Structural Frequency Effects in Noisy-channel Comprehension

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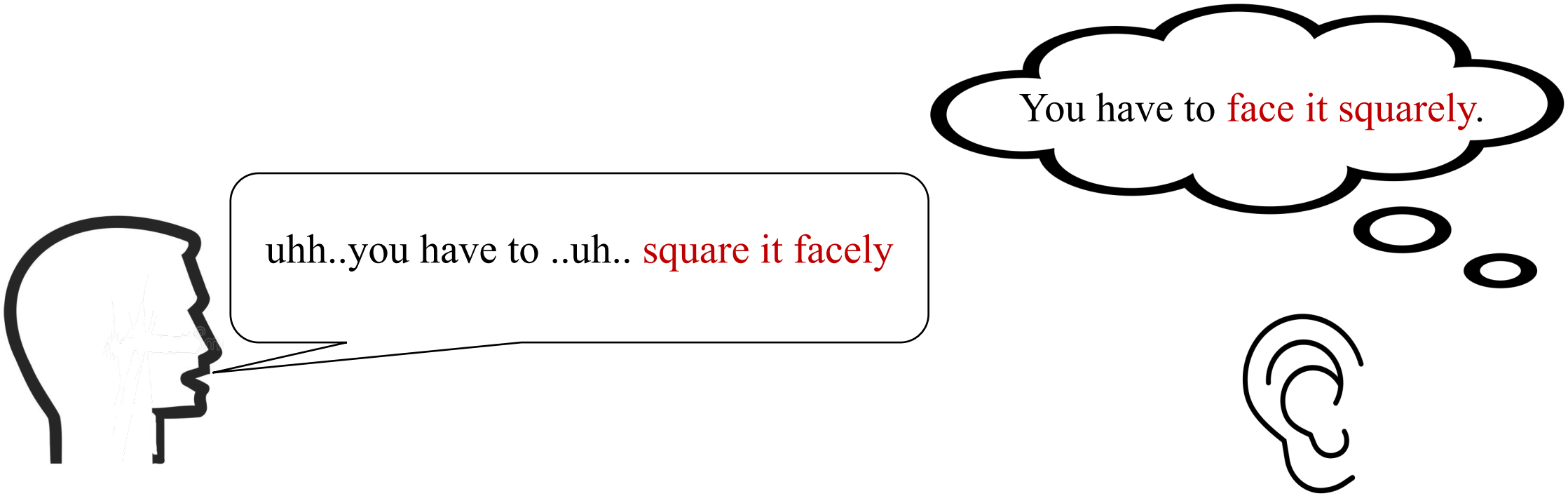
Communication in the context of noise

- Noise is present in typical language use.
- Comprehenders can often successfully figure out what the speaker wants to convey, even when the utterance is corrupted by noise.



Comprehension of possibly corrupted input

Sentence: The mother gave the candle the daughter.
Question: Did the daughter receive something/someone?

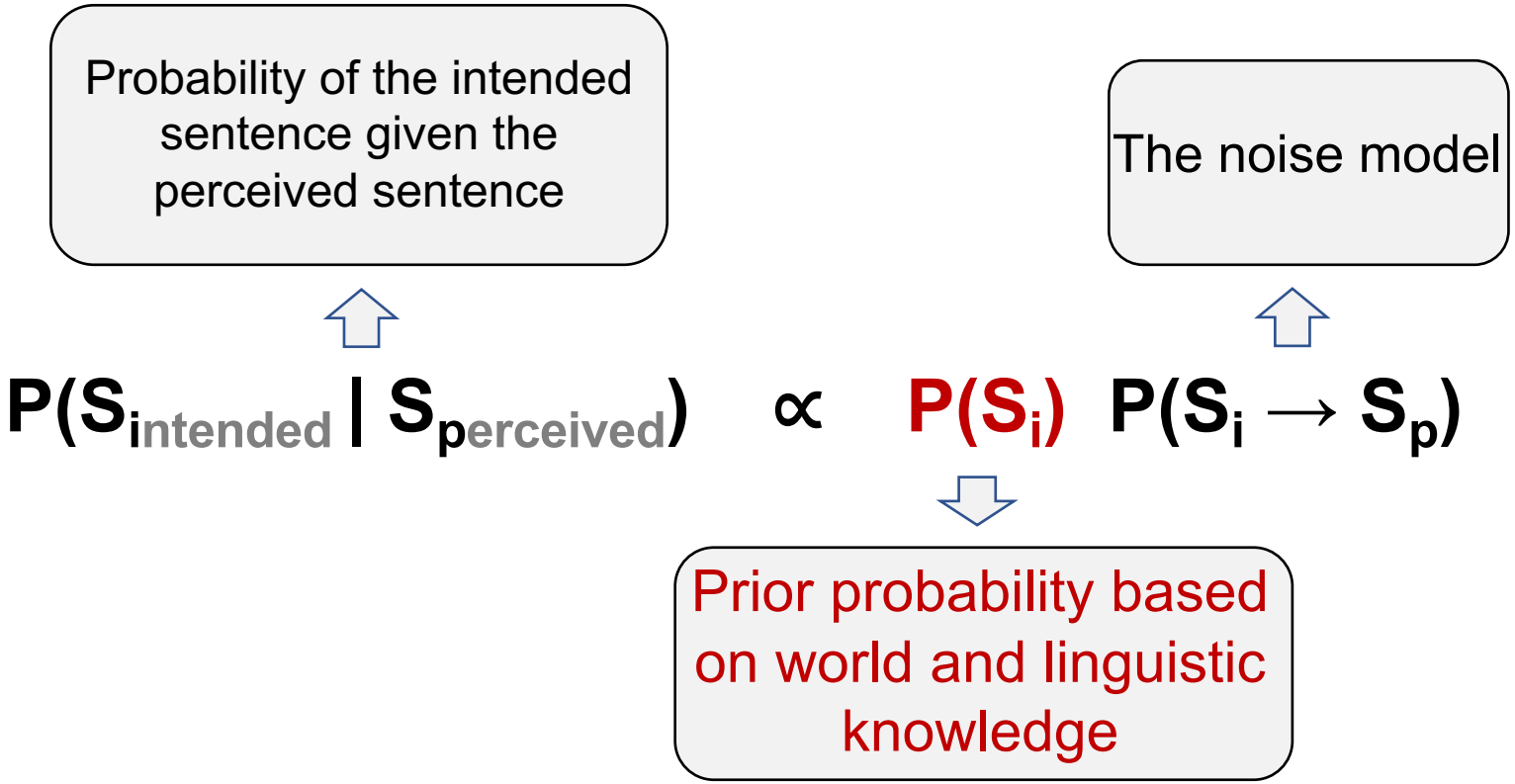
- ○ Yes (Non-literal response) **52%**
- ○ No (Literal response) **48%**

(Gibson et al.,2013)

- How to capture these observations?

The noisy-channel model of sentence comprehension

- The language comprehension mechanism is well-designed for recovering the intended utterance from noisy input.



(e.g., Levy, 2008; Gibson et al., 2013; Poppels & Levy, 2016; Ryskin et al., 2018; Keshev & Meltzer-Asscher, 2021)

Sentence comprehension over a noisy-channel

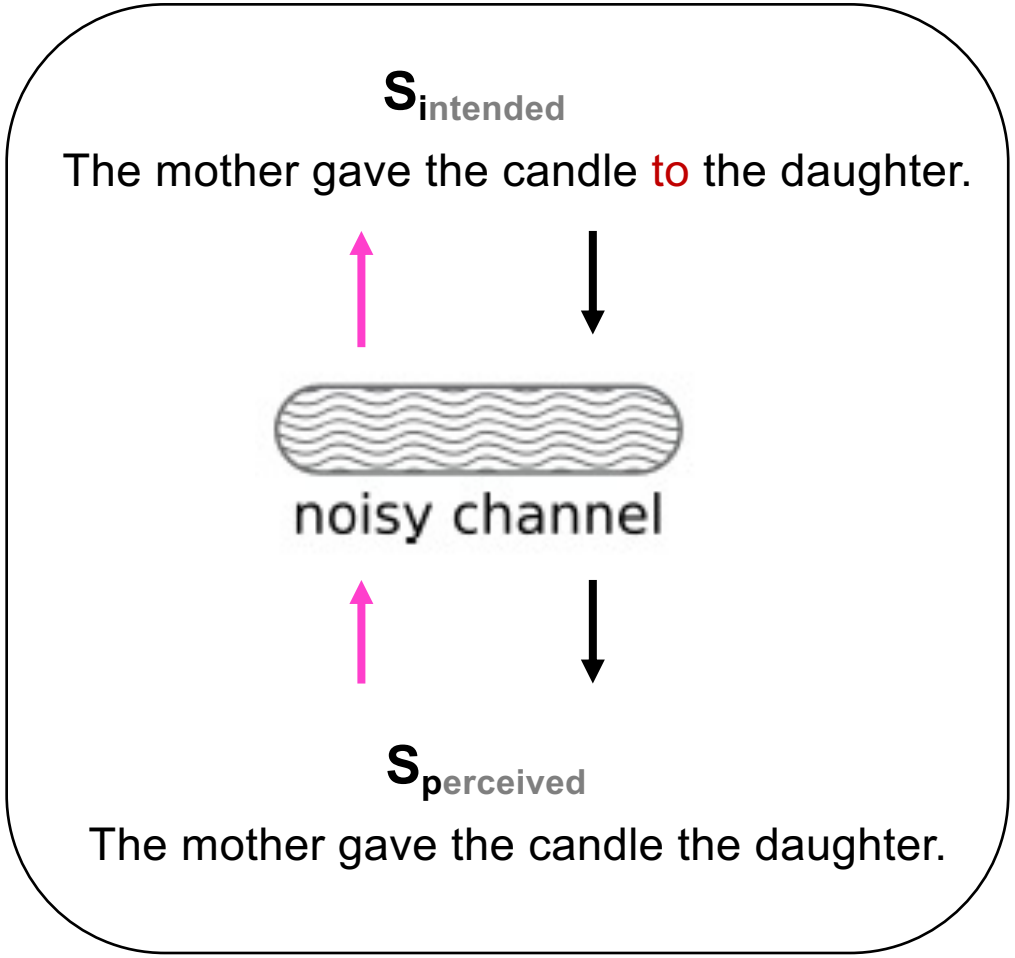
Sentence: The mother gave the candle to the daughter.

Question: Did the daughter receive something/someone?

- ✓ Yes (Non-literal response)
- ○ No (Literal response)

(Gibson et al.,2013)

Sentence comprehension over a noisy-channel



$$P(S_p \mid S_p) \propto P(S_p)\ P(S_p \rightarrow S_p)$$

medium **low** **high**

$$P(S_i \mid S_p) \propto P(S_i)\ P(S_i \rightarrow S_p)$$

high **high** **medium**

Our proposal

- Previous works have mainly focused on the meaning prior

  $P(S_i \mid S_p) \propto P(S_i)\, P(S_i \rightarrow S_p)$

- $P(s_i) = P(s_{i\_structure}, s_{i\_meaning})$

➢ $P(S_i \mid S_p) \propto P(s_{i\_structure}, s_{i\_meaning})\, P(S_i \rightarrow S_p)$

(cf. Bergen et al., 2012; Poppels & Levy, 2016; Keshev & Meltzer-Asscher, 2021)

- Prediction of our proposed noisy-channel model

➢ Comprehenders draw more inferences for sentences formed in low-frequency structures compared to those formed in high-frequency structures.

Experiments 1-2 & Corpus search

- **Goal:** Quantitatively measure the degree to which English and Mandarin Chinese allow the six logically possible word orders (SVO, OSV, SOV, VOS, OVS, VSO).

➢ While there is consensus about English, it is unclear to what extent Chinese allows various word orders and there has been no experimental measurement for that.

Experiments 1-2

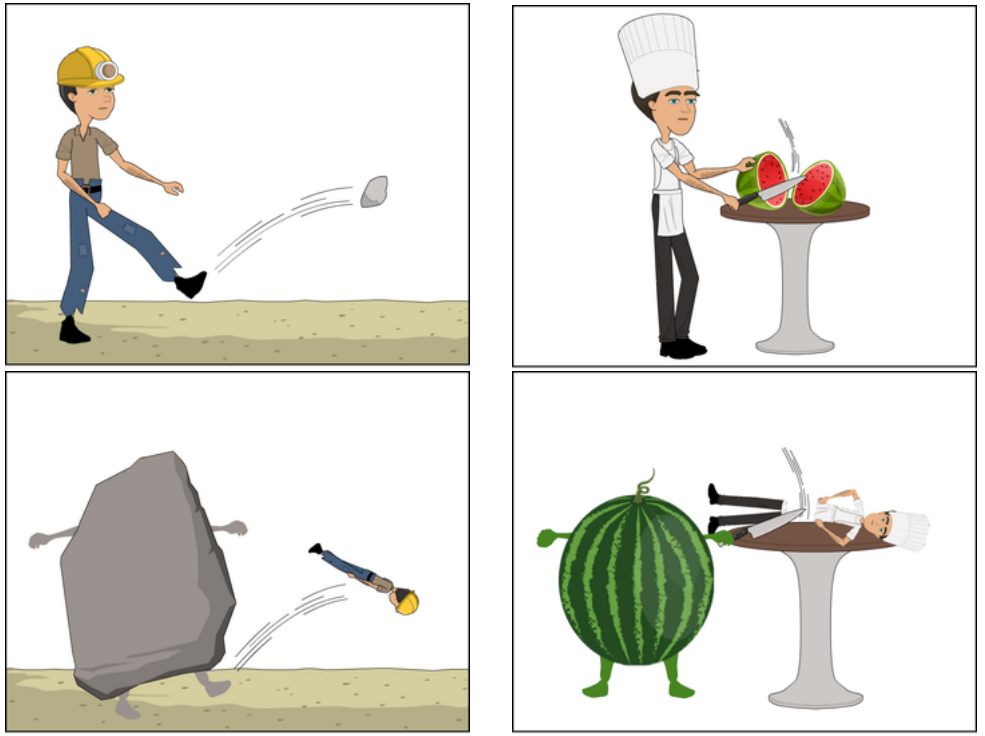
- Behavioral experiments in English and Chinese (N=30 in both languages):

Sample trial (English)

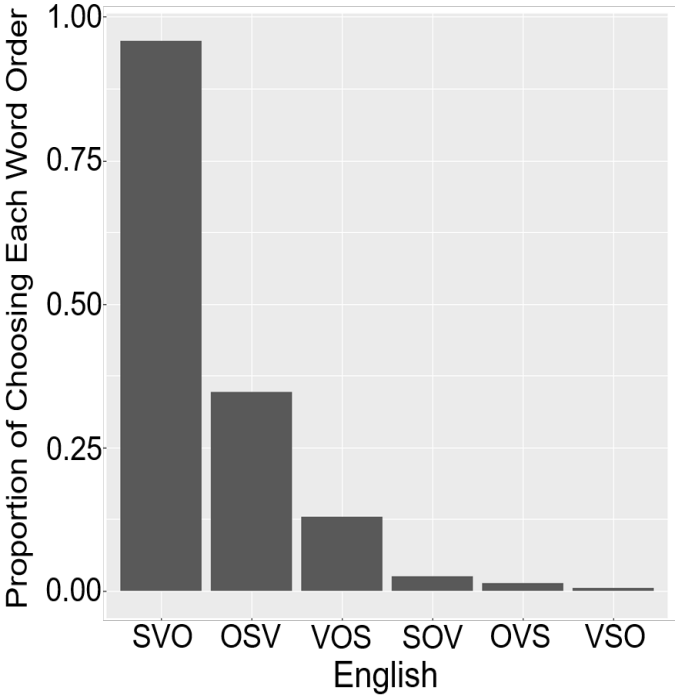
Please select ALL the acceptable English description(s) of the picture.

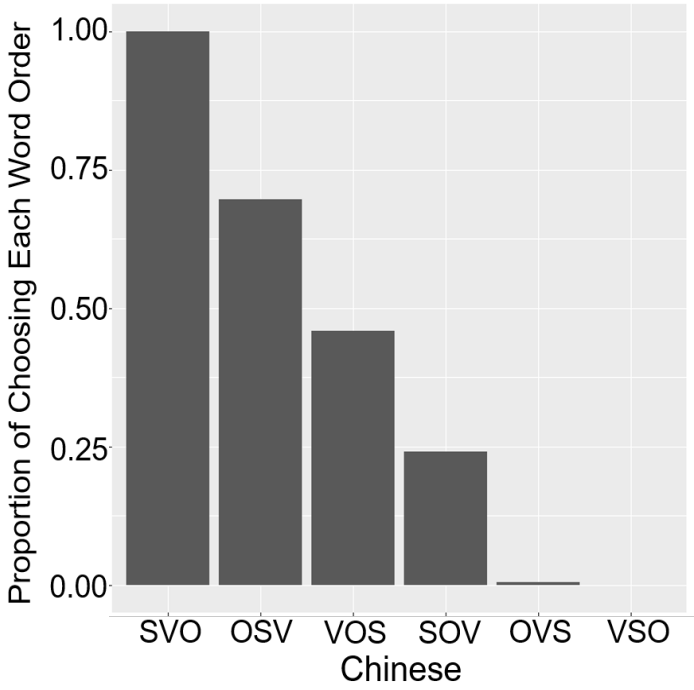
- ☐ The boy threw the trash. (SVO)
- ☐ The trash, the boy threw.(OSV)
- ☐ Threw the trash, the boy.(VOS)
- ☐ The boy, the trash threw.(SOV)
- ☐ The trash threw the boy. (OVS)
- ☐ Threw the boy, the trash.(VSO)

Example pictures:



Results





- SVO is more frequently chosen than OSV, while other word orders are less common ($\beta s > 8$, $ps < 0.01$).
- Mandarin has a higher word order flexibility than English. The entropy in the distribution of allowable Mandarin word orders ($H = 1.28$, 95% CI=[1.26, 1.3]) is larger than that in English ($H = 0.95$, 95% CI=[0.9, 1]).

Corpus search

- Frequency of SVO and OSV word order in English and Chinese Penn Treebank.

➢Results from written text in Penn Treebank

	Raw counts		Probability of each structure	
	SVO	OSV	SVO	OSV
English	87515	176	0.62	0.001
Chinese	65688	1693	0.64	0.015

Experiments 3-4

- **Goal:** Test our proposed noisy-channel model with consideration of the structural prior

➢ English and Chinese speakers' comprehension of implausible and plausible sentences formed in SVO or OSV.

Sample trial (English)

Sentence: The trash threw the boy. (SVO_implausible)

Question: Did the boy throw something/someone?

○ Yes (Noisy-channel inference response)

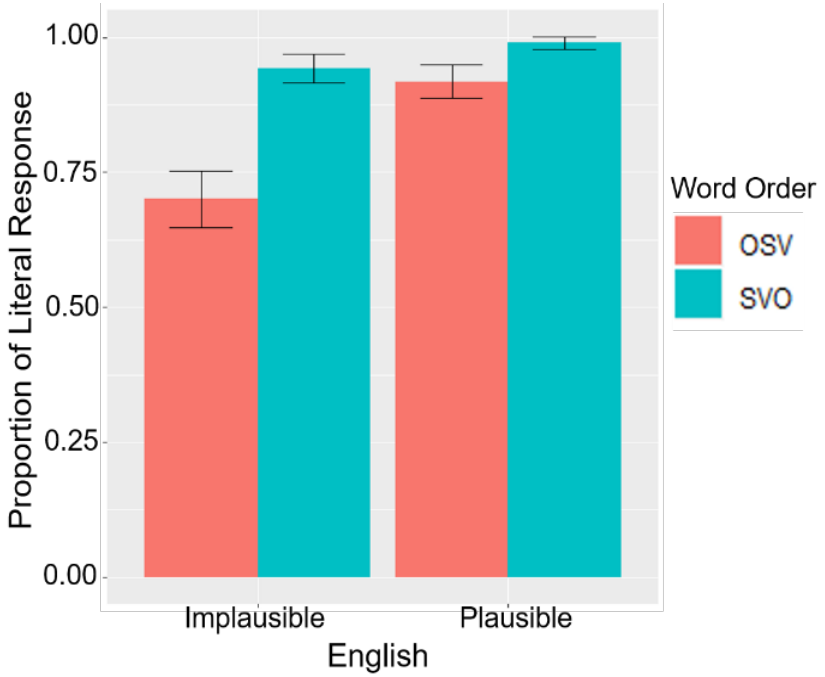
○ No (Literal response)

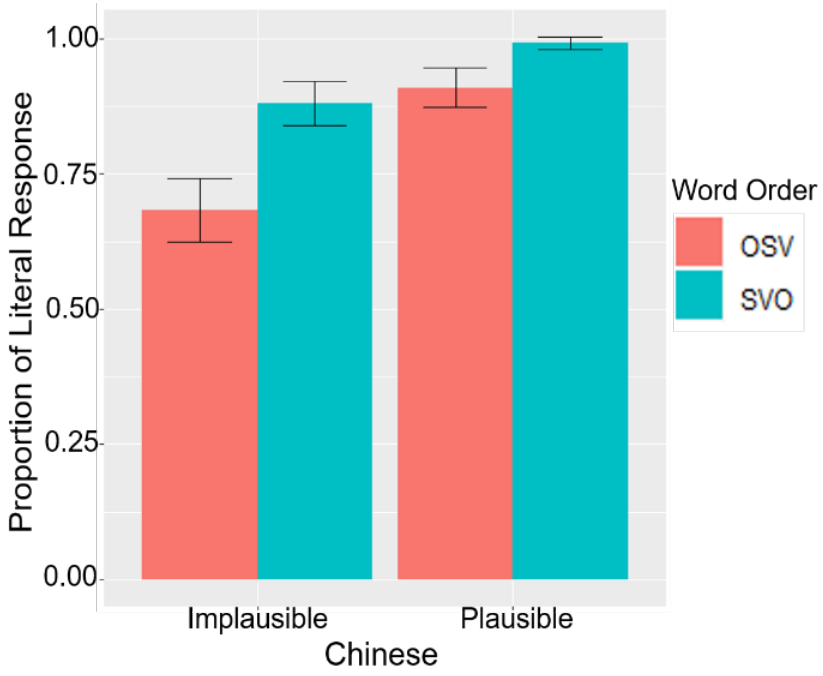
Example materials (English):

The boy threw the trash. (SVO_plausible)
The trash, the boy threw. (OSV_plausible)
The trash threw the boy. (SVO_implausible)
The boy, the trash threw. (OSV_implausible)

(N=97 for English; N=81 for Chinese).

Results





- OSV sentences were more likely to be interpreted non-literally compared to SVO sentences in both English and Mandarin ($\beta s > 1.5$, $zs > 6.5$, $ps < 0.01$).

- As predicted, people are much more likely to interpret “The boy, the trash threw” as the more plausible “The boy threw the trash” than they are to interpret “The trash threw the boy” in the more plausible way.

→ Comprehenders draw more inferences for low-frequency constructions, supporting our proposed noisy-channel model with implementation of the structure prior.

What kind of frequencies are comprehenders tracking?

- The 'grain sizes' distributional syntactic information stored by language users.

?

Pair	Sentence	Construction	String
Simple transitives	The trash threw the boy.	SVO	NVN
	The boy, the trash threw.	OSV	NNV
Clefts	It was the trash that threw the boy.	Subj cleft	NVN
	It was the boy that the trash threw.	Obj cleft	NNV

➢ ***Construction-based hypothesis:***
Comprehenders track frequencies of each of the four constructions (Goldberg, 2016; Abeillé et al., 2020).

→ **Prediction**: Variation between SVO/OSV and clefts.

➢ ***Linear string-based hypothesis:***
The comprehension mechanism only tracks two kinds of strings – NVN for SVO & subj cleft, and NNV for OSV and obj cleft. (Bates et al., 1982; Ferreira 2003).

→**Prediction:** NO variation between SVO/OSV and clefts

Experiment 5

- Goals:

➢Test of our proposed noisy-channel model - subject/object clefts.

➢Evaluation of the two hypotheses about distributional syntactic information stored by language users *(construction-based vs. linear string-based)* with SVO/OSV and clefts.

→Expt 5a: replication of Expt 3 of English SVO/OSV with a new paradigm

→Expt 5b: test of English clefts

Experiments 5

- Paradigm:

_ __ ___ ____ ___ ____ ___ __

It ___ _____ _____ _____ _____ ____ ____

__ was ____ _____ ____ _____ ___ ___

__ ___ the _____ ____ _____ ___ ___

__ ___ ____ trash ____ ____ ___ ___

__ ___ ____ _____ that ____ ___ ___

__ ___ ____ _____ ____ threw ___ ___

__ ___ ____ _____ ____ ____ the ___

__ ____ _____ _____ _____ _____ ____ boy.

- *1.Comprehension question about the sentence you just read*

  Did the boy throw something/someone?

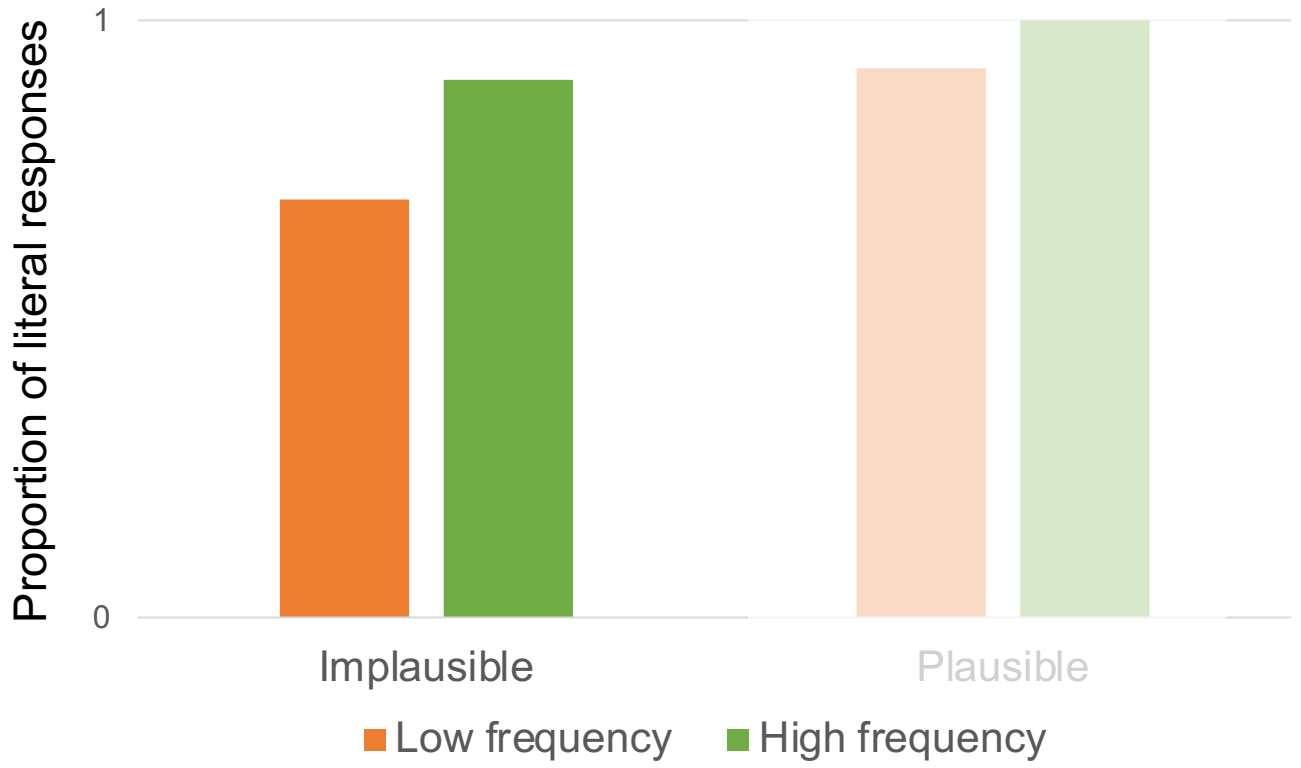
  - Yes
  - No

- *2. Please type the sentence exactly in the form you just read.*

Prediction of the comprehension task

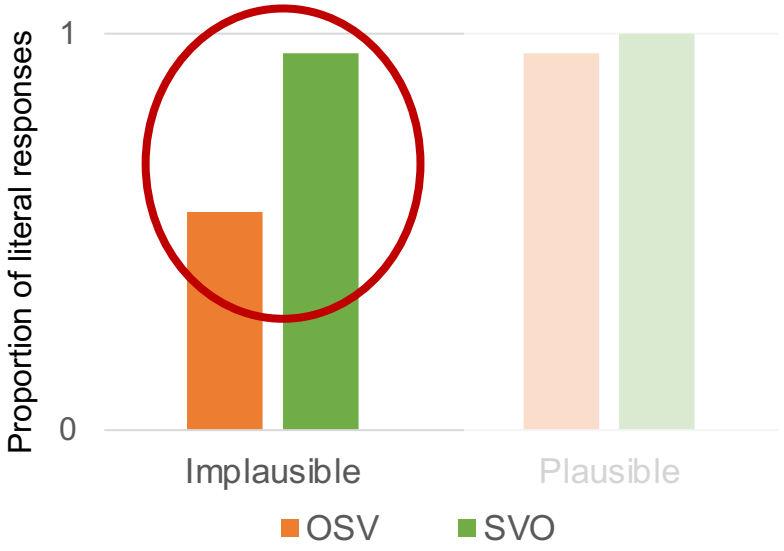
- Our proposed noisy-channel model:

➢ More inferences for low-frequency constructions

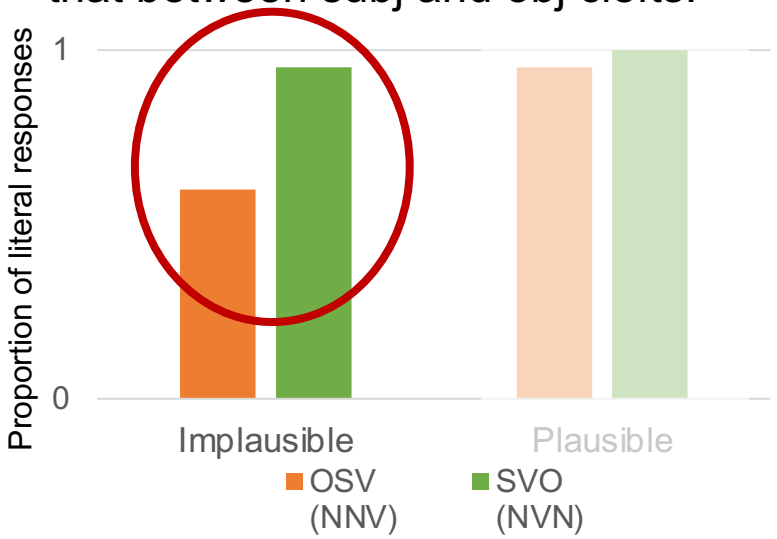


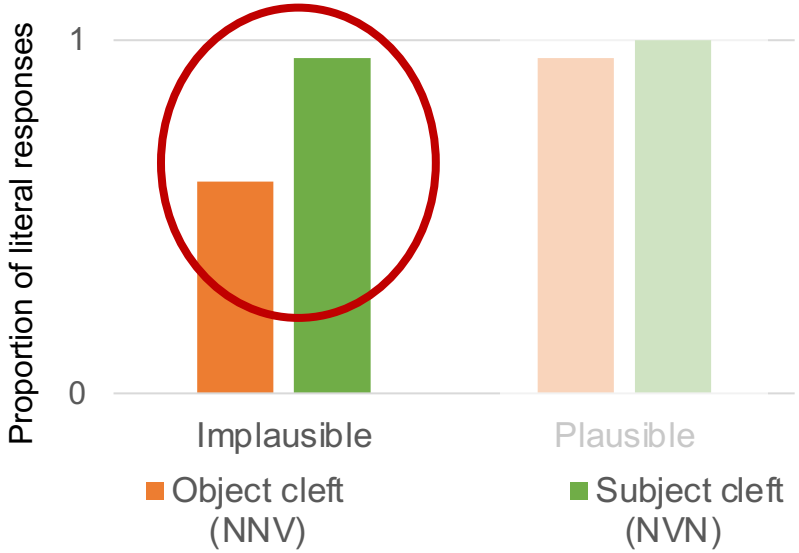
➢ Is there difference between clefts and SVO/OSV?

- **Construction-based hypothesis**: the difference in inference rate is larger between SVO and OSV than between the two types of clefts (SVO: OSV = 497: 1; Subject vs. Object cleft = 17:1 in Penn Treebank)

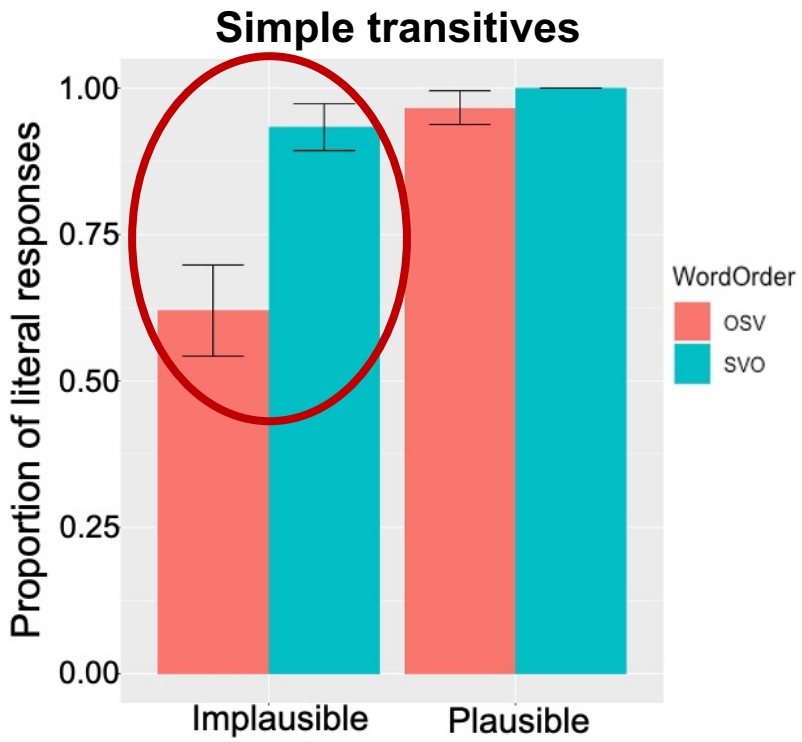


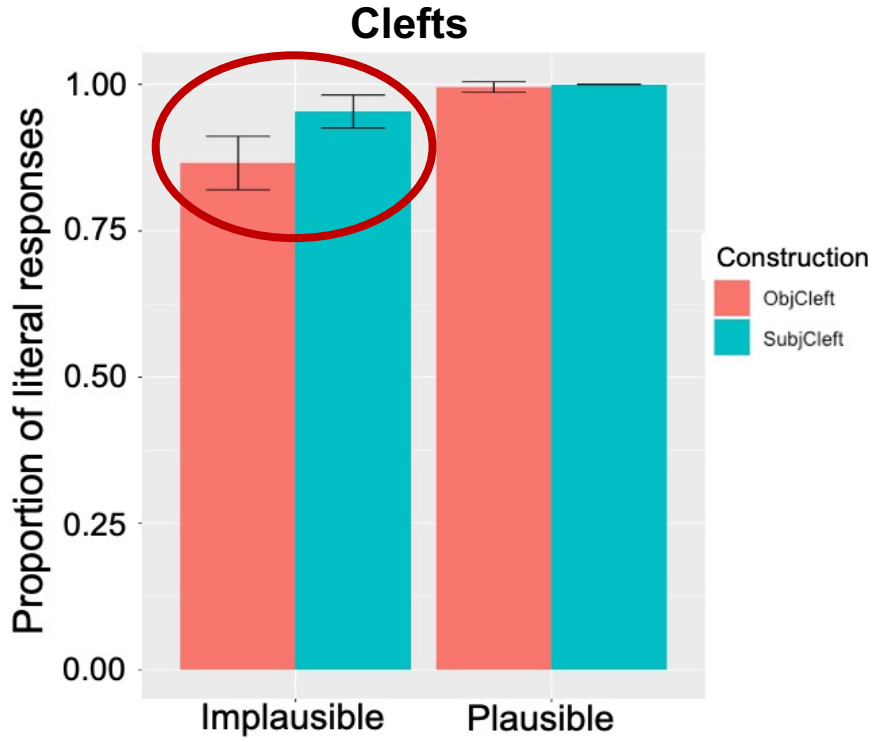
- **Linear string-based hypothesis:** the inference rate difference between SVO and OSV should be similar to that between subj and obj clefts.





Results of the comprehension questions





- Replicated Expt3: OSV sentences were more likely to be interpreted non-literally than SVO (p<0.01).
- As predicted, more non-literal responses for object clefts than for subject clefts (p<0.02).

→Comprehenders draw more inferences for low-frequency constructions

- The difference in inference rate between SVO vs. OSV is larger than that between subject and object clefts (p<0.01), supporting the construction-based hypothesis, not the linear string-based hypothesis.

Where do the non-literal responses come from?

- Our ***speaker's/transmission channel hypothesis:***

Comprehenders are fully aware of the input sentence. They draw rational inferences about the intended utterance possibly corrupted due to the speaker/transmission procedure.

- Alternative ***comprehender's channel hypothesis:***

Comprehenders are NOT fully aware of the input sentence. They mis-read/mis-retrieve the input sentence, leading to an 'incorrect' interpretation (c.f., Ferreira, 2003).

Sample trial

Sentence: The boy, the trash threw.

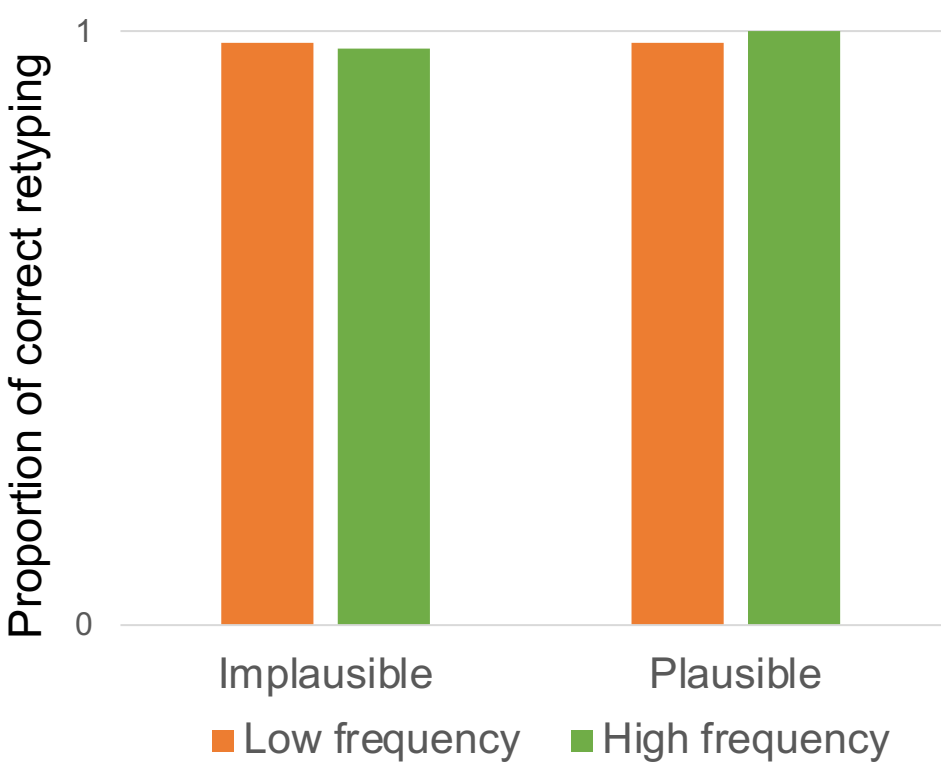
Question: Did the boy throw something/someone?

Yes (Non-literal response)

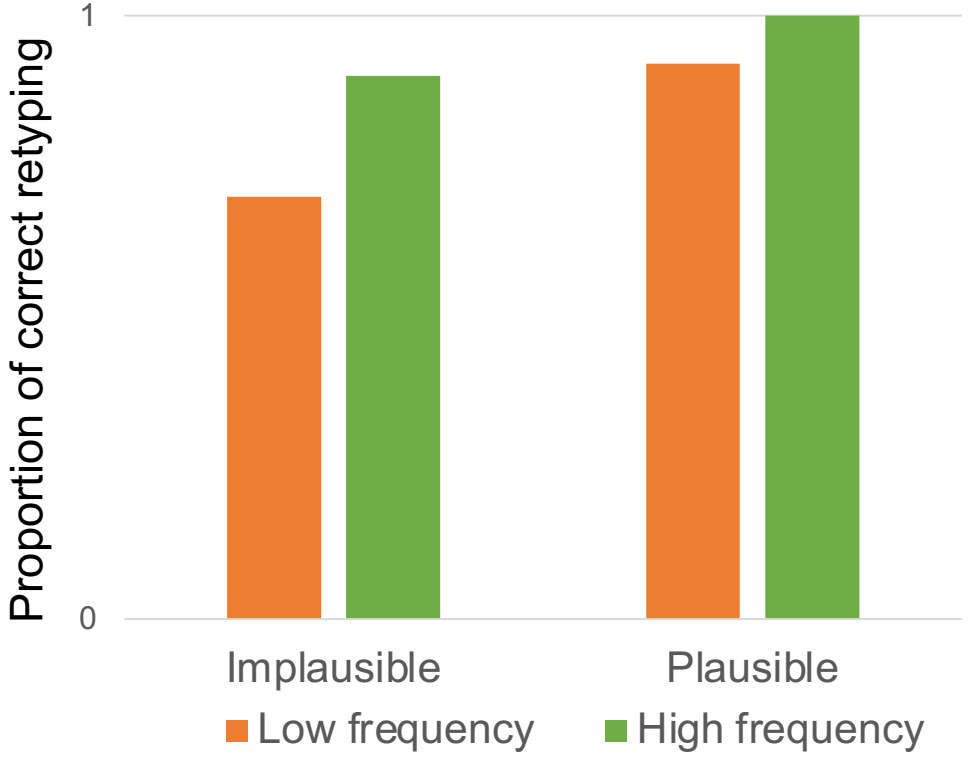
No (Literal response)

Predictions of the retyping task:

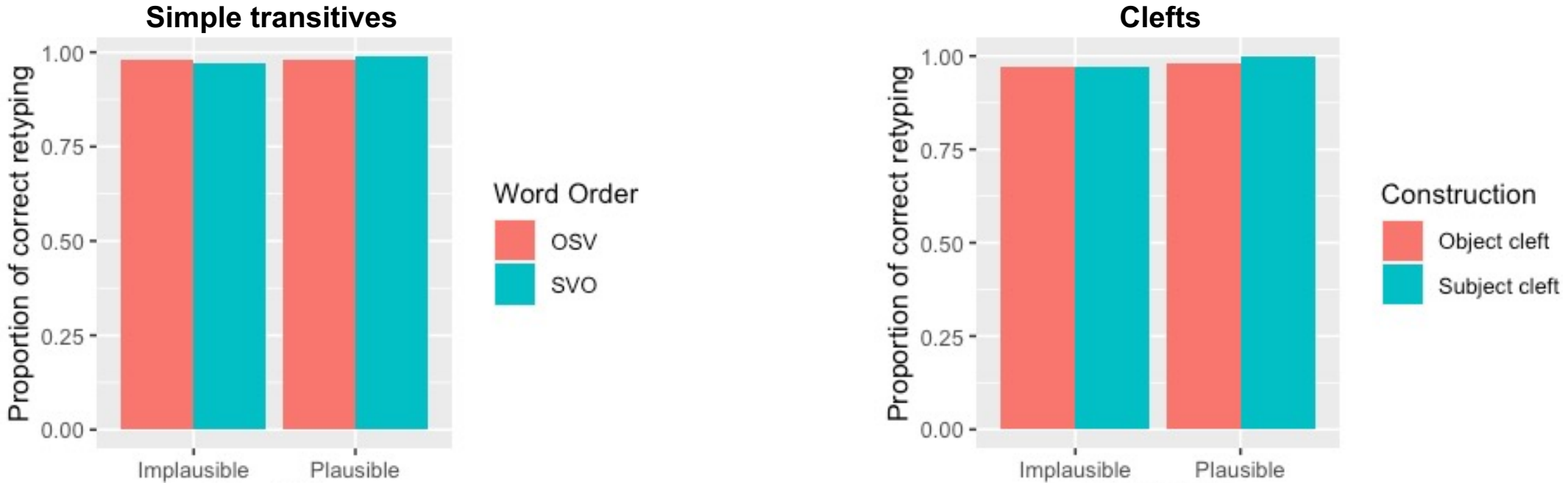
- **Speaker's channel hypothesis:**
(in our proposed noisy-channel model)
Almost no incorrect retyping



- **Comprehender's channel hypothesis:**
The proportion of incorrect retyping aligns the amount of non-literal responses



Results of the retyping task:



- The proportion of non-literal responses do not align the amount of incorrect retyping. No error in retyping even for non-literal responses.

→No evidence for the comprehender's channel hypothesis. Our speaker's channel hypothesis is more on the right track.

Discussion

- Supportive evidence for structural frequency effects in comprehenders' noisy-channel processing.

- Comprehenders track each construction separately, not just the linear string.

- The non-literal interpretations come from comprehenders' rational inferences of the intended utterance, rather than misperception.

Thank you!

Questions?

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