Consolidating linguistic tendencies at the level of individuals and populations for Zipf's Law of Abbreviation

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Background

- Zipf's Law of Abbreviation: frequent forms are shorter
- Inverse relationship between *use* and *linguistic reduction*
- Kanwal et al. (2017): study what drives this relationship by controlling for communicative pressures

Background

Zipf's Law of Abbreviation: frequent forms are shorter
at the level of languages

Zipf (1935): The Psycho-Biology of Language

Sigurd et al. (2004): Word length, sentence length and frequency – Zipf revisited

Piantadosi et al. (2011): Word lengths are optimized for efficient communication

Ferrer-i-Cancho et al. (2013): Compression as a Universal Principle of Animal Behavior

…

Background

Inverse relationship between *use* and *linguistic reduction*
across strata

Clark & Wilkes-Gibbs (1986): Referring as a collaborative process

Kim et al. (2011): Phonetic convergence in spontaneous conversations as a function of interlocutor language distance

Pickering & Ferreira (2008): Structural priming: A critical review

Hawkins et al (2017): Convention-formation in iterated reference games

...

Background

Kanwal et al. (2017) study what drives the relationship between frequency and form by controlling for communicative pressures **at the level of dyads**

Kanwal et al. (2017): Zipf's Law of Abbreviation and the Principle of Least Effort: Language users optimise a miniature lexicon for efficient communication. *Cognition*

The study I'll build on today

Modest re-analysis of Kanwal et al. (2017) to

- explicitly model subjects' behavior
- gain insight into how population-level, dyadic-level and individual-level relate to each other; and how to possibly begin to link them

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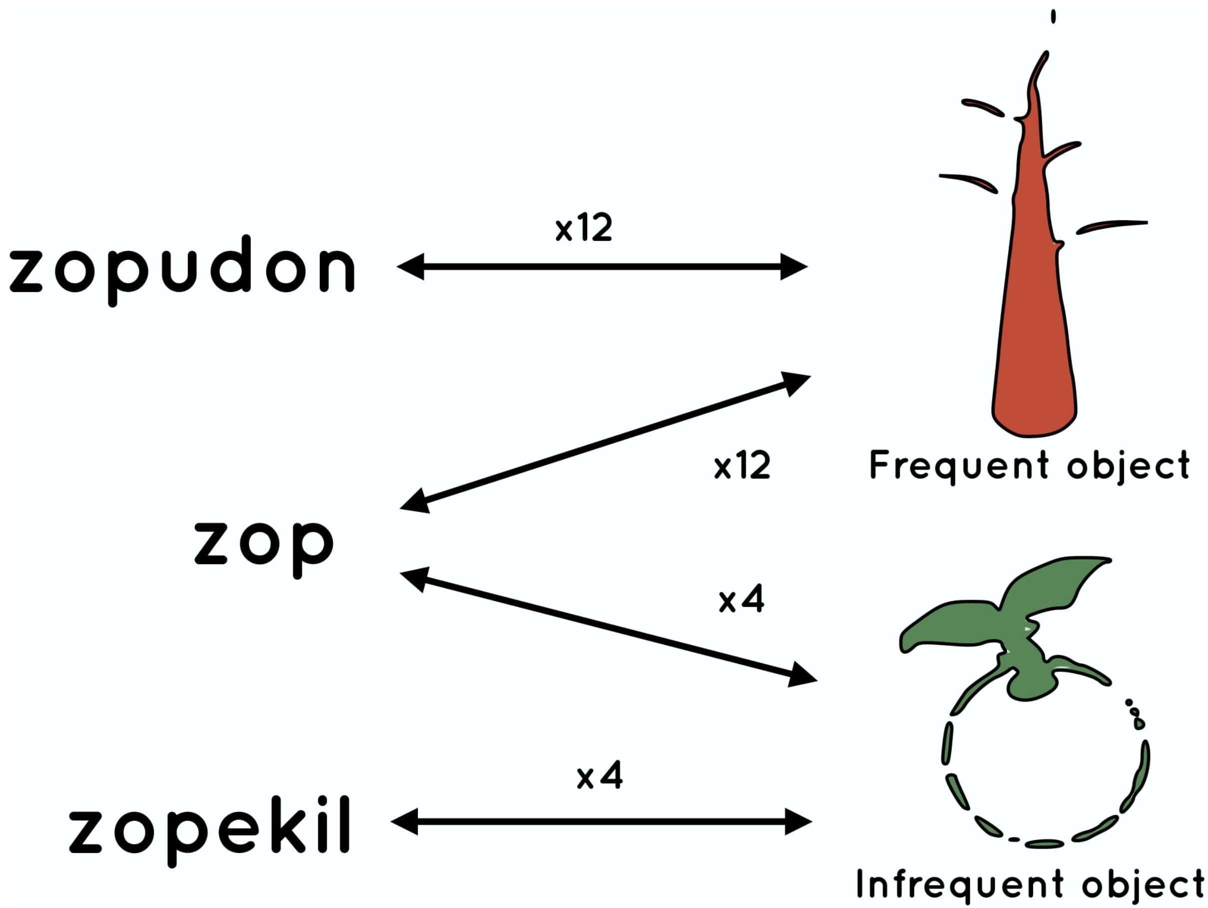
Brochhagen (2021): Brief at the risk of being misunderstood: Consolidating population- and individual-level tendencies. *Computational Brain & Behavior*

Experimental setup

Kanwal et al. (2017) condition 4

Training (miniature lexicon acquisition)



Testing (condition 4)

- Pair subjects and let them interact for 62 trials

  32 sender trials, 32 receiver trials (alternating)

- Same object frequencies as in training

- Message transmission time is proportional to message length
  $\rightarrow$ Sending ambiguous *zop* takes $\frac{3}{7}$ of the time of alternatives

- The fastest & most accurate pairs win a prize
  $\rightarrow$ Pressure to use short form if you believe your interlocutor will get it

Kanwal et al's analysis

- Logistic regression with short name as binary response
- Object frequency (frequent/infrequent), trial number, and their interaction as fixed effects
- By-participant intercepts and slopes as random effects for object frequency and trial number

Finding: Positive effect of trial number on short form use only for frequent object

Some open questions

1. How did individual speakers behave?
    - Change over time
    - On what strategies did they converge
2. How did their behavior compare to that of their partners?
3. How do population-level predictions compare to (1) and (2)?
4. How can we relate trends from individuals and dyads to a community of speakers?

Some model desiderata

- Accommodate for multiple association patterns (cf. Parikh 2000)
- Accommodate for signaling behavior that can change as a function of interlocutor's behavior

Parikh (2000): Communication, Meaning, and Interpretation

Brochhagen (2017): Signalling under Uncertainty: Interpretative Alignment without a Common Prior

Hawkins et al (2017): Convention-formation in iterated reference games

Speaker model

We return to model identifiability between Brochhagen (2017) and Hawkins et al. (2017) at the end

Intuitions

- RSA-style choice functions (*soft-max*; *Luce's rule*; *rationality parameter*)

  "If I believe you expect one object over the other (by a large enough margin) I will use the ambiguous but preferred form to convey that object. Otherwise, I'll play it safe."

- Players can change beliefs over time, based on past success/failure using an ambiguous form

  "You interpreted my use of an ambiguous form in a certain way before. Consequently, I believe you expected this object (and therefore I will be more likely to signal this object with this expression later)"

Parameters to estimate from the data

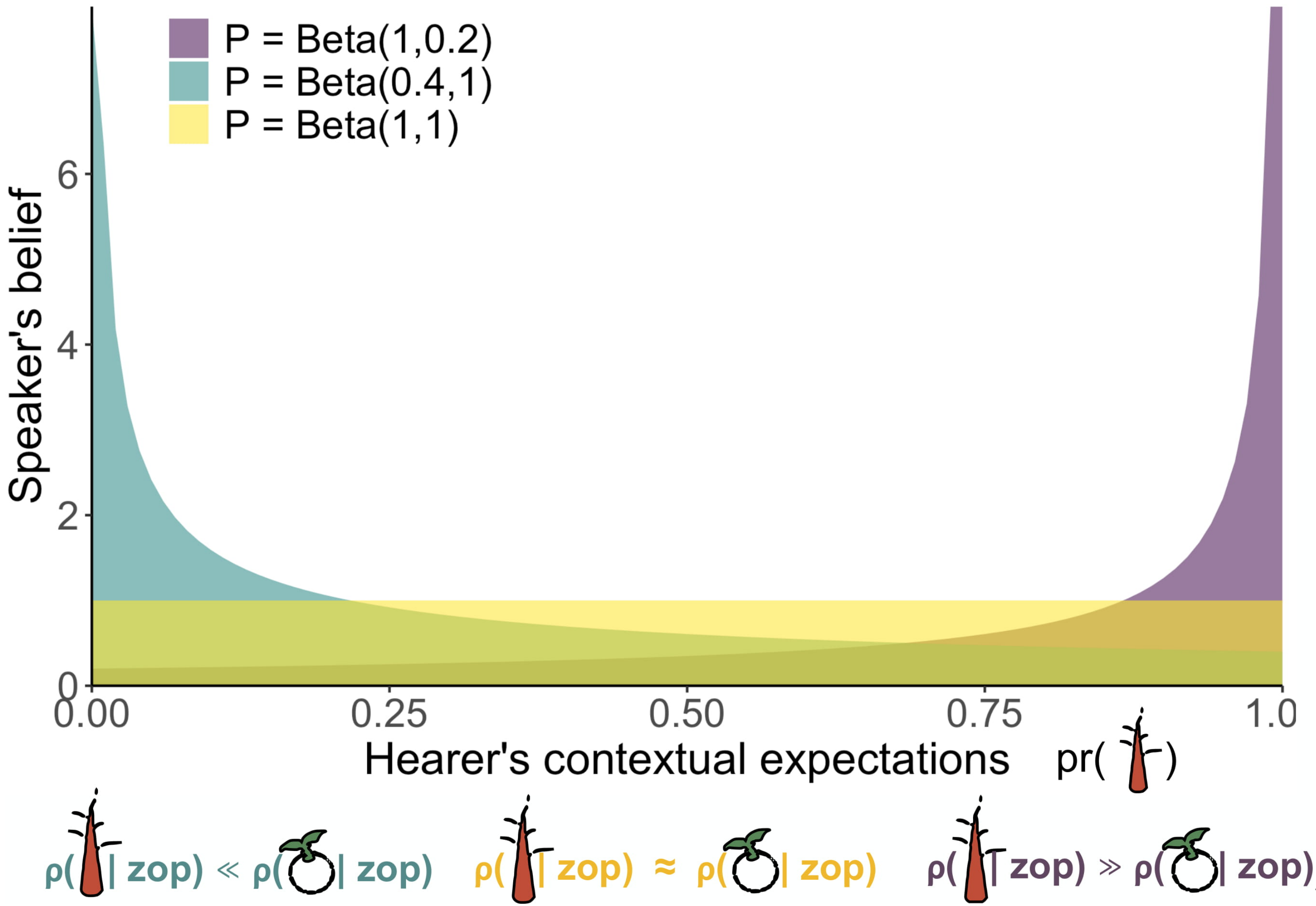
λ usual soft-maximization parameter, $\lambda \geq 0$

$pr \sim P$

less usual beliefs over (non-common) prior

$P = \text{Beta}(\alpha, \beta)$

Latent beliefs over expectations



The full speaker model

$$\rho(r \mid m; pr) \propto L(r, m)\ pr(r),$$
$$\sigma(m \mid r; P) \propto \exp(\lambda((\int P(\theta)\rho(r \mid m; \theta) d\theta) - c(m)))$$

and

$$P_{t+1}(pr \mid w(r); m) \propto (\sum_{r' \in w(r)} \rho(r' \mid m; pr) P_t(pr)),$$

with $w(r) = \{r\}$ if the interaction was successful and $R \setminus \{r\}$ otherwise.

Parameters to estimate from the data

λ	soft-maximization parameter, $\lambda \geq 0$
$P = \mathrm{Beta}(\alpha, \beta)$	beliefs over (non-common) prior

Models

Overview

Model	Population parameters	Individual parameters
NoPool	--	$\lambda_i, \alpha_i, \beta_i$
FullPool λ, α, β	α, λ, β	--
FullPool λ	λ	α_i, β_i
HM λ	μ_λ	$\lambda_i \sim N(\mu_\lambda, 2)$ α_i, β_i
HM λ, α, β	$\mu_\lambda, \mu_\alpha, \mu_\beta$	$\lambda_i \sim N(\mu_\lambda, 2)$, $\alpha_i \sim N(\mu_\alpha, 2)$ $\beta_i \sim N(\mu_\beta, 2)$

Results

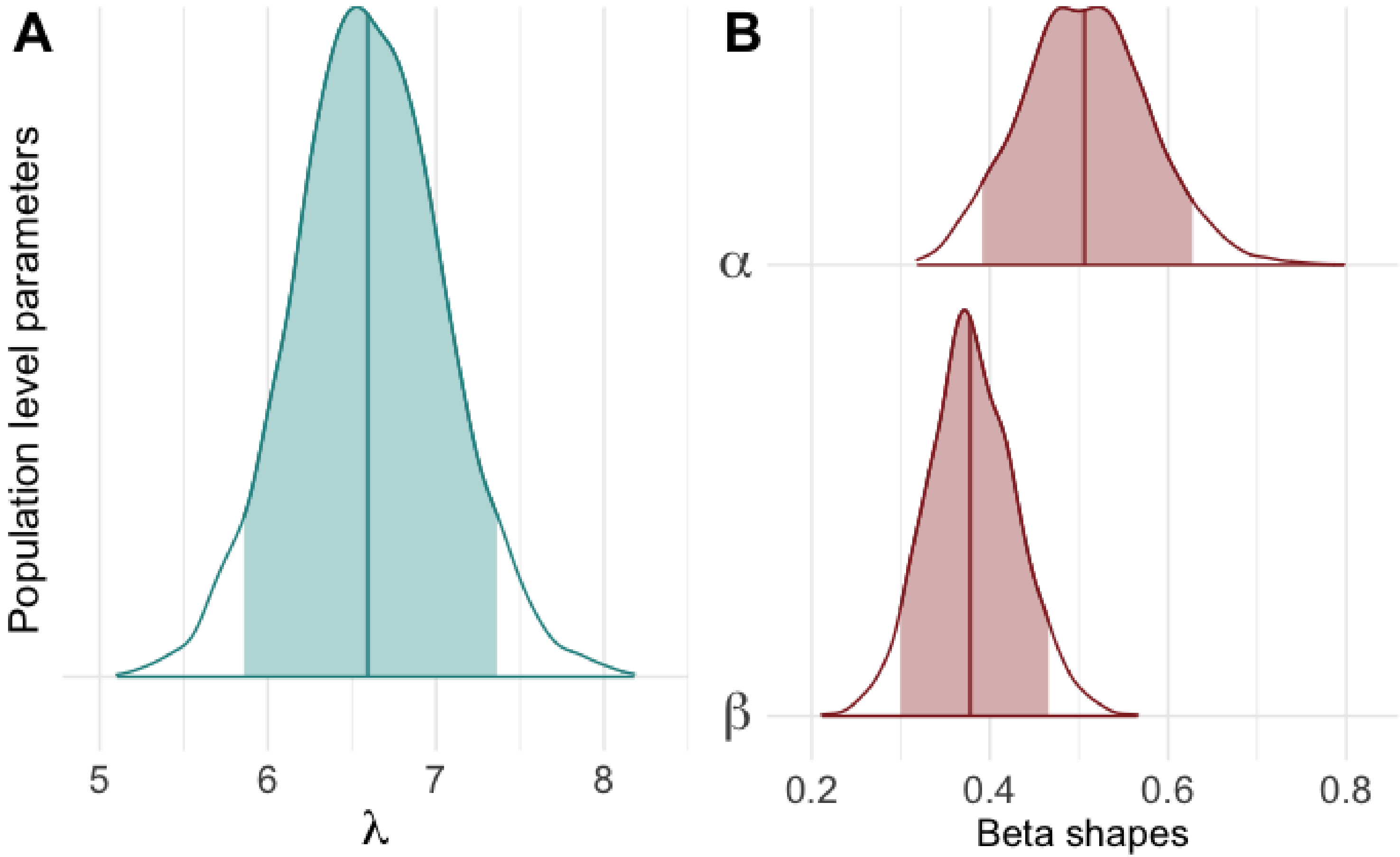
All models were diagnosed to rule out pathologies, and cross-validated.

Model comparison (full dataset)

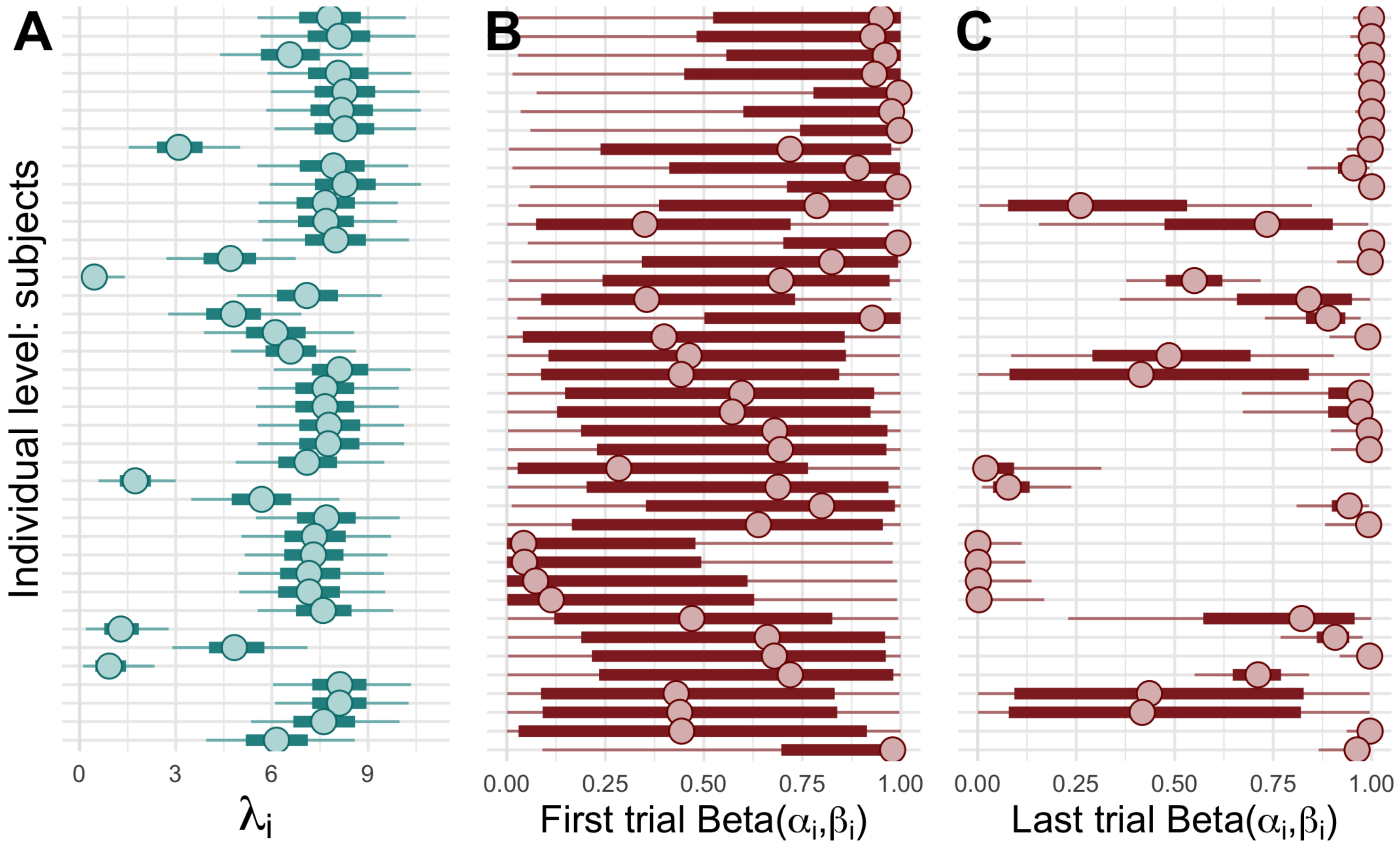
	ELPD diff (SE)	ELPD (SE)
HM λ, α, β	0.00 (0.00)	-471.63 (18.74)
HM λ	-38.16 (5.74)	-509.79 (18.24)
FullPool λ, α, β	-148.24 (12.17)	-619.88 (22.23)
FullPool λ	-154.21 (11.61)	-625.84 (21.24)
NoPool	-201.02 (34.55)	-672.65 (51.02)

Finding The best model, $HM_{\lambda,\alpha,\beta}$, is ranked first, also across other data subsets and when splitting dyads up

Population-level estimates



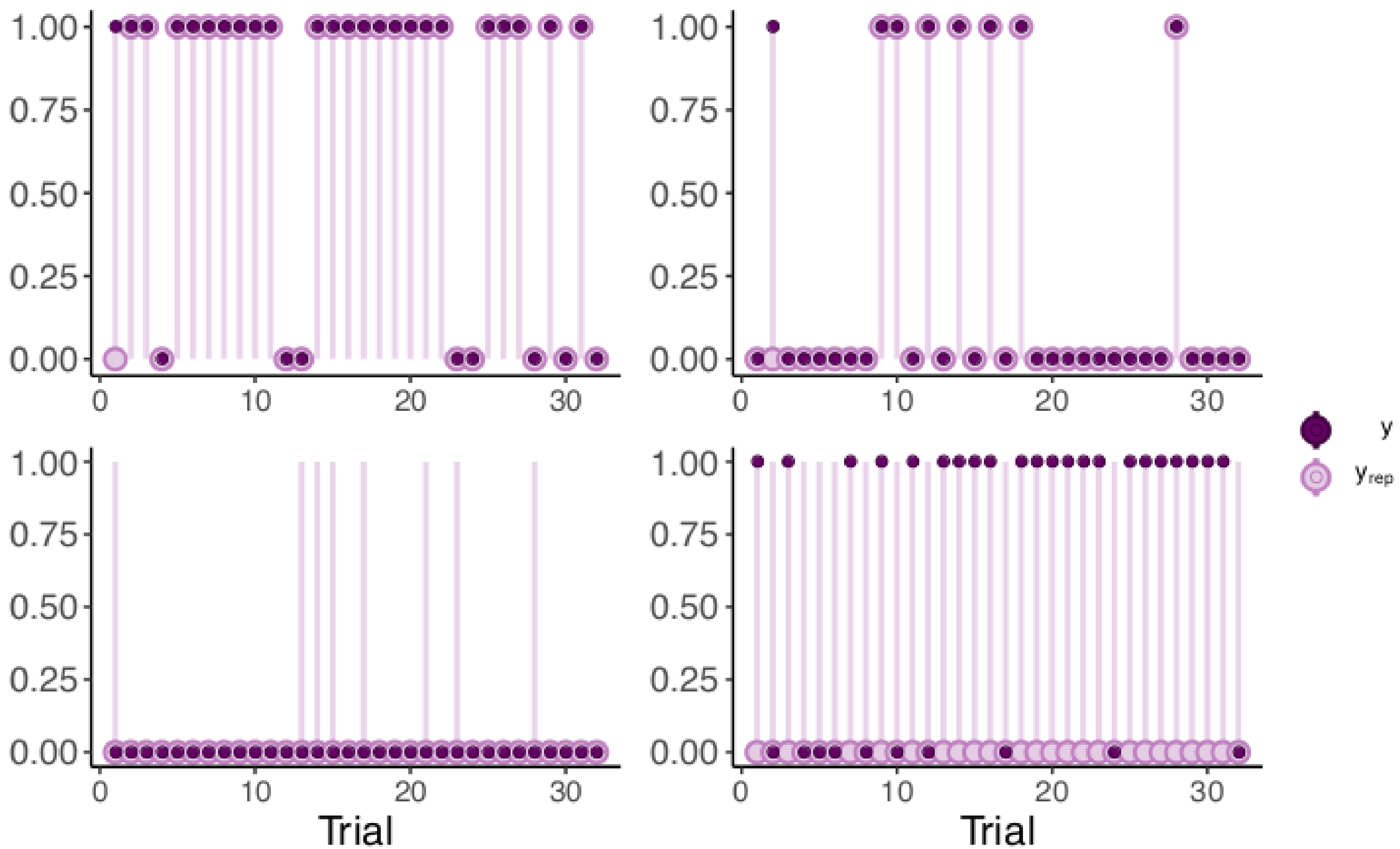
Individual-level estimates



Other relationships

- Individuals' expected rationality, $E[\lambda_i]$, correlates with number of successes ($r \approx 0.84$)
- Uncertainty about partner's expectations decrease over time ($r \approx -0.55$ between trial number and width of $P_i' s\ \ 0.89\%$ HPDI)
- Individual's beliefs diverge from population but grow closer to their partner's over time
($r \approx 0.56$ and $r \approx -0.23$, measured as Kullback-Leibler divergence)
- Subject's own beliefs stabilize over time
($r \approx -0.22$ between trial number and KL divergence)
- Neither divergence from population belief nor width of the P_i's HPDI are related to individuals' rates of success ($r \approx 0.004$ and $r \approx 0.02$)

Predictions



Accuracy

- $HM_{\lambda,\alpha,\beta}$ has RMSE of 0.32
- Always predicting short for frequent has RMSE of 0.63 (cf. Parikh 2000)
- Always predicting short for infrequent has RMSE of 0.78
- Always avoiding it has RMSE of 0.67

RMSE of best model reduces to 0.28 or 0.24 when excluding 4 or 8 worst-faring subjects

Taking stock

Narrower remarks

- Population-level trend is held up: short(er) patterns with more frequent
  - Rooted in expectations carried over from training
- Over time, individuals' established conventions of all flavors
  - frequent $\rightarrow$ shorter
  - infrequent $\rightarrow$ shorter
  - (in)frequent $\rightarrow$ longer
- This is one possible explanation of Zipf's Law of Abbreviation, but
  - Link between dyads and population missing
  - In particular: neutral alternatives

Broader remarks

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    - model variation at multiple levels
    - make relationship between levels explicit

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4. How dyadic-conventions find their way into the population is still a major and fascinating open question (cf. Hawkins et al. *forthcoming*)
5. Whether the association of the ambiguous form with the (in)frequent meaning is semantic or pragmatic in nature is another open question

Thank you

Data: http://datashare.is.ed.ac.uk/handle/10283/2702

Code: https://osf.io/7m9np/

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