Contrasting facilitation profiles for agreement and reflexives revisited

A large-scale empirical evaluation of the cue-based retrieval model

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Cue-based retrieval: The ACT-R model

Anderson et al., 2004; Lewis & Vasishth, 2005

Retrieval latency and probability are determined by:

i) Match of the retrieval cues

ii) Similarity-based interference

Facilitatory interference in ungrammatical sentences

No interference

*The bodybuilder$^{-plur}_{+c\text{-}com}$ injured themselves$\{^{plur}_{c\text{-}com}\}$.

Interference

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Facilitatory interference in ungrammatical sentences

No interference

*The bodybuilder$^{-plur}_{+\,c\text{-}com}$ who worked with the trainer$^{-plur}_{-\,c\text{-}com}$ injured themselves$\{^{plur}_{c\text{-}com}\}$.

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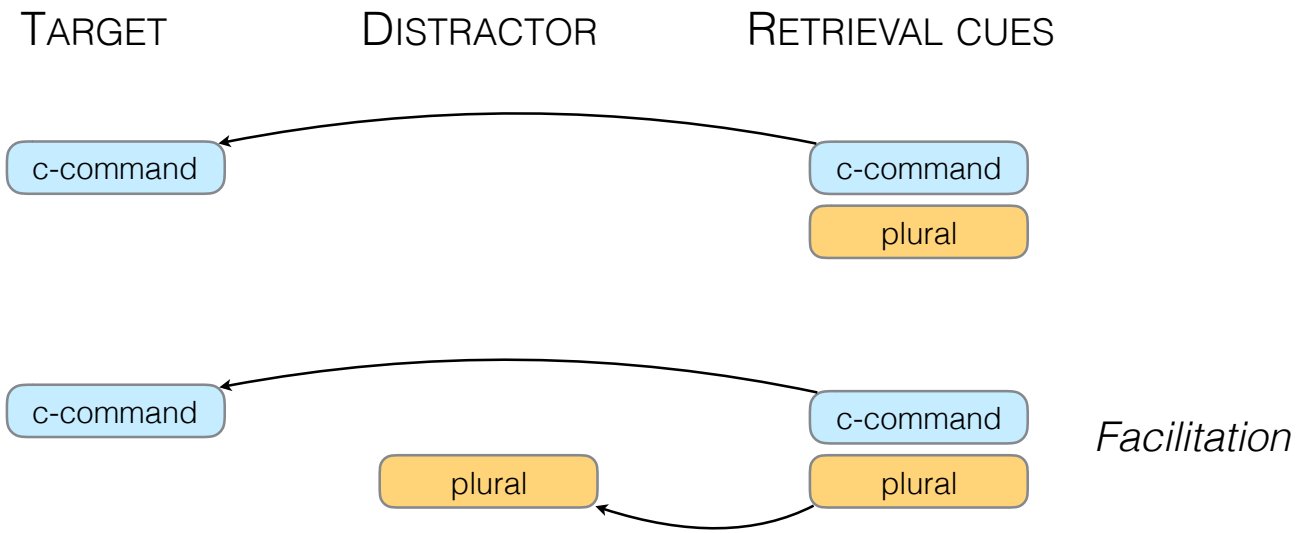

Which cues are used?

→ **Implicit assumption of Lewis & Vasishth, 2005:**

- All available cues are used equally.

→ No qualitative differences between dependency types.

↯ Dillon et al. (2013). Contrasting intrusion profiles for agreement and anaphora, JML, 69, 85–103.

Dillon, Mishler, Sloggett, & Phillips (2013)

- Direct comparison of interference effects in reflexives and subject-verb agreement.

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- Facilitatory interference in subject-verb agreement.

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- No facilitatory interference in reflexives.

$\longrightarrow$ Are structural cues given priority in reflexives?

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$\longrightarrow$ Are structural cues given priority in reflexives?

? Low statistical power.

Dillon, Mishler, Sloggett, & Phillips (2013)

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Dillon et al, 2013	-119 $[-205, -33]$ ms
Meta-analysis of Jäger et al., 2017	-22 $[-36, -9]$ ms

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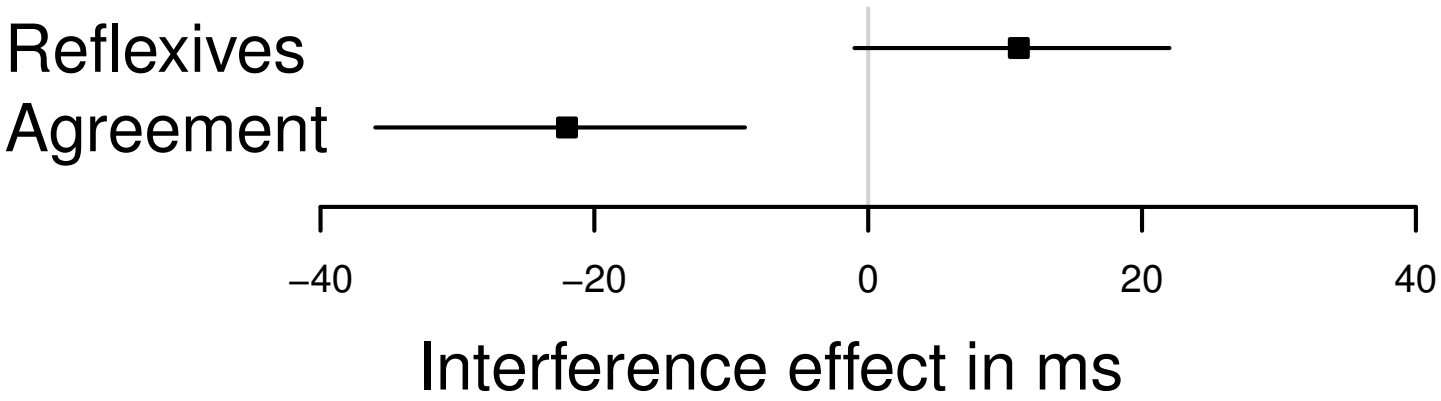
→ see also Vasishth, Mertzen, Jäger, & Gelman (2018). The statistical significance filter leads to overoptimistic expectations of replicability, JML.

Meta-analysis: Interference in ungrammatical conditions



Jäger, Engelmann, & Vasishth: Similarity-based interference in sentence comprehension: Literature review and Bayesian meta-analysis, JML 94, 2017.

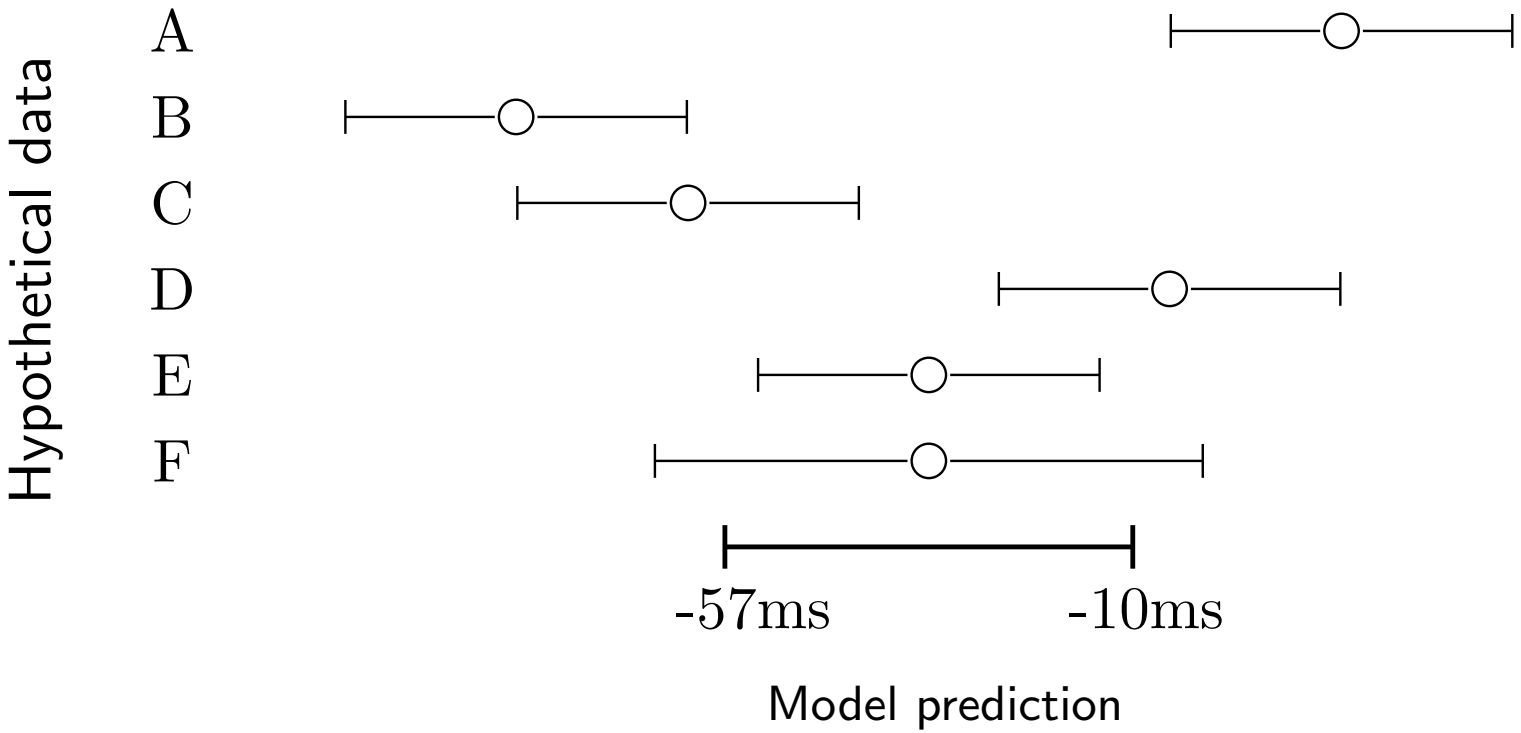
Our study

- Large-sample replication of Dillon et al. (2013)

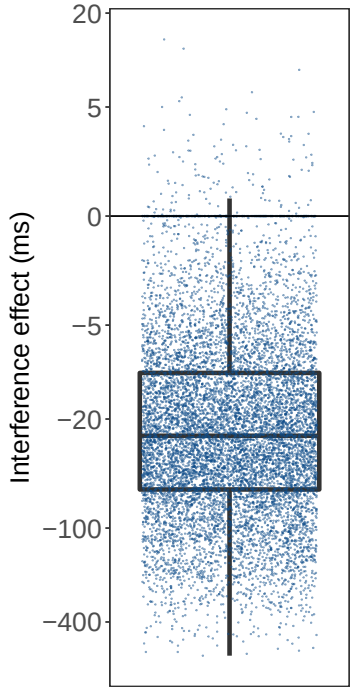
→ Bayesian parameter estimation.

- Quantitative evaluation of the Lewis & Vasishth (2005) ACT-R cue-based retrieval model.

Model evaluation: the ROPE approach (Kruschke, 2015)



ACT-R simulations



- Parameter combinations:
  - Latency factor $F \in \{0.05, 0.06, ..., 0.6\}$
  - Noise parameter $ANS \in \{0.1, 0.2, 0.3\}$
  - Maximum associative strength $MAS \in \{1, 2, 3, 4\}$
  - Mismatch penalty $MP \in \{0, 1, 2\}$
  - Retrieval threshold $\theta \in \{-2, -1.5, ..., 0\}$
- 6000 iterations per parameter configuration

Simulations conducted by Engelmann, Jäger, & Vasishth: The effect of prominence and cue association in retrieval processes: A computational account, `https://osf.io/b56qv/`

Ungrammatical conditions from Dillon et al., 2013

Agreement; no interference

*The amateur bodybuilder$^{-plur}_{+local\ subj}$ who worked with the personal trainer$^{-plur}_{-local\ subj}$ amazingly were$\{^{plur}_{local\ subj}\}$ competitive for the gold medal.

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Reflexive; no interference

*The amateur bodybuilder$^{-plur}_{+\ c\text{-}com}$ who worked with the personal trainer$^{-plur}_{-\ c\text{-}com}$ amazingly injured themselves$\{^{plur}_{c\text{-}com}\}$ on the lightest weights.

Reflexive; interference

*The amateur bodybuilder$^{-plur}_{+\ c\text{-}com}$ who worked with the personal trainers$^{+plur}_{-\ c\text{-}com}$ amazingly injured themselves$\{^{plur}_{c\text{-}com}\}$ on the lightest weights.

Method and Procedure

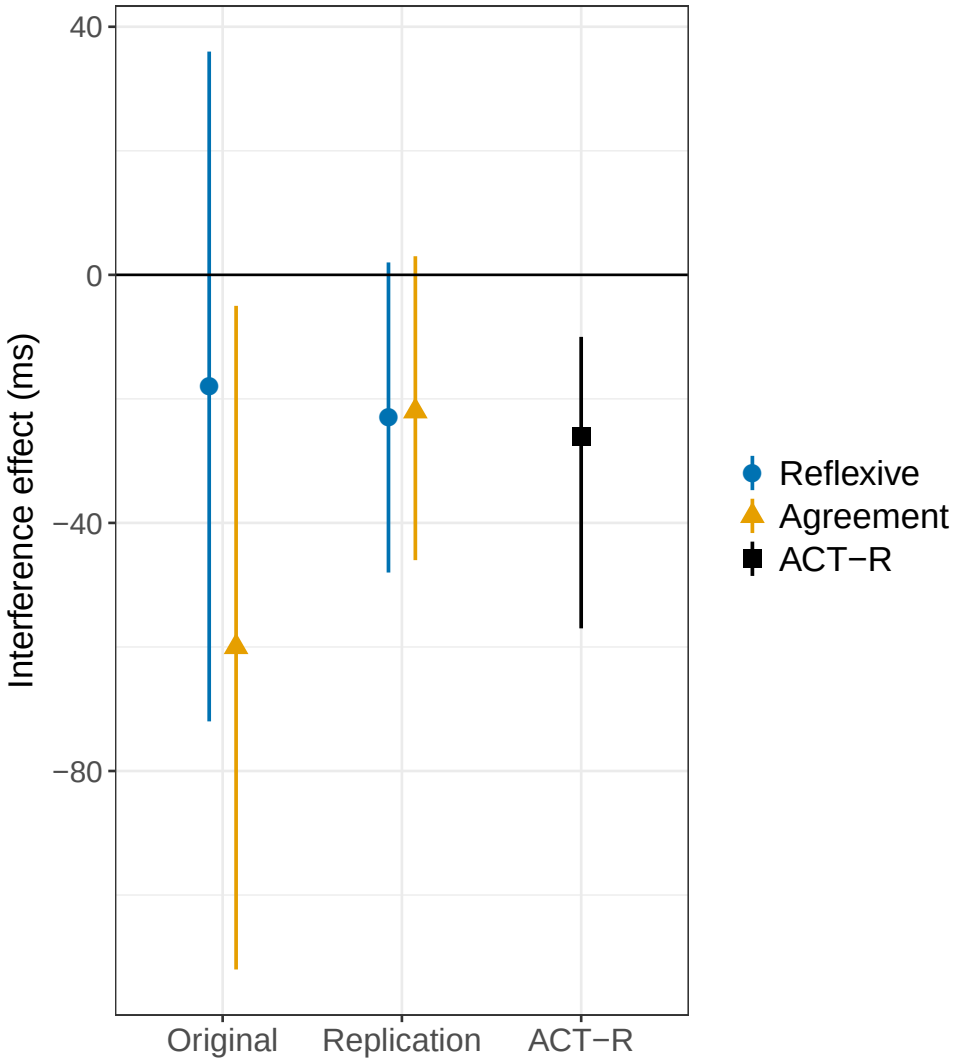
- Eyetracking-while-reading.
- 181 native speakers of English.
- 48 experimental items from Dillon et al. (2013), Expt. 1.
- Eyelink 1000 (1000Hz) with desktop mount camera.

Bayesian analysis of eye movements

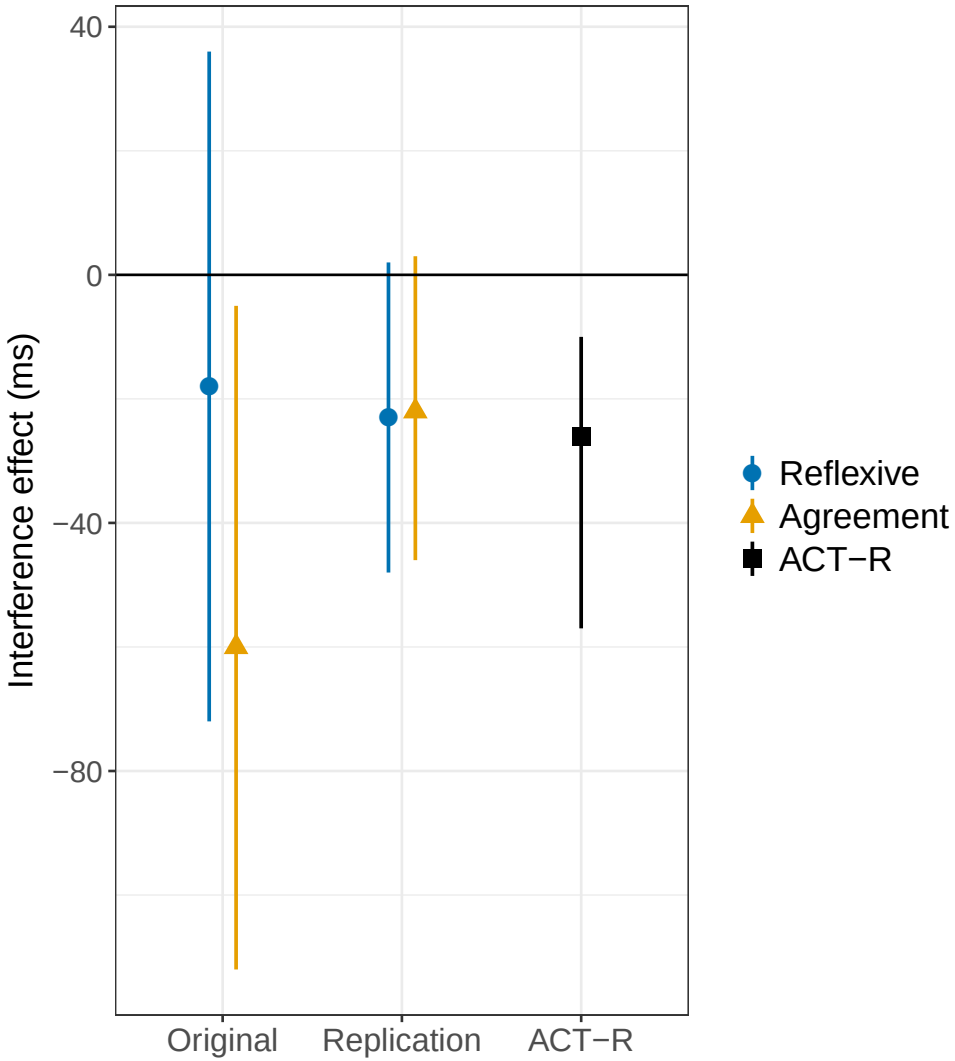
Following Dillon et al., 2013:

- Region of interest: verb/reflexive plus subsequent word
- Dependent variable: total fixation times

Results


40
0
−40
−80
Interference effect (ms)
Original
Replication
ACT−R
Reflexive
Agreement
ACT−R

Results



- Similar facilitation profiles in agreement and reflexives.

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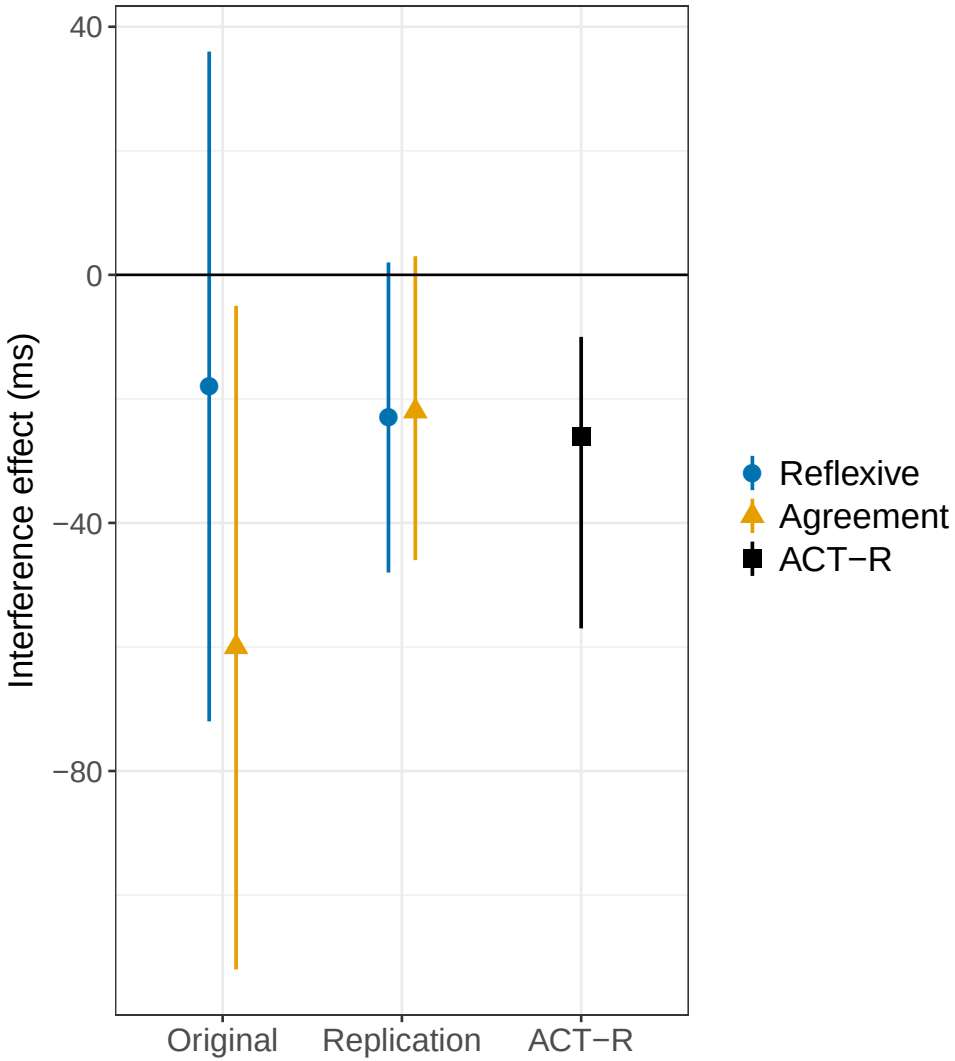

- Similar facilitation profiles in agreement and reflexives.
- Weak support for the Lewis & Vasishth (2005) ACT-R model.

Conclusion

- Very similar estimates for reflexives and agreement.
- Facilitatory interference in both agreement and reflexives of approx. 20ms.

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Conclusion

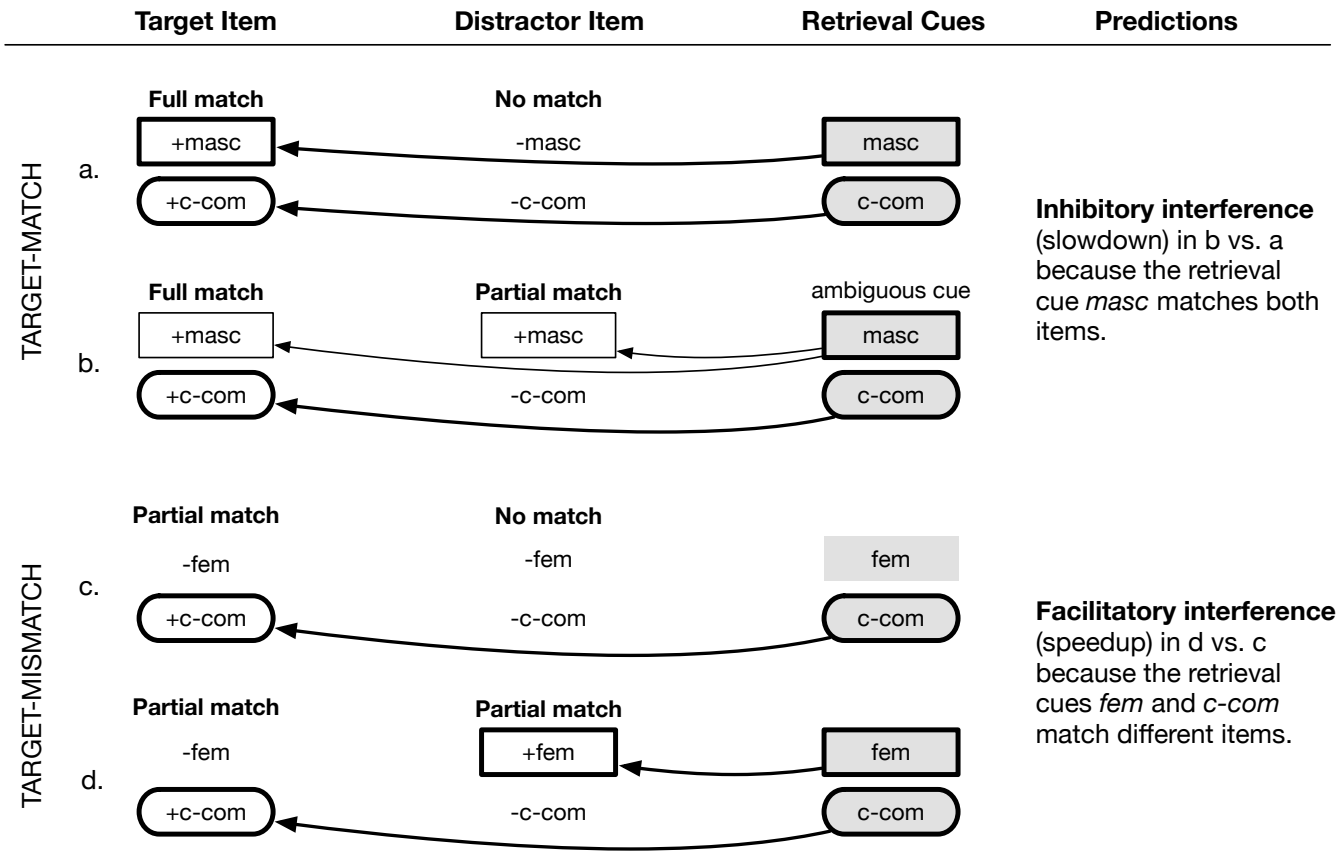
- More precise estimates for evaluating the predictions of quantitative models are needed.
  - Larger sample size.
  - Reduction of measurement error.
  - Manipulations with larger effects.

Thank you!

ACT-R equations

- Retrieval latency of item i: $RT := F \cdot e^{-A_i}$
- Activation of item i: $A_i := B_i + S_i + \epsilon$
- Baseline activation of item i: $B_i := ln(\sum_{j=1}^{n} t_j^{-d}) + \beta_i$
- Spreading activation S_i received by item i:
  $S_i := \sum_{j \in Cues} W_j S_{ij})$

  $S_{ij} := MAS - ln(fan_j$ $W_j :=$ activation from cue j



source: Jäger, Engelmann & Vasishth, JML, 2015

ACT-R prediction: Inhibition in grammatical conditions

Agreement

No interference

Interference

cue overload $\rightarrow$ **inhibition**

ACT-R prediction: Inhibition in grammatical conditions

Reflexives

No interference

Interference

cue overload $\rightarrow$ **inhibition**

ACT-R prediction: Facilitation in ungrammatical conditions

Agreement

No interference

Interference

race → **facilitation**

ACT-R prediction: Facilitation in ungrammatical conditions

Reflexives

No interference

Interference

race → **facilitation**

Bayesian hierarchical regression

Random effects prior distributions:

$$\beta_{subj}, \beta_{item} \sim N_4(\vec{0}, Cov) \tag{1}$$

$$Cov = \begin{bmatrix} \sigma_0 & & \\ & \ddots & \\ & & \sigma_3 \end{bmatrix} \cdot R \cdot \begin{bmatrix} \sigma_0 & & \\ & \ddots & \\ & & \sigma_3 \end{bmatrix} \tag{2}$$

$$\sigma_{1,\ldots,3} \sim N_+(0, 1) \tag{3}$$

$$R \sim LKJ(2) \tag{4}$$

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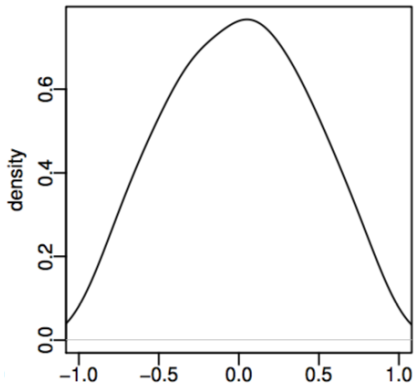

$$R \sim LKJ(2) \tag{4}$$

Results: Original data

Effect	**Posterior mean (ms)**
Dependency	119 [71, 169]
Grammaticality	100 [69, 134]
Dependency×Grammaticality	9 [-18, 36]
Interference [grammatical] [reflexives]	2 [-57, 60]
Interference [grammatical] [agreement]	-34 [-85, 15]
Interference [ungrammatical] [reflexives]	-18 [-72, 36]
Interference [ungrammatical] [agreement]	-60 [-112, -5]

Results: Original data

	Effect	Posterior mean (ms)
all	Dependency	119 [71, 169]
	Grammaticality	100 [69, 134]
	Dependency×Grammaticality	9 [-18, 36]
Model 1	Interference	-27 [-56, 1]
	Dependency×Interference	-20 [-46, 6]
	Grammaticality×Interference	-11 [-38, 15]
	Dependency×Grammaticality×Interference	-2 [-27, 24]
Model 2	Interference [grammatical]	-16 [-52, 20]
	Interference [ungrammatical]	-38 [-79, 1]
	Dependency×Interference [grammatical]	-17 [-56, 19]
	Dependency×Interference [ungrammatical]	-21 [-56, 12]
Model 3	Interference [grammatical] [reflexives]	2 [-57, 60]
	Interference [grammatical] [agreement]	-34 [-85, 15]
	Interference [ungrammatical] [reflexives]	-18 [-72, 36]
	Interference [ungrammatical] [agreement]	-60 [-112, -5]

Results: Replication experiment

Effect	**Posterior mean (ms)**
Dependency	141 [100, 184]
Grammaticality	121 [100, 141]
Dependency×Grammaticality	-17 [-30, -5]
Interference [grammatical] [reflexives]	12 [-16, 43]
Interference [grammatical] [agreement]	5 [-18, 28]
Interference [ungrammatical] [reflexives]	-23 [-48, 2]
Interference [ungrammatical] [agreement]	-22 [-46, 3]

Results: Replication experiment

	Effect	Posterior mean (ms)
all	Dependency	141 [100, 184]
	Grammaticality	121 [100, 141]
	Dependency×Grammaticality	-17 [-30, -5]
Model 1	Interference	-7 [-19, 5]
	Dependency×Interference	-2 [-14, 10]
	Grammaticality×Interference	-16 [-30, -2]
	Dependency×Grammaticality×Interference	2 [-11, 16]
Model 2	Interference [grammatical]	9 [-9, 28]
	Interference [ungrammatical]	-23 [-41, -5]
	Dependency×Interference [grammatical]	-4 [-21, 13]
	Dependency×Interference [ungrammatical]	1 [-17, 18]
Model 3	Interference [grammatical] [reflexives]	12 [-16, 43]
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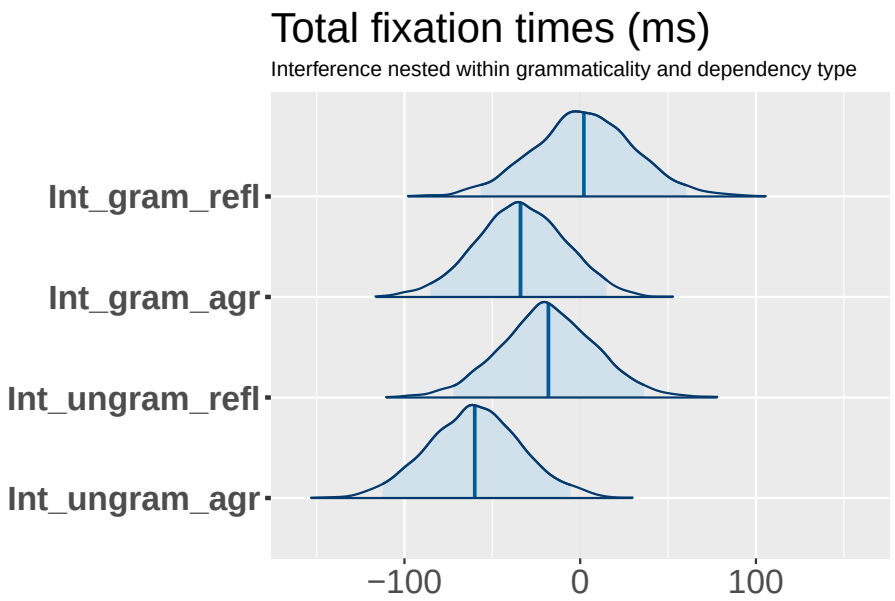
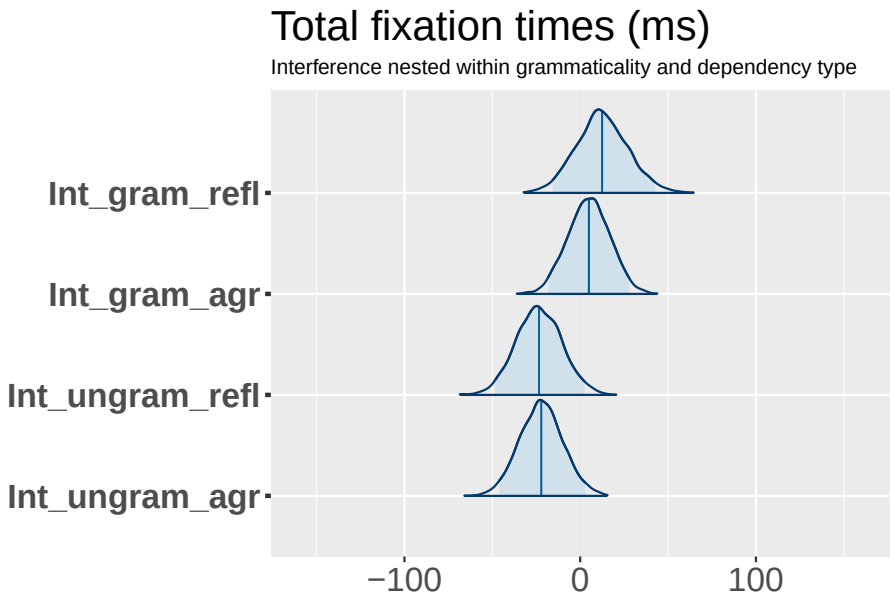
Total fixation times

Dillon et al., 2013

Large-sample study

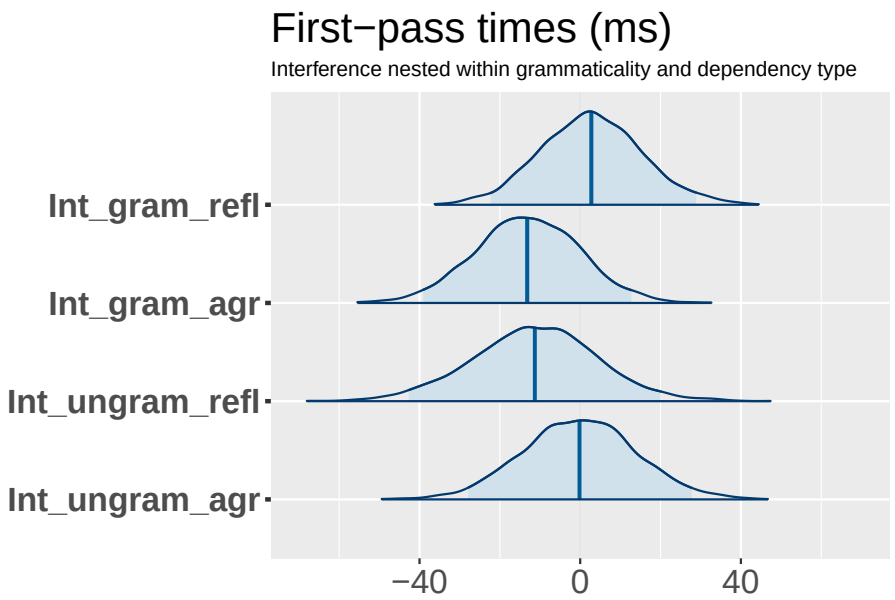


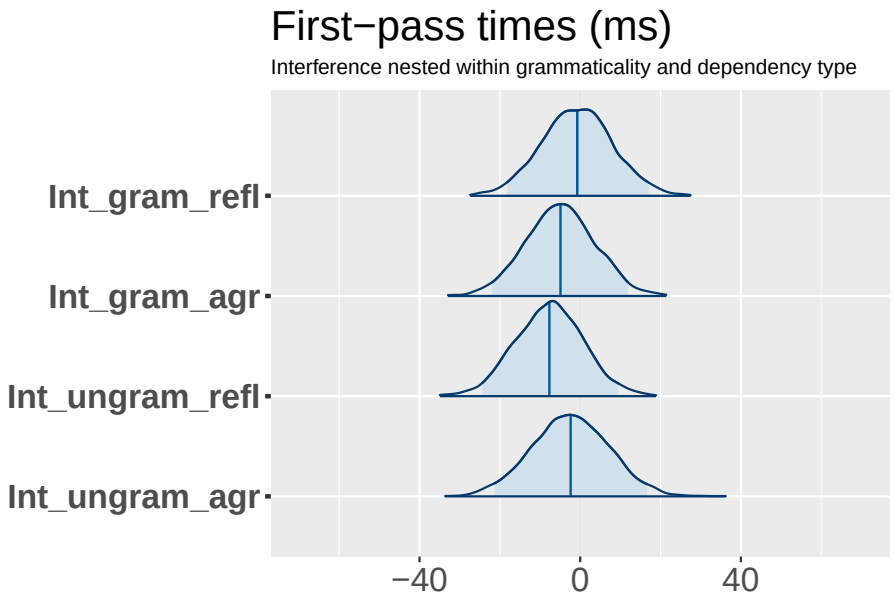


First-pass reading times

Dillon et al., 2013

Large-sample study





Proportion of first-pass regressions

Dillon et al., 2013

Large-sample study