object Topicalization



Note: significant effects of **Year, Obj, Sbj**, sig **Obj:Sbj** interaction, but no sig Obj, Sbj interactions with Year (Constant Rate Effect).

Further Work: Non-V2 Object Topicalization

- Is accent clash continuous or categorical?
- Speyer suggested two levels of accent clash, but not more.
- Both dimensions are likely in operation, but can they be distinguished?

  (15) Joel, Bob likes.

  (16) Joel, the cats like.

- Calibrated DORM and accent clash are both bounded dimensions.

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- **Other Implications:** derivational ordering effects, where sbj/obj type and perhaps headedness precede movement.
- Minimizing DORM is a tough planning problem, making it hard to do with other constraints.
- **Exploratory Work:** information uniformity can be a continuous dimension of specialization, slowing change in non-V2 topicalization.

Future Work

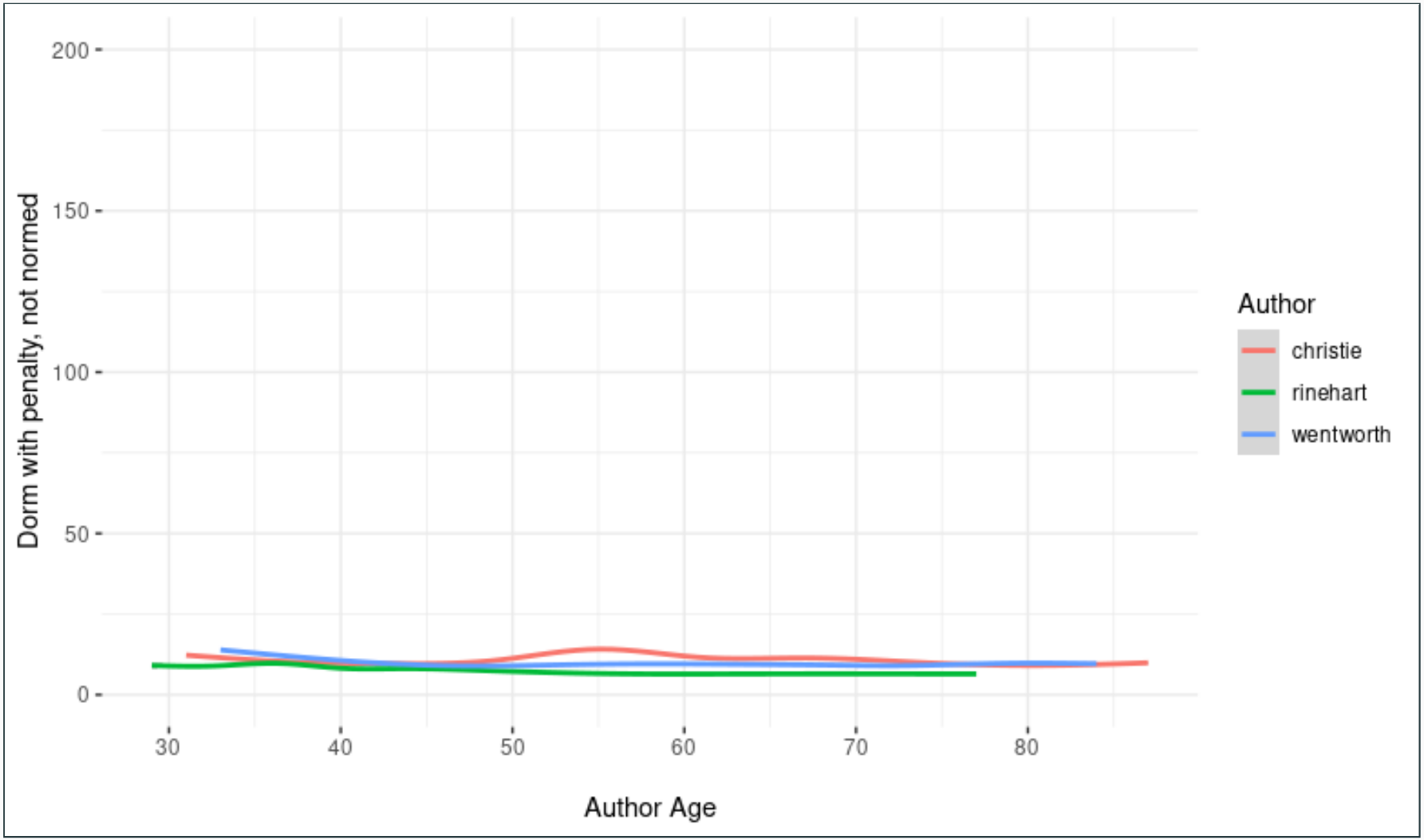
- Estimate the threshold for information loss?
- Nail down Icelandic results with the Gigawork Icelandic Corpus.
- Nail down English results with lemmatized PPCHE.
- Experiment with Calibrated DORM and conditional entropies.
- Experiment with contextual probabilities derived from word-embeddings (e.g. RoBERTa embeddings), to model left- and right-context.
- DORM and individual differences: ageing, Parkinsons.

Acknowledgements, and thanks for listening!

Thank you to my collaborators, audiences at NYU, Saarbrucken, Manchester, Konstanz and the late great Anthony Kroch.

Questions?

More Exploratory Work: Anything to See Here?
3 Writers; 200,000-500,000 sentences each



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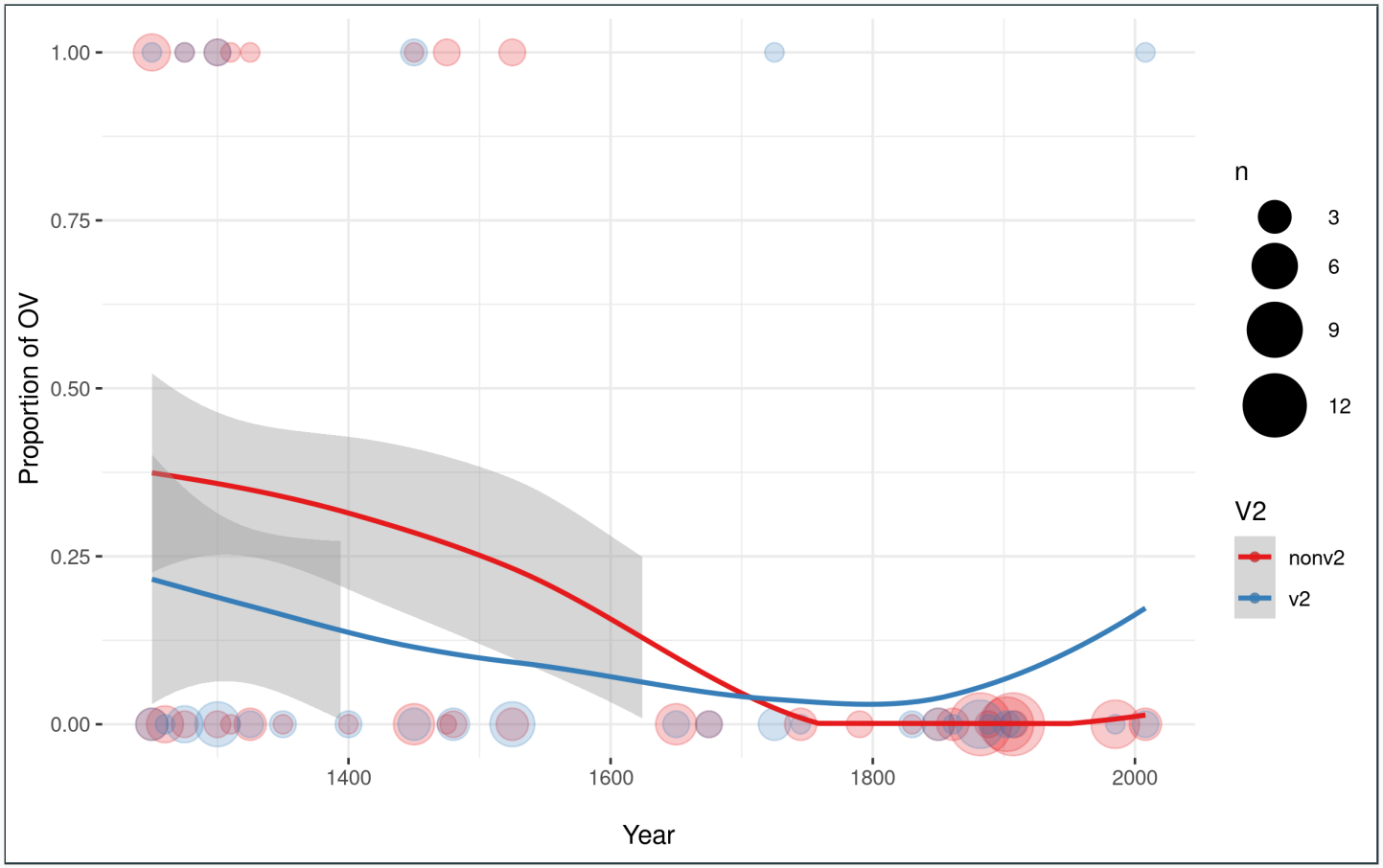
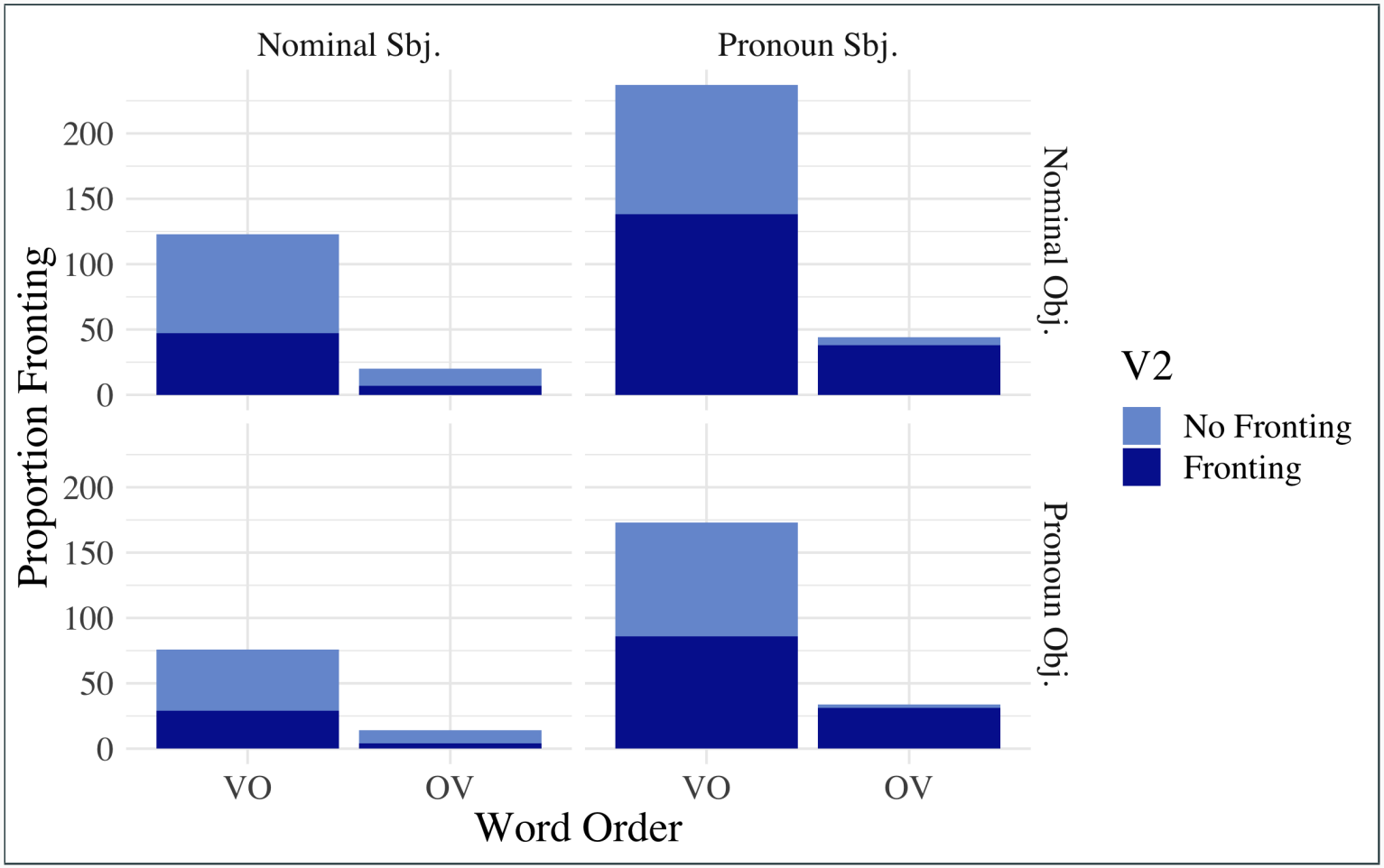
Study 2 Results:
OV disfavoured by adjunct-fronting through OV-to-VO



Study 2 Results:
Count data for V2 in Icelandic