Does the interpretation of null pronouns in Mandarin follow a Bayesian approach?

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Models in pronoun interpretation

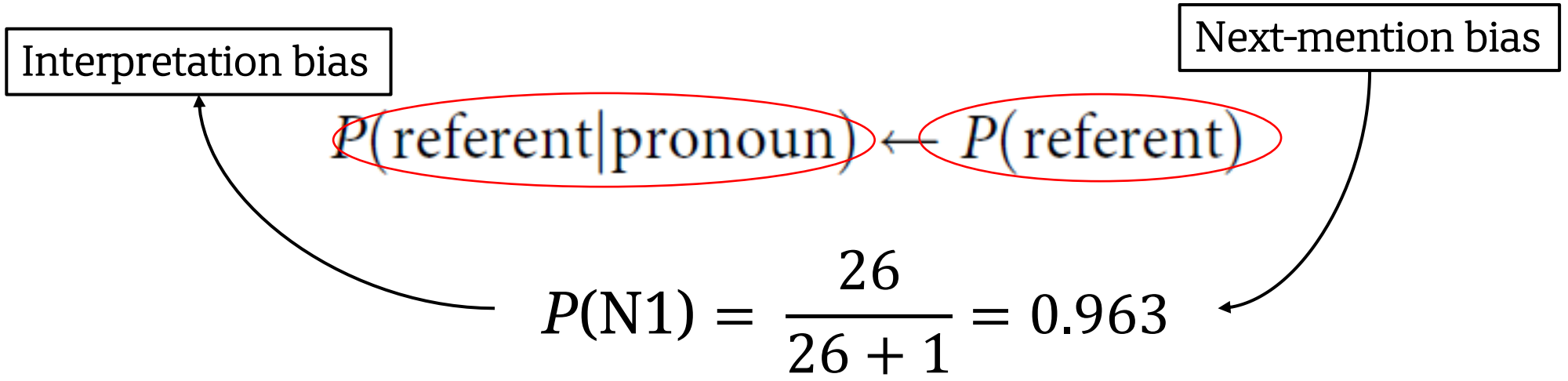
Expectancy Hypothesis
(e.g., Arnold, 2001)

Mirror Model
(e.g., Ariel, 1990; Givón, 1983; Gundel et al., 1993)

Bayesian Approach
(e.g., Kehler et al., 2008)

Models in pronoun interpretation

1. Expectancy Hypothesis



小玲吓到了嘉怡，因为…
Xiaoling frightened Jiayi, because…

Continuations about Xiaoling (N1): 26
Continuations about Jiayi (N2): 1

Models in pronoun interpretation

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(e.g., Arnold, 2001)

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Bayesian Approach
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Models in pronoun interpretation

2. Mirror Model

Interpretation bias

Production bias

$$P(\text{referent}|\text{pronoun}) \leftarrow \frac{P(\text{pronoun}|\text{referent})}{\sum_{\text{referent}\in\text{referents}} P(\text{pronoun}|\text{referent})}$$

$$\frac{P(\text{overt}\,|\,\text{N1})}{P(\text{overt}\,|\,\text{N1}) + P(\text{overt}\,|\,\text{N2})} = \frac{0.615}{0.615 + 0}$$

小玲吓到了嘉怡，因为…
Xiaoling frightened Jiayi, because…

Continuations about Xiaoling (N1): 26
Using Overt pronoun: 16

$$P(\text{overt}\,|\,\text{N1}) = \frac{16}{26} = 0.615$$

Continuations about Jiayi (N2): 1
Using Overt pronoun: 0

$$P(\text{overt}\,|\,\text{N2}) = \frac{0}{1} = 0$$

Models in pronoun interpretation

Expectancy Hypothesis
(e.g., Arnold, 2001)

Mirror Model
(e.g., Ariel, 1990; Givón, 1983; Gundel et al., 1993)

Bayesian Approach
(e.g., Kehler et al., 2008)

Models in pronoun interpretation

3. Bayesian approach

Interpretation bias

Next-mention bias
Production bias

$$P(\text{referent}|\text{pronoun}) = \frac{P(\text{pronoun}|\text{referent})P(\text{referent})}{\sum_{\text{referent}\in\text{possible referents}} P(\text{pronoun}|\text{referent})P(\text{referent})}$$

$$\text{P(N1|overt)} = \frac{(0.963 \times 0.615)}{(0.963 \times 0.615)+(0\times 0.037)}$$

小玲吓到了嘉怡，因为…
Xiaoling frightened Jiayi, because…

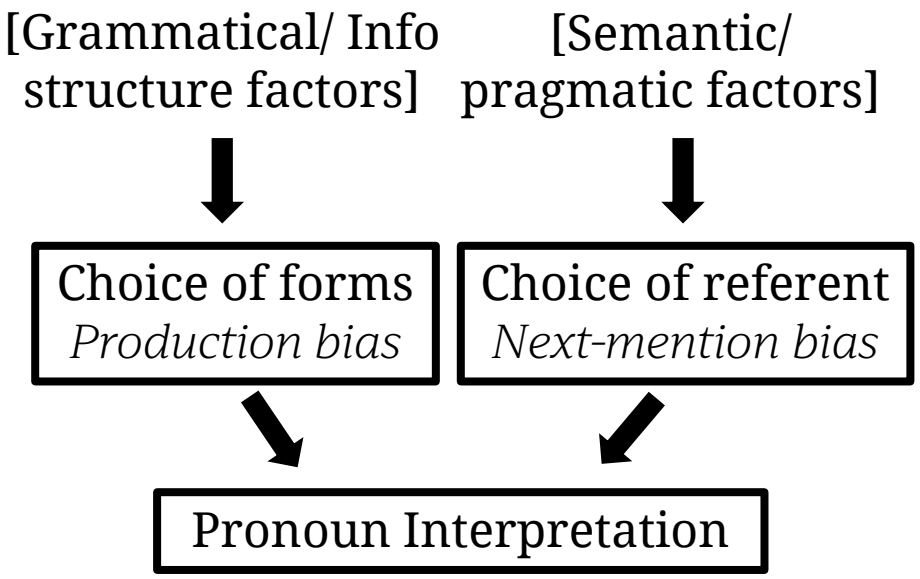
$$P(\text{N1}) = \frac{26}{27} = 0.963 \quad P(\text{N2}) = \frac{1}{27} = 0.037$$

$$P(\text{overt}|\text{N1}) = \frac{16}{26} = 0.615 \quad P(\text{overt}|\text{N2}) = \frac{0}{1} = 0$$

Models in Pronoun Interpretation

Bayesian Model

Asymmetry between interpretation and production/next-mention bias



Performed the best in:

- ✓ English overt pronouns (Rhode & Kehler, 2014; Kehler & Rhode, 2019)
- ✓ Chinese overt pronouns (Zhan et al., 2020)
- ✓ German personal pronouns (Patterson et al., 2020)

Research question:
Which model best explains the interpretation of null pronoun?

Overt and null pronouns are different:

- Null pronoun interpretation is more strongly subject-biased (e.g., Japanese: Ueno & Kehler, 2016; Mandarin: Zhang, 2018)
- Null pronoun interpretation is not sensitive to pragmatic factors like aspect in Japanese (Ueno & Kehler, 2016)

Methods

- Two passage-continuation experiments on overt pronouns (exp.1) and null pronouns (exp.2)

Implicit causality (IC) verbs: Verb Bias x Prompt Type, with connective "because"

Subject (N1)-biased verb	Object (N2) -biased verb	→ Next-mention bias
小玲吓到了嘉怡，因为…	嘉怡害怕小玲，因为…	
Xiaoling frightened Jiayi, because	Jiayi scares Xiaoling, because	

Transfer-of-possession (TOP) verbs: Verb Bias x Prompt Type, with connective "so"

Subject (N1)-biased verb	Object (N2)-biased verb
立强从小刚那里收到了一个包裹，所以…	小刚向立强寄了一个包裹，所以…
Liqiang received a package from Xiaogang, so	Xiaogang sent a package to Liqiang, so

Methods

- Two passage-continuation experiments on overt pronouns (exp.1) and null pronouns (exp.2)

Implicit causality (IC) verbs: Verb Bias x Prompt Type, with connective "because"

Subject (N1)-biased verb

小玲吓到了嘉怡，因为…
Xiaoling frightened Jiayi, because

Object (N2) -biased verb

嘉怡害怕小玲，因为…
Jiayi scares Xiaoling, because

→ Next-mention bias

Free prompt

因为 (free)…
because…

Pronoun prompt

因为她 (overt)…
because she…

因为想 (null)…
because wants to/think…

Free: Next-mention and production bias
Pronoun: Interpretation bias

Transfer-of-possession (TOP) verbs: Verb Bias x Prompt Type, with connective "so"

Subject (N1)-biased verb

立强从小刚那里收到了一个包裹，所以…
Liqiang received a package from Xiaogang, so

Object (N2)-biased verb

小刚向立强寄了一个包裹，所以…
Xiaogang sent a package to Liqiang, so

Free prompt

所以 (free)…
so…

Pronoun prompt

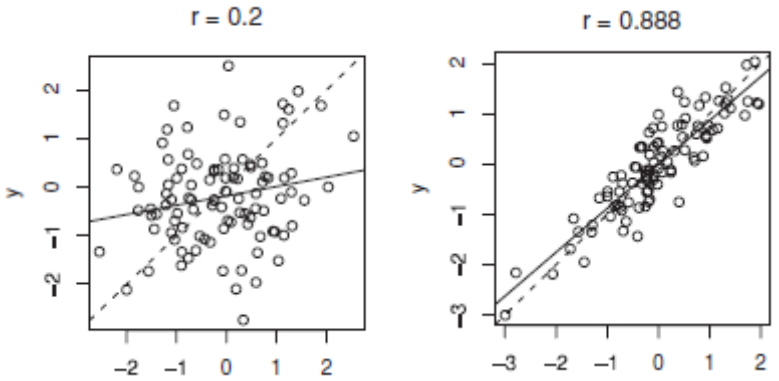
所以她 (overt)…
so she…

所以想 (null)…
so wants to/think…

Evaluation Metrics

Correlation: R-squared (R2)

- How well the observed values are replicated by the predicted value



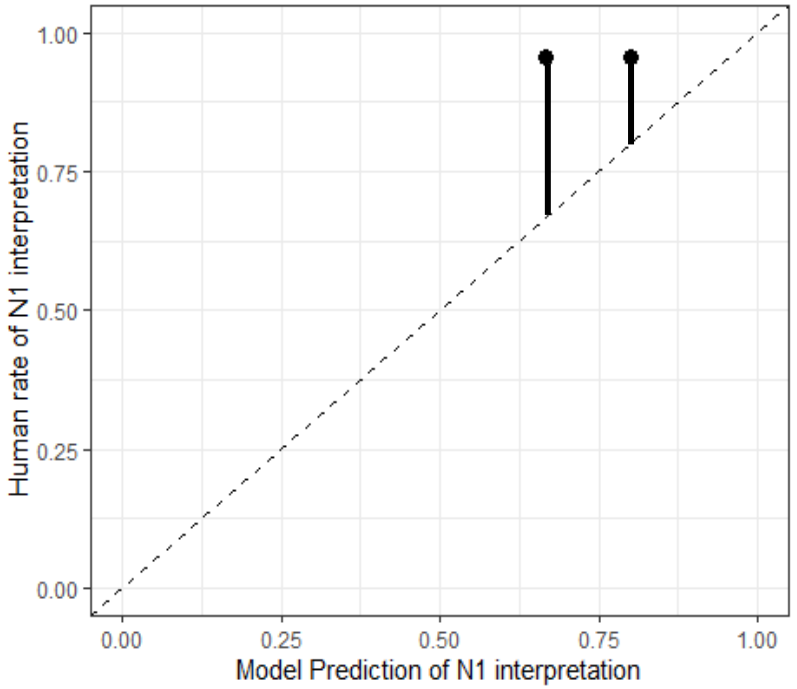
(Baayen, 2008; P.88)

Prediction error: Mean squared error (MSE)

- Reflects how far away the prediction is from the observation

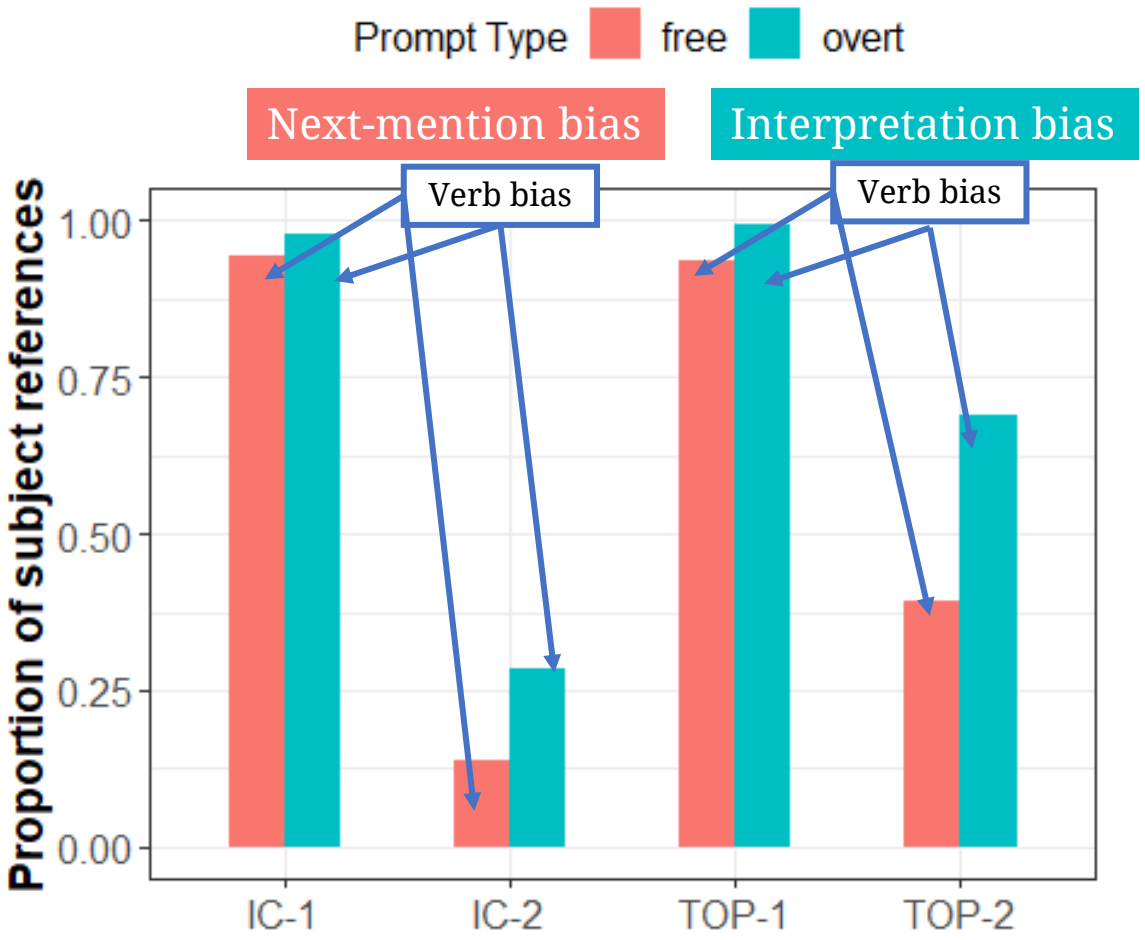
Prediction error: Average Cross Entropy (ACE)

- Reflects how far away the prediction is from the observation in a logarithmic scale
- Gives more weight to extreme deviations



Overt pronoun (Experiment 1) results: Choice of referents and forms

Choice of referent



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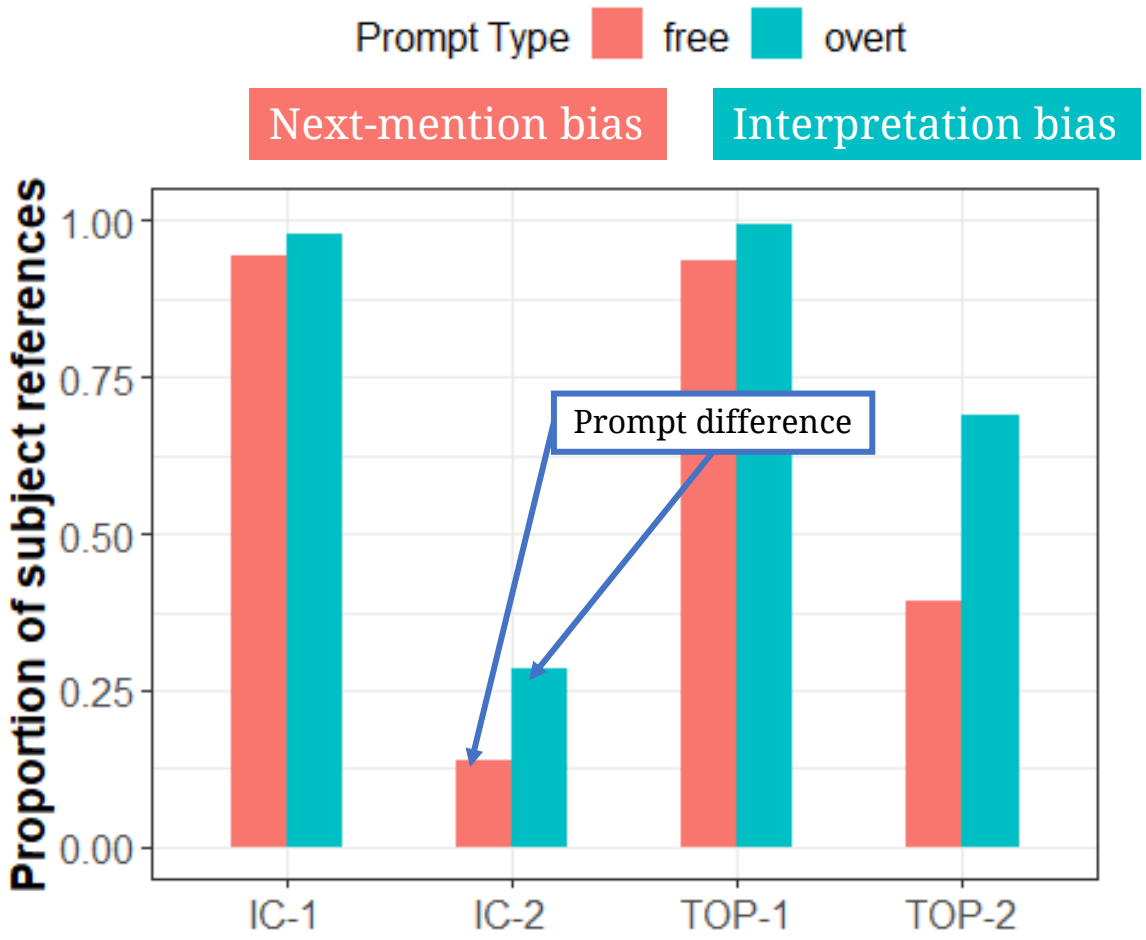

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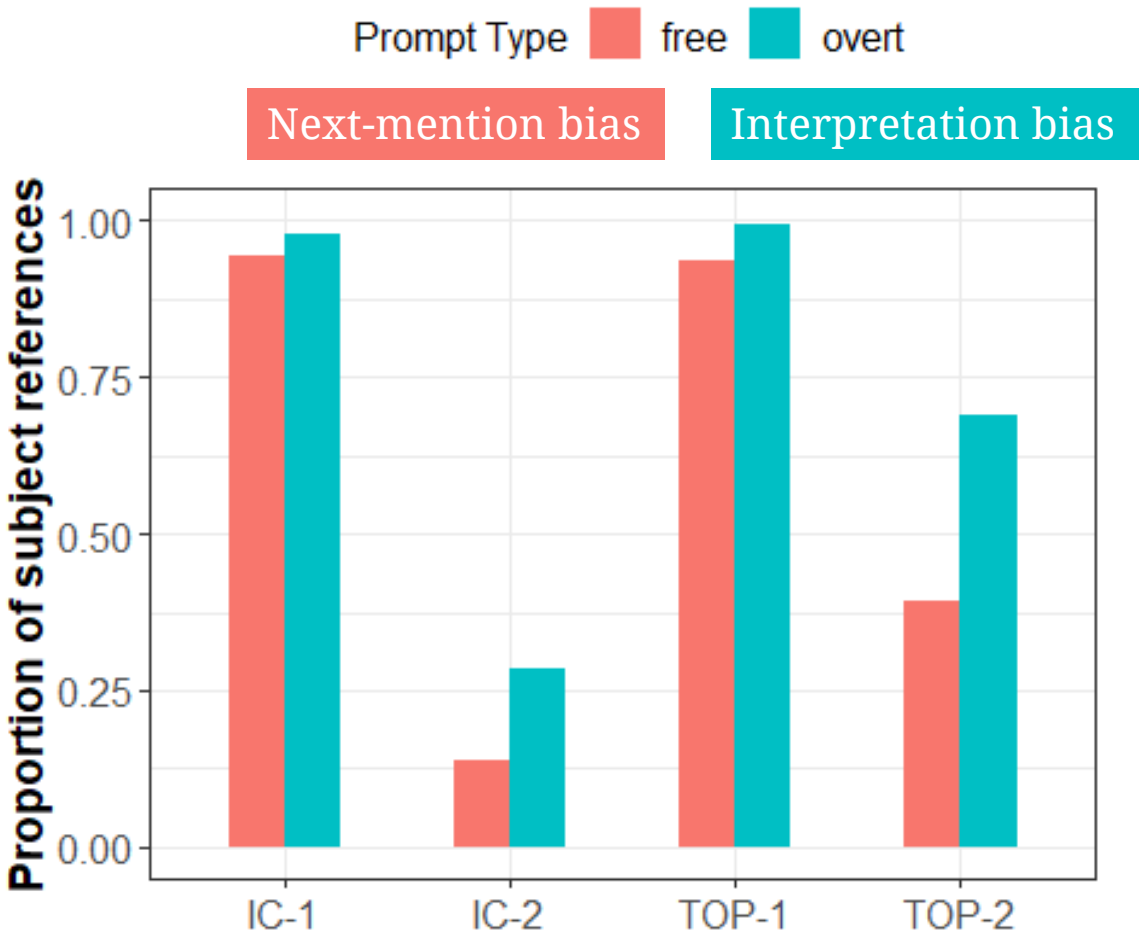
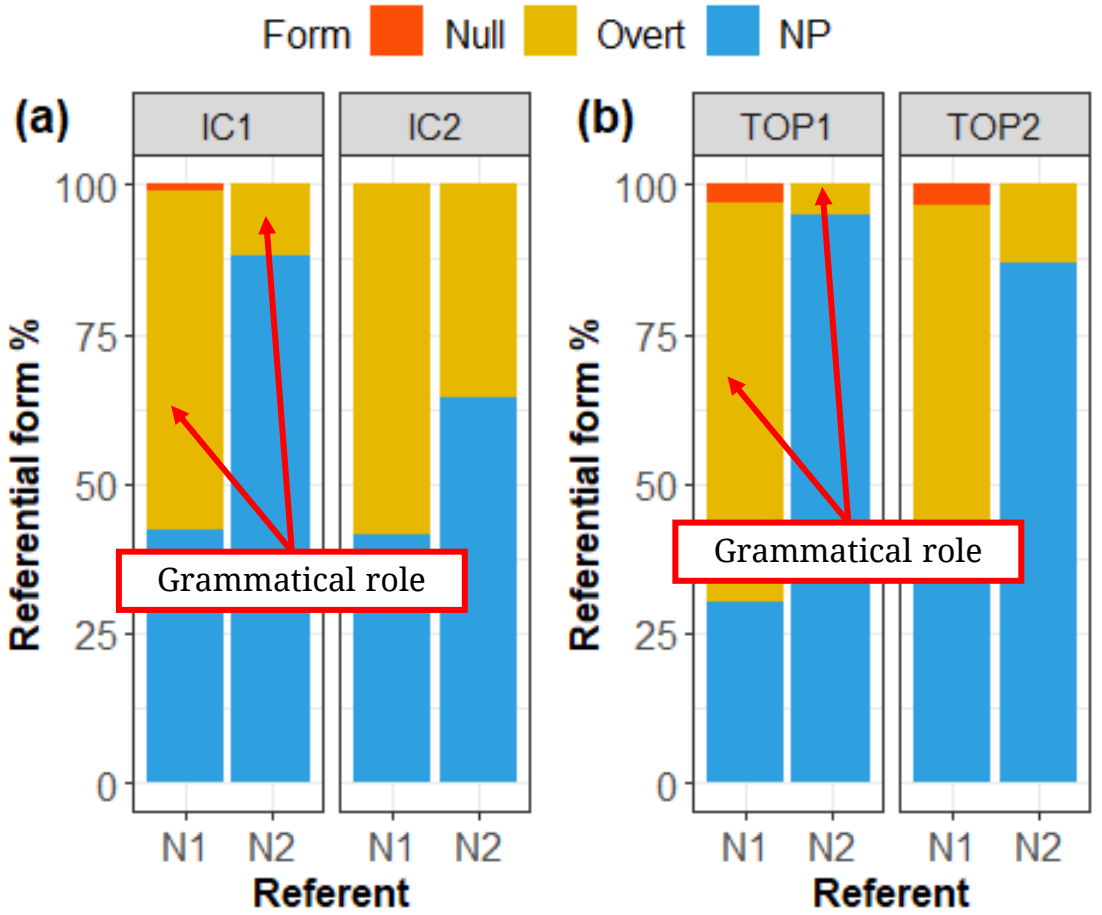
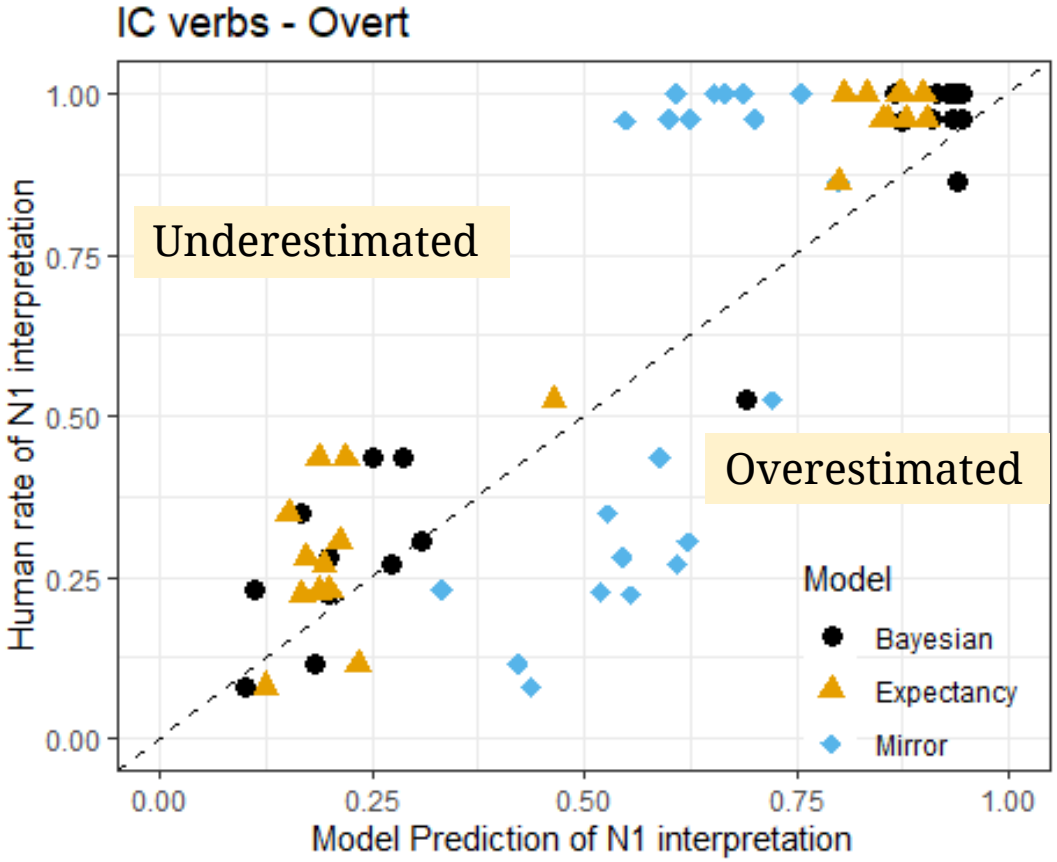
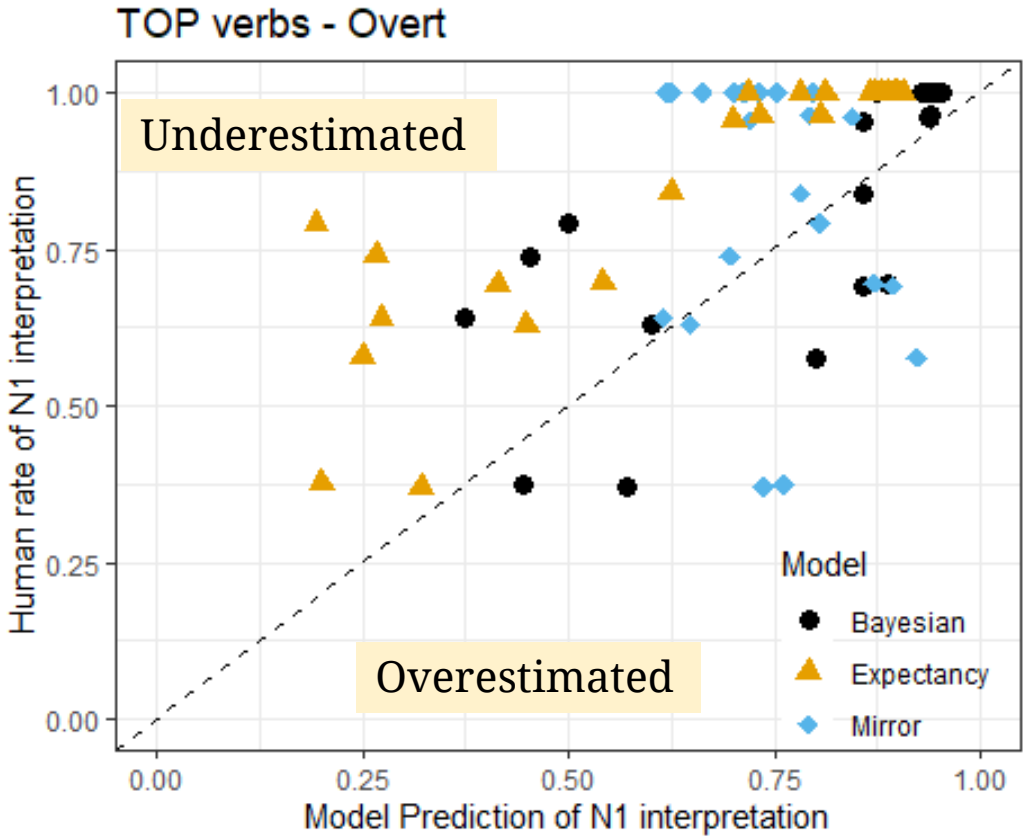


Choice of referential form (Production bias)



Model Evaluation – Overt pronoun





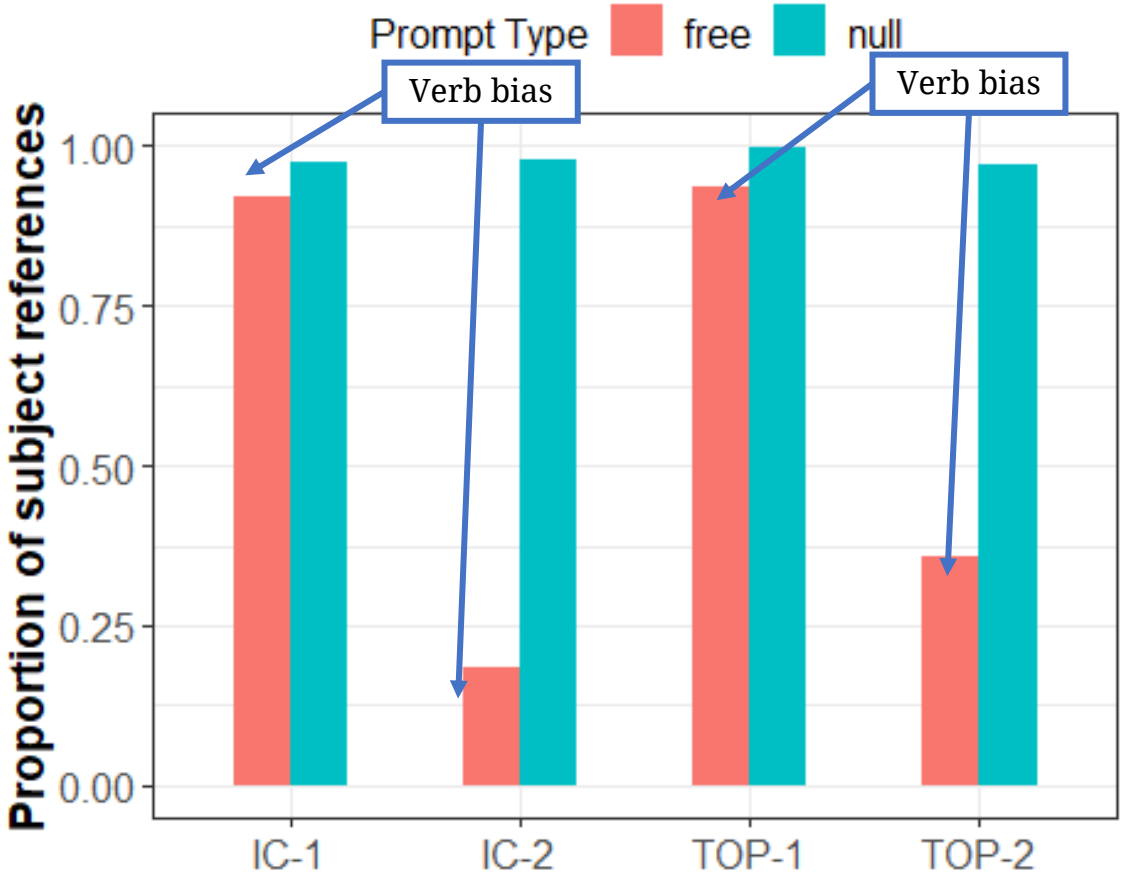
IC Overt	**Bayesian**	**Expectancy**	**Mirror**
R^2	0.950***	**0.952*** **	0.491***
MSE	**0.009**	0.016	0.085
ACE	0.804	0.888	**0.521**

TOP Overt	**Bayesian**	**Expectancy**	**Mirror**
R^2	0.585***	**0.772*** **	0.080
MSE	**0.019**	0.060	0.068
ACE	**0.253**	0.575	0.309

***: $p < .001$; **: $p < .01$; *: $p < .05$;

Results: Experiment 2 (Null pronoun) - Choice of referents and forms

Choice of referent
(Next-mention/Interpretation bias)



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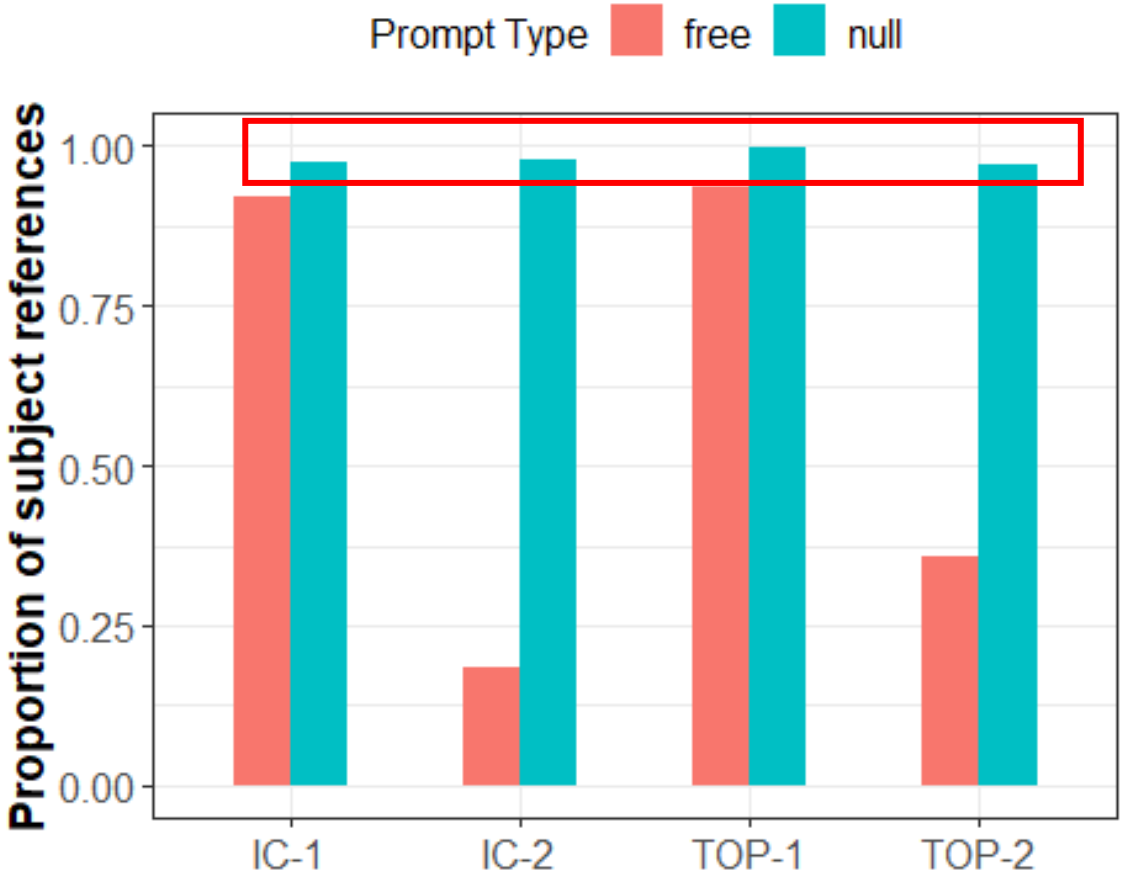
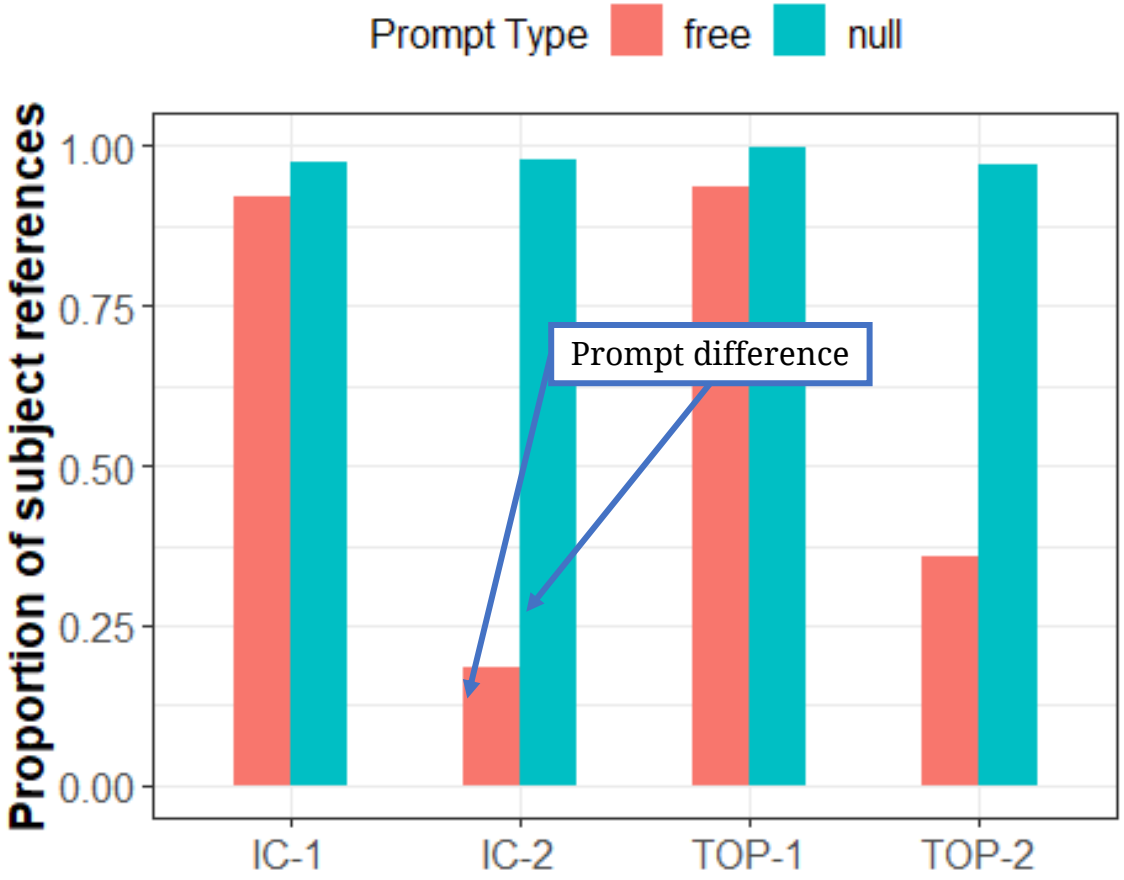
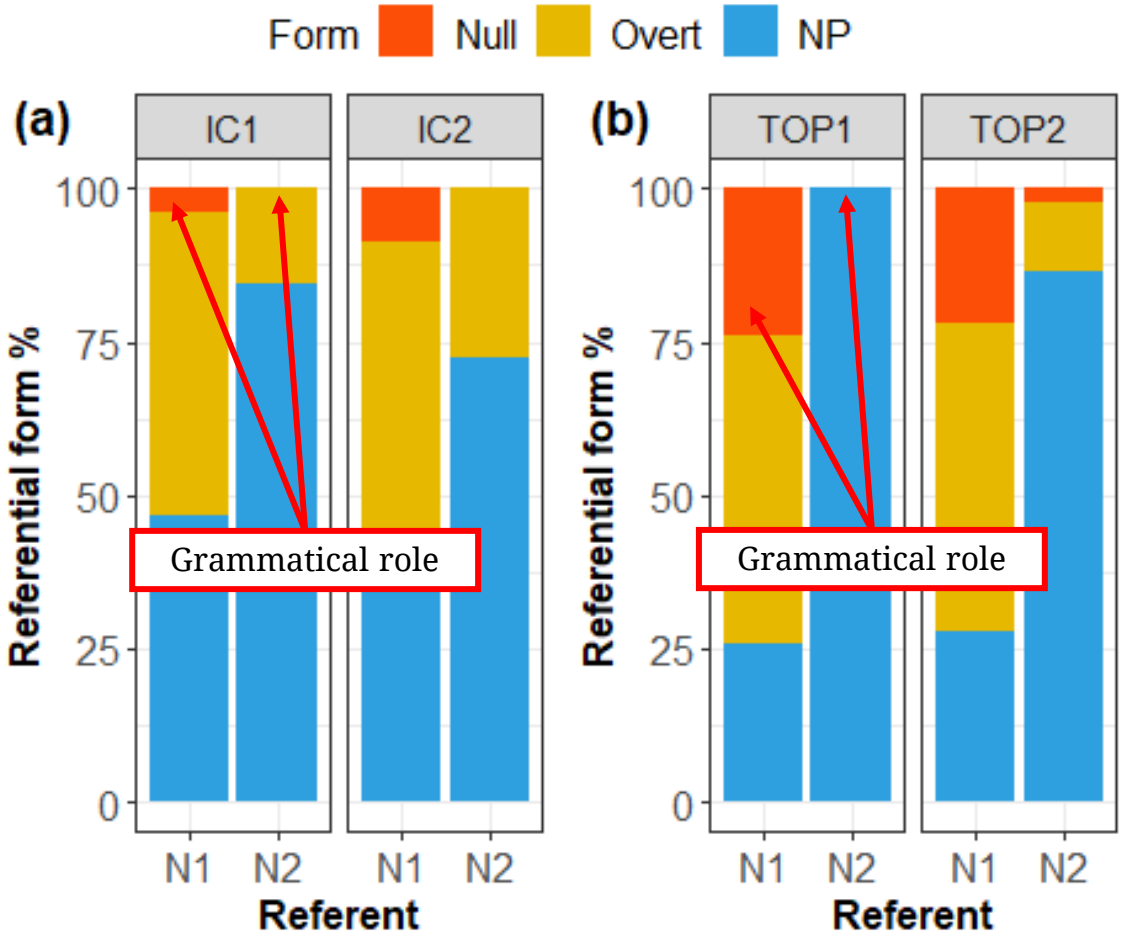


Results: Experiment 2 (Null pronoun) - Choice of referents and forms

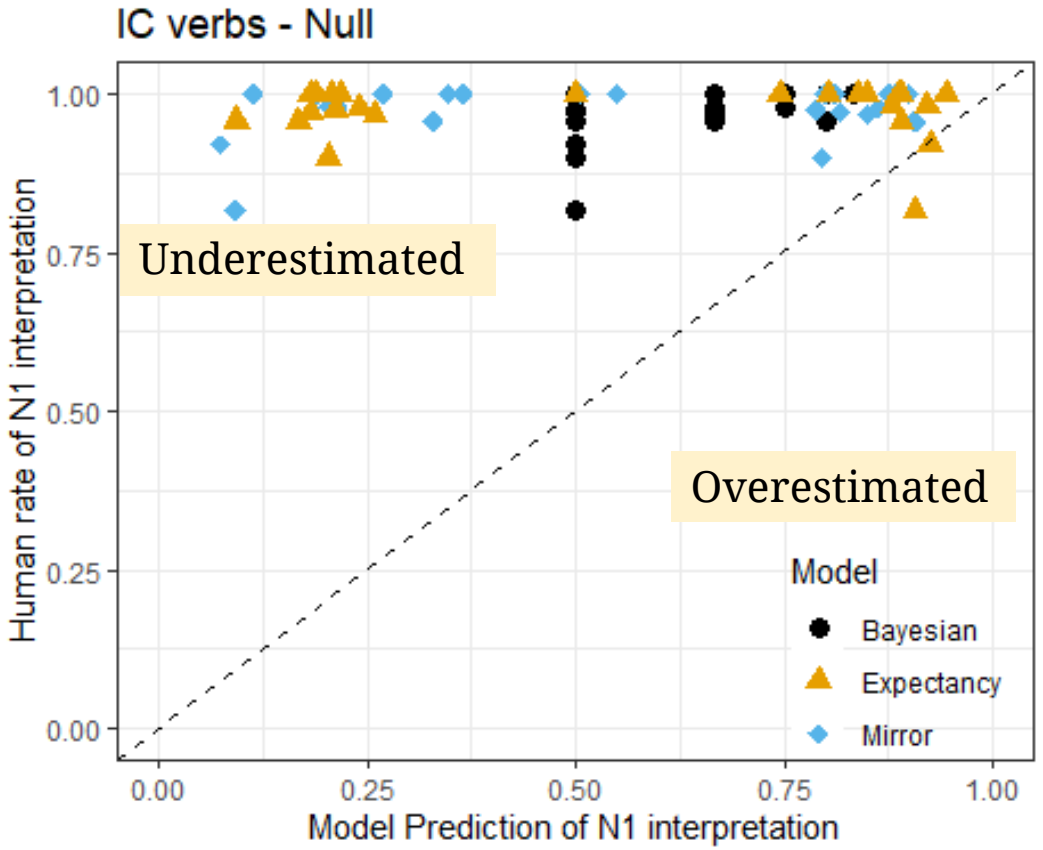
Choice of referent (Next-mention/Interpretation bias)

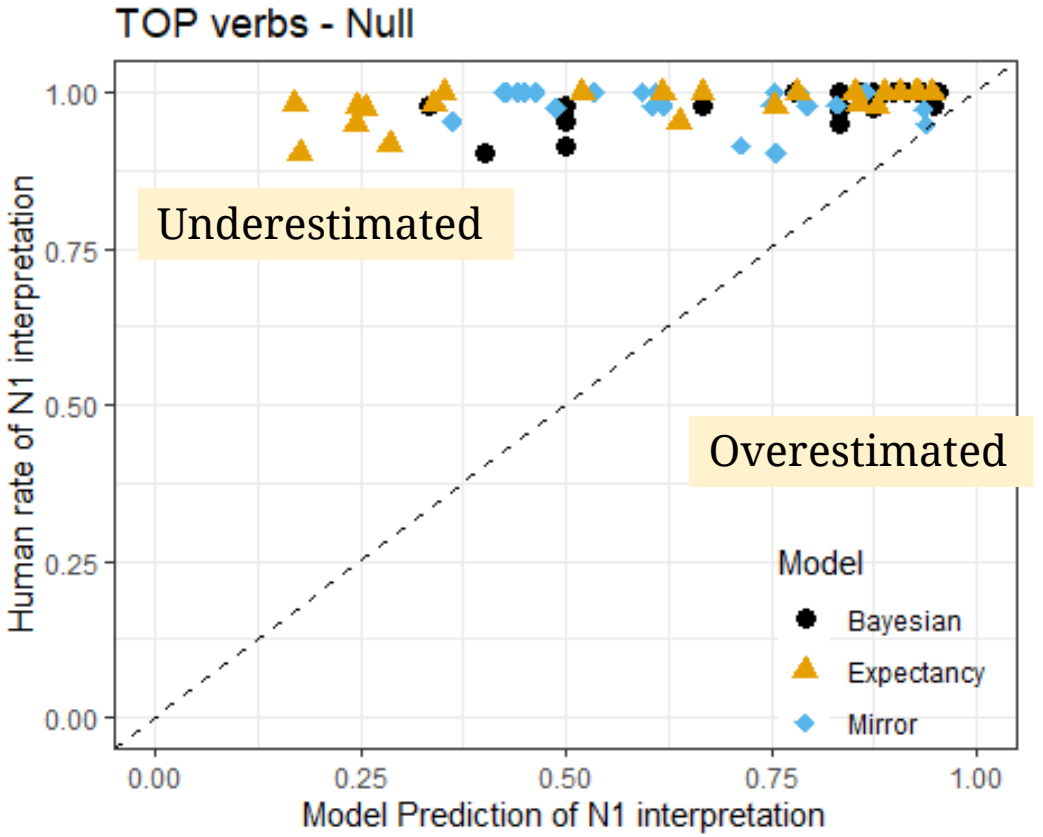


Choice of referential form (Production bias)



Model Evaluation – Null pronoun





IC Null	**Bayesian**	**Expectancy**	**Mirror**
R^2	**0.253***	0.004	0.045
MSE	**0.114**	0.297	0.262
ACE	**0.445**	0.858	0.820

TOP Null	**Bayesian**	**Expectancy**	**Mirror**
R^2	**0.488*****	0.383**	0.041
MSE	**0.067**	0.197	0.137
ACE	**0.277**	0.606	0.452

***: $p < .001$; **: $p < .01$; *: $p < .05$;

Conclusion: Take-home messages

Overt pronoun

Well-explained by the Bayesian approach

- Except that verb bias also affects the production of overt pronoun in TOP verbs
- Interpretation is subject to multiple processes instead of a single next-mention or production bias

Null pronoun

None of the model explains well

- Interpretation is always highly N1-biased
- Less sensitive to the verb bias, and none of the model can capture the sensitivity well

Thank you!

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Additive smoothing

- Pseudo-count one occurrence for each referential form (Names, overt, null) under each possible referent

Next-mention bias without smoothing

$$\frac{Count(\text{referent})}{Count(\text{Subject}) + Count(\text{object})}$$

Production bias without smoothing

$$\frac{Count(\text{referent ^ pronoun})}{Count(\text{referent})}$$

Next-mention bias with smoothing

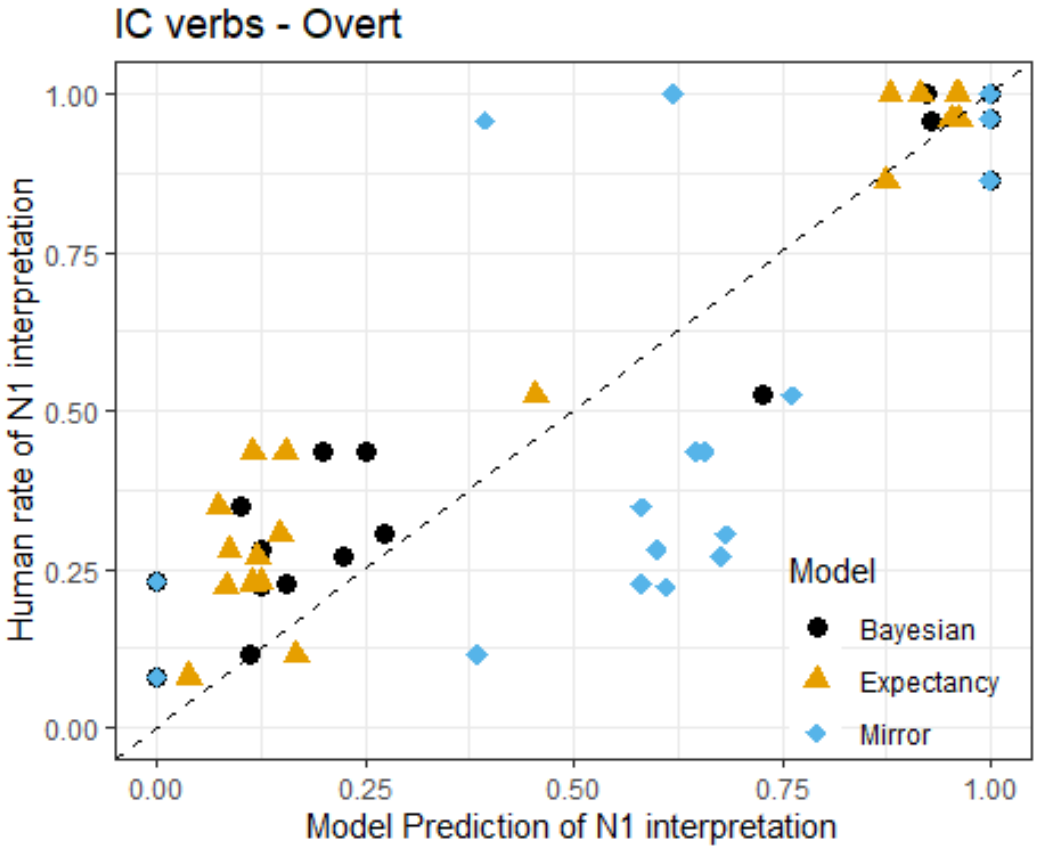
$$\frac{Count(\text{referent}) + 3}{Count(\text{Subject}) + Count(\text{object}) + 2 \times 3}$$

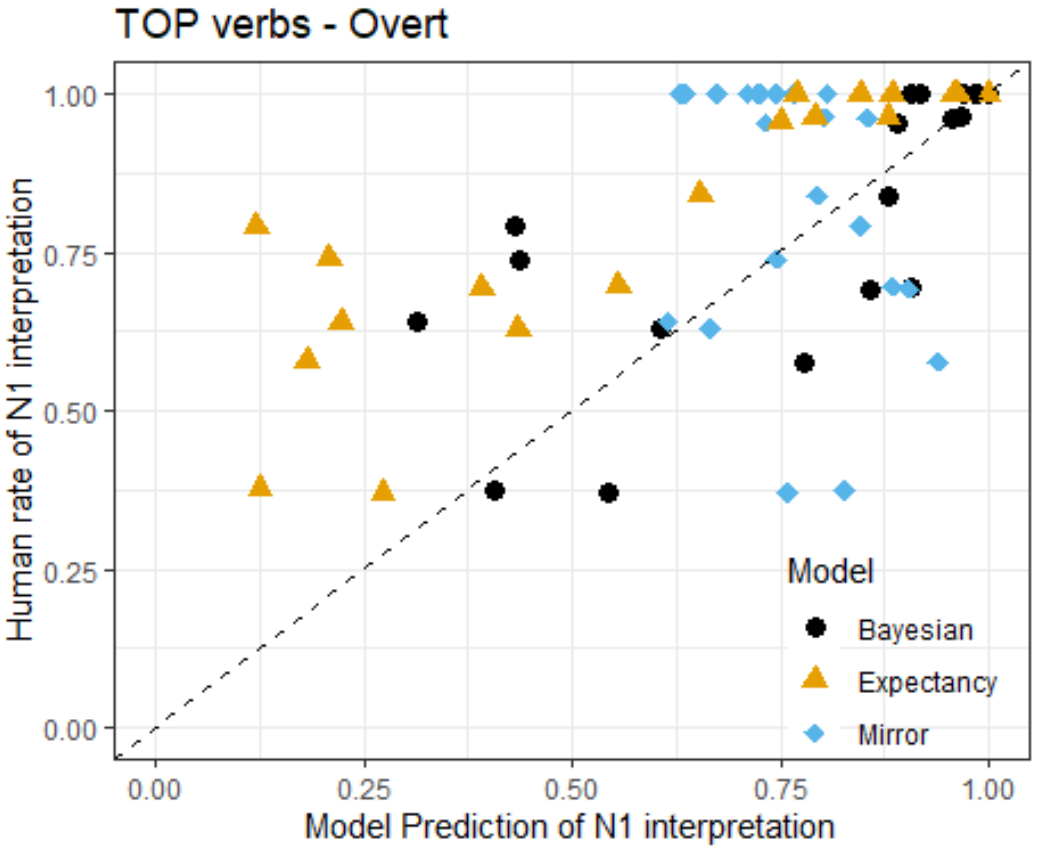
Production bias with smoothing

$$\frac{Count(\text{referent ^ pronoun}) + 1}{Count(\text{referent}) + 3}$$

Model Evaluation – Overt pronoun

Without smoothing





Model Evaluation – Null pronoun

Without smoothing