Similarity-based interference in sentence comprehension: A new computational model

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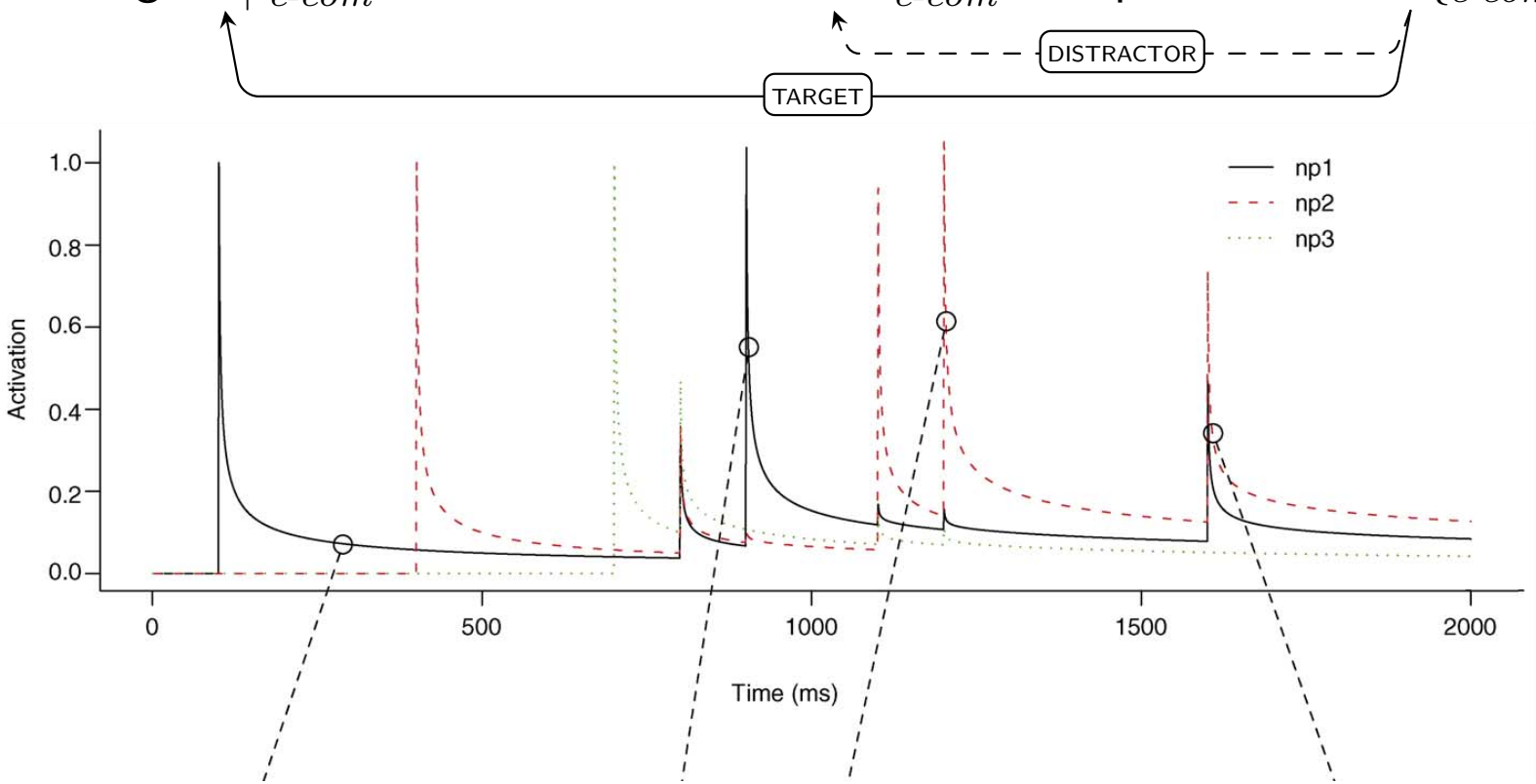
August, 2016

Cue-based retrieval (ACT-R, LV05)

Anderson et al. (2004); Lewis and Vasishth (2005)

The surgeon $^{+masc}_{+c\text{-}com}$ who treated Jonathan $^{+masc}_{-c\text{-}com}$ had pricked himself $\{^{masc}_{c\text{-}com}\}$ ...



Decay Retrieval Interference

(Lewis, Vasishth, & Van Dyke, 2006, Fig. 2)

Cue-based retrieval (ACT-R, LV05)

Anderson et al. (2004); Lewis and Vasishth (2005)

The retrieval time of an item is a function of its activation A_i:

$$RT = Fe^{-(f \times A_i)} \tag{1}$$

$$A_i = B_i + S_i \tag{2}$$

Base-level activation:

$$B_i = \ln(\sum_{j=1}^{n} t_j^{-d}) + \beta_i \tag{3}$$

An item receives spreading activation from all matching cues:

$$S_i = \sum_j W_j S_{ji} \tag{4}$$

Cue-based retrieval (ACT-R, LV05)

Anderson et al. (2004); Lewis and Vasishth (2005)

The spreading activation depends on the associative strength between each cue and the item:

$$S_{ji} = MAS - \ln(fan_{ji}) \tag{5}$$

The cue-item association is weakened by competitor items matching the cue:

$$fan_{ji} = 1 + items_j \tag{6}$$

This is called the **fan effect**.

Inhibitory interference

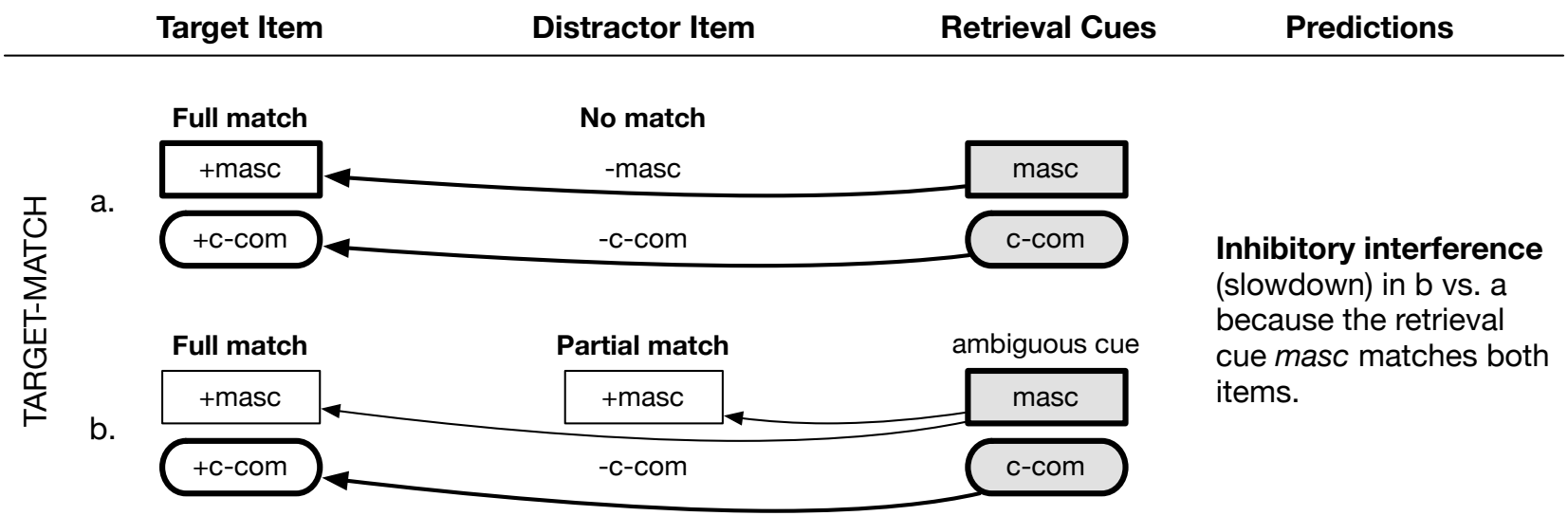
a. The surgeon $\begin{smallmatrix}+masc\\+c\text{-}com\end{smallmatrix}$ who treated Jennifer $\begin{smallmatrix}-masc\\-c\text{-}com\end{smallmatrix}$ had pricked himself $\{\begin{smallmatrix}masc\\c\text{-}com\end{smallmatrix}\}$ . . .

TARGET

b. The surgeon $\begin{smallmatrix}+masc\\+c\text{-}com\end{smallmatrix}$ who treated Jonathan $\begin{smallmatrix}+masc\\-c\text{-}com\end{smallmatrix}$ had pricked himself $\{\begin{smallmatrix}masc\\c\text{-}com\end{smallmatrix}\}$ . . .

DISTRACTOR

TARGET



Inhibitory interference (slowdown) in b vs. a because the retrieval cue *masc* matches both items.

Facilitatory interference

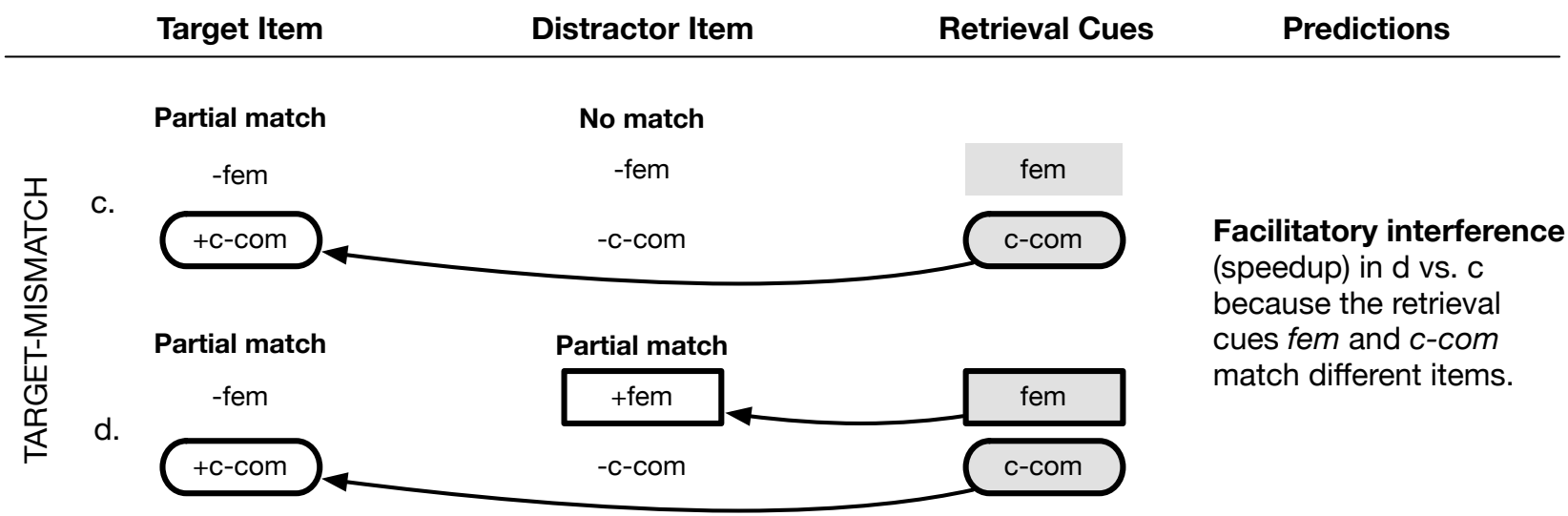
c. The surgeon $^{-fem}_{+c\text{-}com}$ who treated Jonathan $^{-fem}_{-c\text{-}com}$ had pricked herself $\{^{fem}_{c\text{-}com}\}$ ...

TARGET

d. The surgeon $^{-fem}_{+c\text{-}com}$ who treated Jennifer $^{+fem}_{-c\text{-}com}$ had pricked herself $\{^{fem}_{c\text{-}com}\}$ ...

DISTRACTOR

TARGET



Facilitatory interference (speedup) in d vs. c because the retrieval cues *fem* and *c-com* match different items.

Retrieval interference - Summary

TARGET-MATCH: inhibitory interference

a. The surgeon $^{+masc}_{+\text{c-com}}$ who treated Jennifer $^{-masc}_{-\text{c-com}}$ had pricked himself $\{^{masc}_{\text{c-com}}\}$ ...

b. The surgeon $^{+masc}_{+\text{c-com}}$ who treated Jonathan $^{+masc}_{-\text{c-com}}$ had pricked himself $\{^{masc}_{\text{c-com}}\}$ ...

TARGET-MISMATCH: facilitatory interference

c. The surgeon $^{-fem}_{+\text{c-com}}$ who treated Jonathan $^{-fem}_{-\text{c-com}}$ had pricked herself $\{^{fem}_{\text{c-com}}\}$ ...

d. The surgeon $^{-fem}_{+\text{c-com}}$ who treated Jennifer $^{+fem}_{-\text{c-com}}$ had pricked herself $\{^{fem}_{\text{c-com}}\}$ ...

Two extensions to the cue-based retrieval model

Principle I: Associative Cues

- A retrieval cue can be associated with multiple feature values in certain contexts (acquired through associative learning).
- Predicts unexpected slow-down in reciprocals (Kush & Phillips, 2014) and Mandarin reflexives (Jäger, Engelmann, & Vasishth, 2015) due to **cue confusion**.

Principle II: Prominence

- The general saliency of items affects the interference effect.
- Predicts unexpected speed-up for experiments with distractors in subject position and being the discourse topic (Cunnings & Felser, 2013; Sturt, 2003).

Engelmann (PhD Thesis, 2016)

Principle I: Associative Cues – Cue confusion

Cue-feature associations are acquired through usage-based associative learning.

Engelmann (PhD Thesis, 2016)

Principle I: Associative Cues – Cue confusion

Cue-feature associations are acquired through usage-based associative learning.

The surgeon had pricked himself $\{^{masc}_{c\text{-}com}\}$ **reflexive**

Engelmann (PhD Thesis, 2016)

Principle I: Associative Cues – Cue confusion

Cue-feature associations are acquired through usage-based associative learning.

The	surgeon	had pricked	himself	$\{^{masc}_{c\text{-}com}\}$	**reflexive**
			herself	$\{^{fem}_{c\text{-}com}\}$	

Engelmann (PhD Thesis, 2016)

Principle I: Associative Cues – Cue confusion

Cue-feature associations are acquired through usage-based associative learning.

The	surgeon	had pricked	himself	$\{^{masc}_{c\text{-}com}\}$	**reflexive**
			herself	$\{^{fem}_{c\text{-}com}\}$	
			itself	$\{^{neut}_{c\text{-}com}\}$	

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			herself	$\{^{fem}_{c\text{-}com}\}$	
			itself	$\{^{neut}_{c\text{-}com}\}$	
			themselves	$\{^{plur}_{c\text{-}com}\}$	

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			herself	$\{^{fem}_{c\text{-}com}\}$	
			itself	$\{^{neut}_{c\text{-}com}\}$	
			themselves	$\{^{plur}_{c\text{-}com}\}$	
The	patients	liked	each other	$\{^{plur}_{c\text{-}com}\}$	**reciprocal**

Engelmann (PhD Thesis, 2016)

Principle I: Associative Cues – Cue confusion

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The	surgeon	had pricked	himself	$\{^{masc}_{c\text{-}com}\}$	**reflexive**
			herself	$\{^{fem}_{c\text{-}com}\}$	
			itself	$\{^{neut}_{c\text{-}com}\}$	
			themselves	$\{^{plur}_{c\text{-}com}\}$	
The	patients	liked	each other	$\{^{plur}_{c\text{-}com}\}$	**reciprocal**
			ziji	$\{^{anim}_{c\text{-}com}\}$	**Mandarin reflexive**

Engelmann (PhD Thesis, 2016)

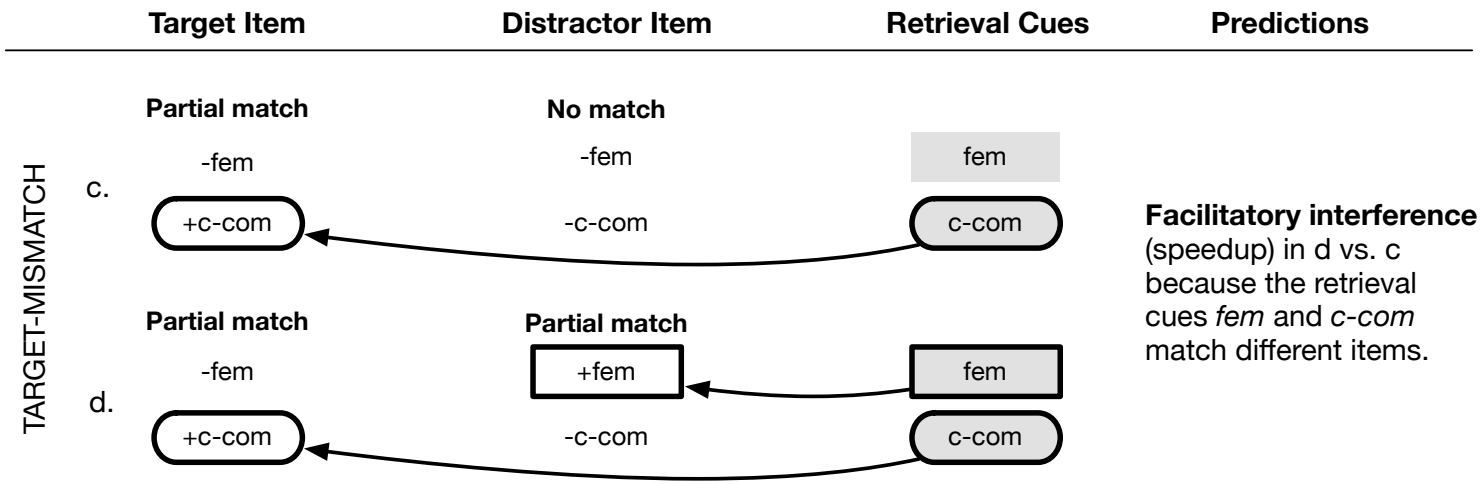
Principle I: Associative Cues – Cue confusion

Cue-feature associations are acquired through usage-based associative learning.

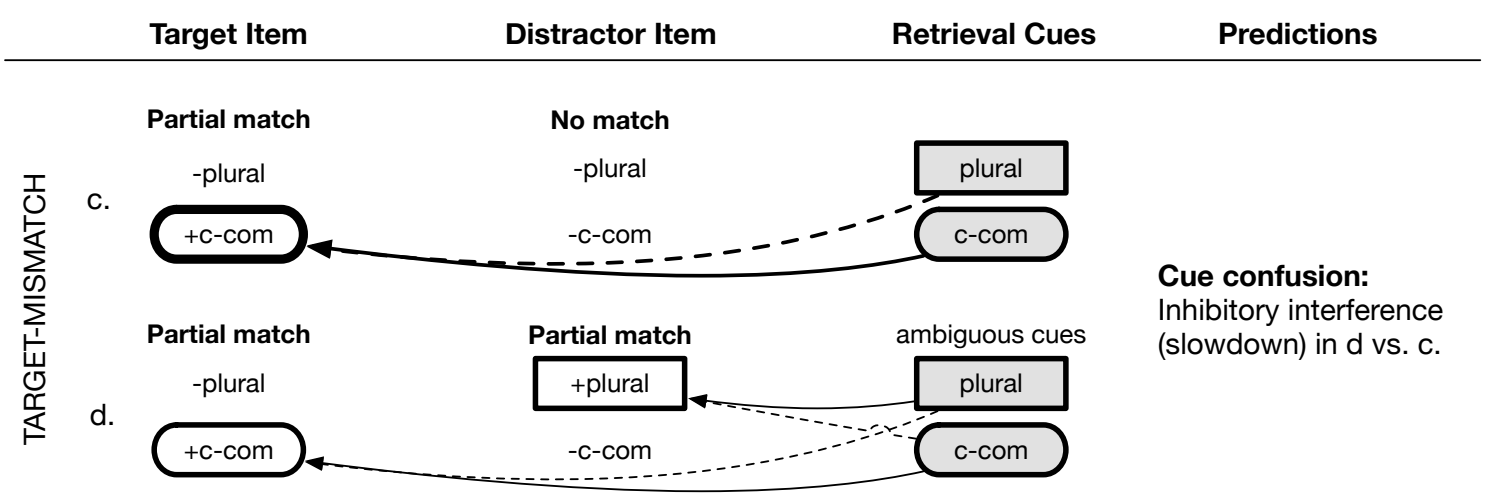
HIGH SELECTIVITY	himself	$\{^{masc}_{c\text{-}com}\}$	**reflexive**
	herself	$\{^{fem}_{c\text{-}com}\}$	
	itself	$\{^{neut}_{c\text{-}com}\}$	
	themselves	$\{^{plur}_{c\text{-}com}\}$	
LOW SELECTIVITY	each other	$\{^{plur}_{c\text{-}com}\}$	**reciprocal**
	ziji	$\{^{anim}_{c\text{-}com}\}$	**Mandarin reflexive**

Engelmann (PhD Thesis, 2016)

Reflexives (HIGH SELECTIVITY)



Reciprocals (LOW SELECTIVITY)



Engelmann (PhD Thesis, 2016)

Implementation – Associative Cues

The association between cue j and item i reflects the probability of the item i being needed given cue j (Schneider & Anderson, 2012, Eq. 2a):

$$S_{ji} = MAS + \ln[P(i|j)] \tag{7}$$

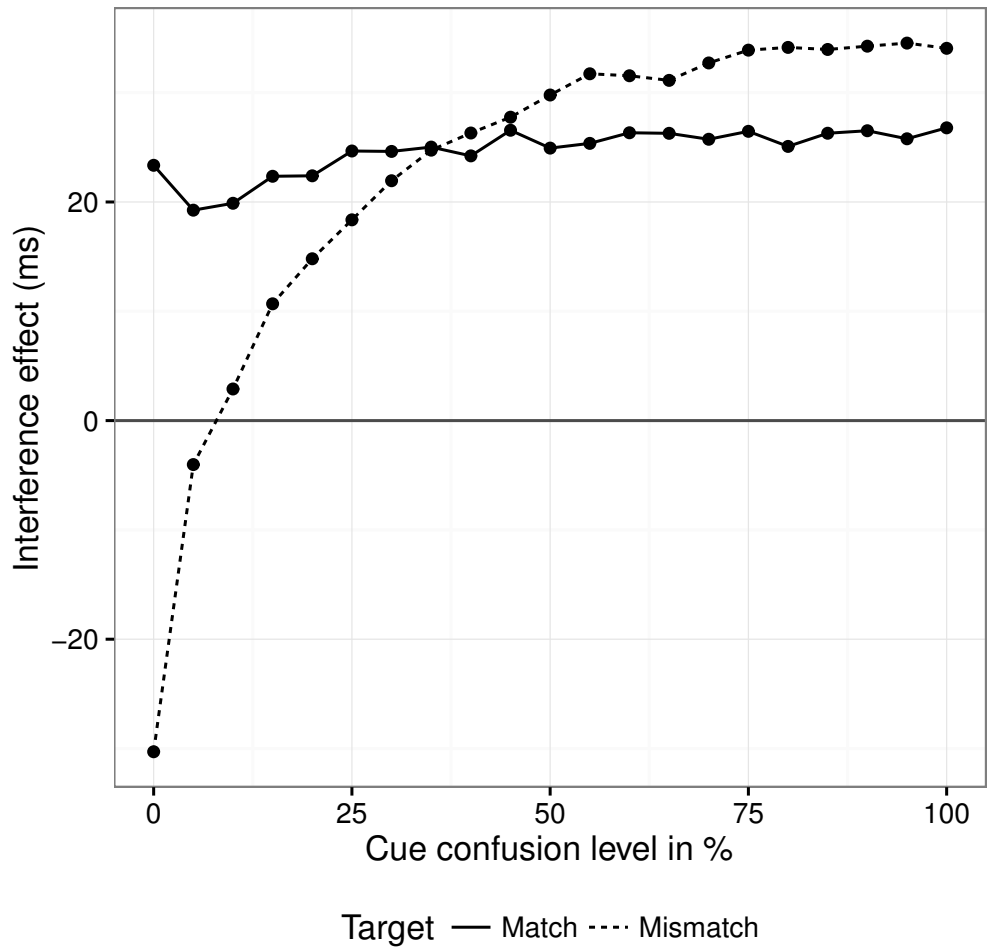
$P(i|j)$ is defined by the **match quality** of item i with cue j in proportion to the match quality of all other active memory items v with j:

$$P(i|j) = \frac{Q_{ji}}{\sum_v Q_{jv}} \tag{8}$$

The individual match quality of cue j with item i depends on the associative strength between j and all features K of i:

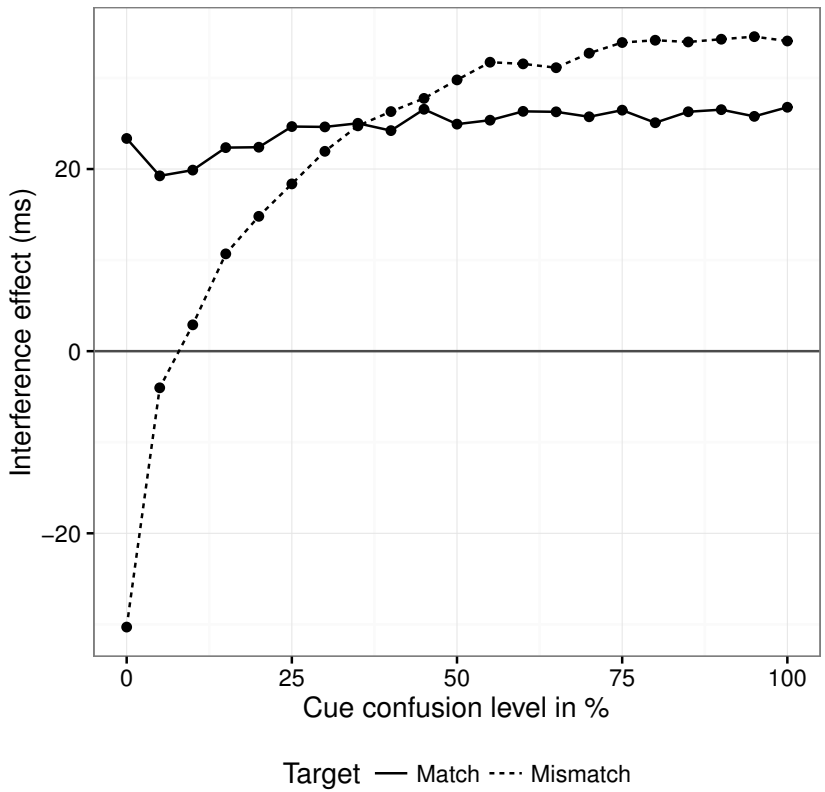
$$Q_{ji} = \sum_{k \in K_i} M_{jk} \tag{9}$$

Predictions – Associative Cues



Engelmann, Jäger, and Vasishth (manuscript)

Predictions – Associative Cues



Inhibitory interference in target-mismatch for low cue-feature selectivity (feature-co-occurrence)

1. Reciprocals
   Kush and Phillips (2014) (Hindi)
2. Mandarin reflexives
   Jäger et al. (2015)

Engelmann, Jäger, and Vasishth (manuscript)

Principle II: Prominence

Stronger inhibitory effect in target-match with prominent distractor.

Subject position

Cunnings and Felser (2013); Patil, Vasishth, and Lewis (2012); Van Dyke and McElree (2011)

(1) The surgeon who treated **Jonathan** had pricked himself with a used syringe needle.

(2) The tough soldier that **Fred** treated in the military hospital introduced himself to all the nurses.

Discourse topic

(3) **James** has worked at the army hospital for years.
The soldier that **he** treated on the ward wounded himself while on duty in the Far East.

Implementation – Prominence

The individual match quality of cue j with item i, Q_{ji} depends on the associative strength between j and all features K of i, **weighted by the general saliency of the item**:

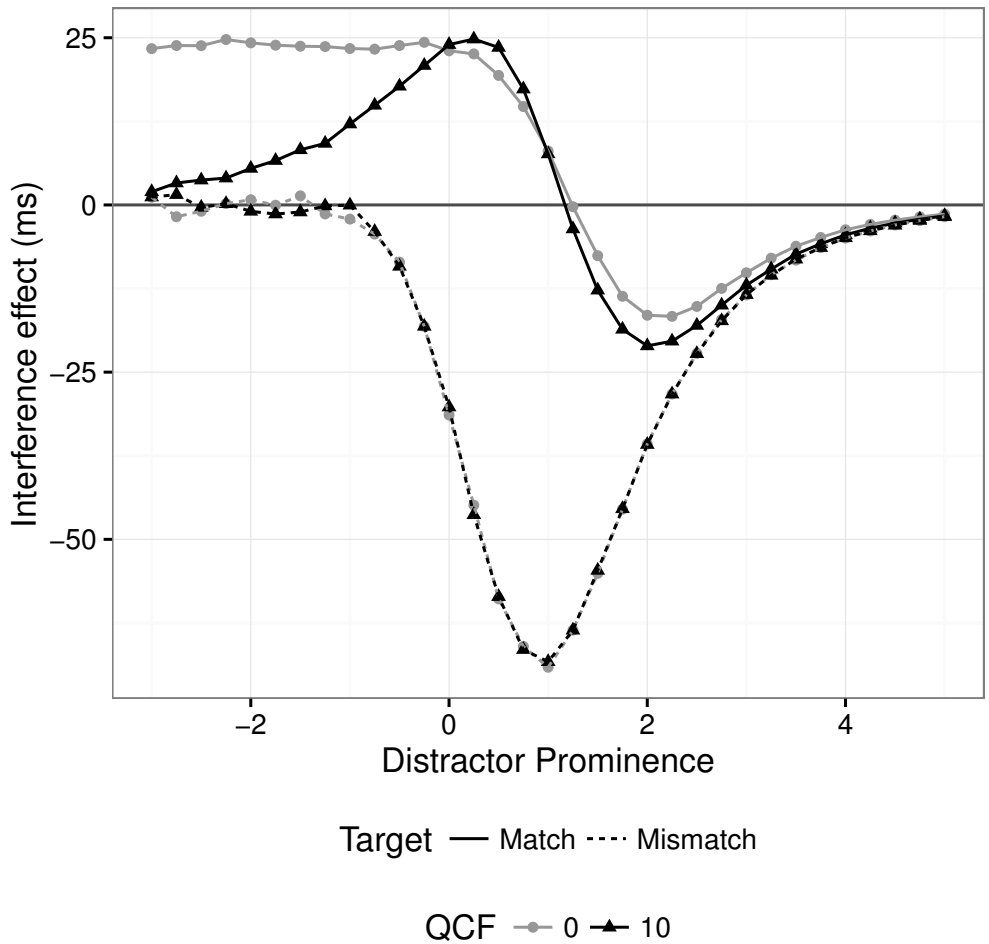
$$Q_{ji} = \sum_{k \in K_i} M_{jk} \times \mathit{saliency}_i \tag{10}$$

The saliency of an item is defined as:

$$\mathit{saliency}_i = \frac{1}{1 + qe^{-(B_i + p_i - \tau)}} \tag{11}$$

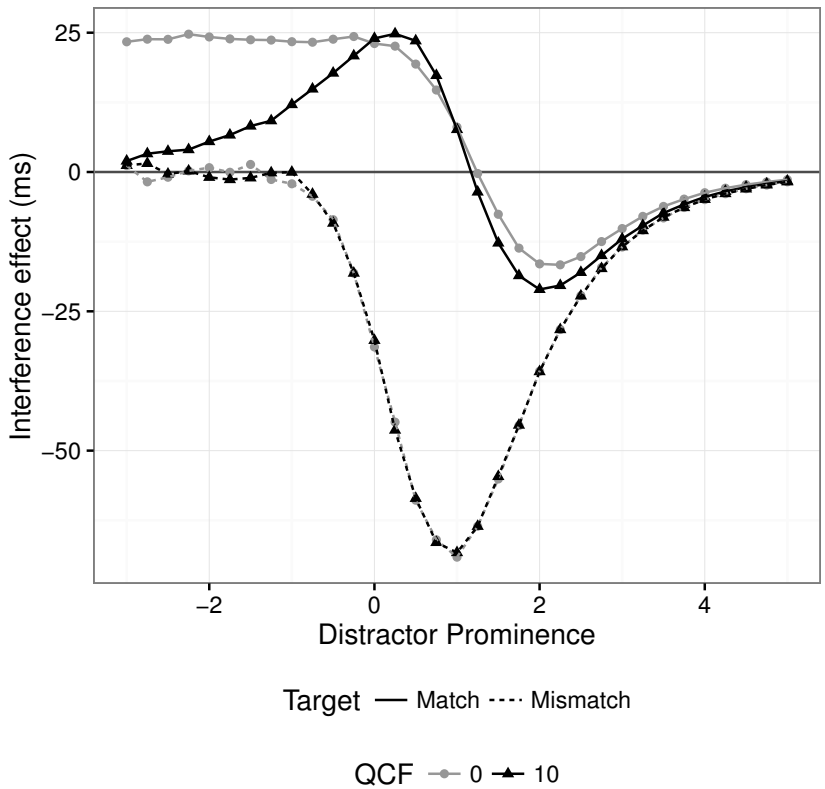
$p_i =$ The **prominence** of i
$q =$ The **quality correction factor QCF**
$B_i =$ The base-level activation of i

Predictions – Prominence



Engelmann, Jäger, and Vasishth (manuscript)

Predictions – Prominence



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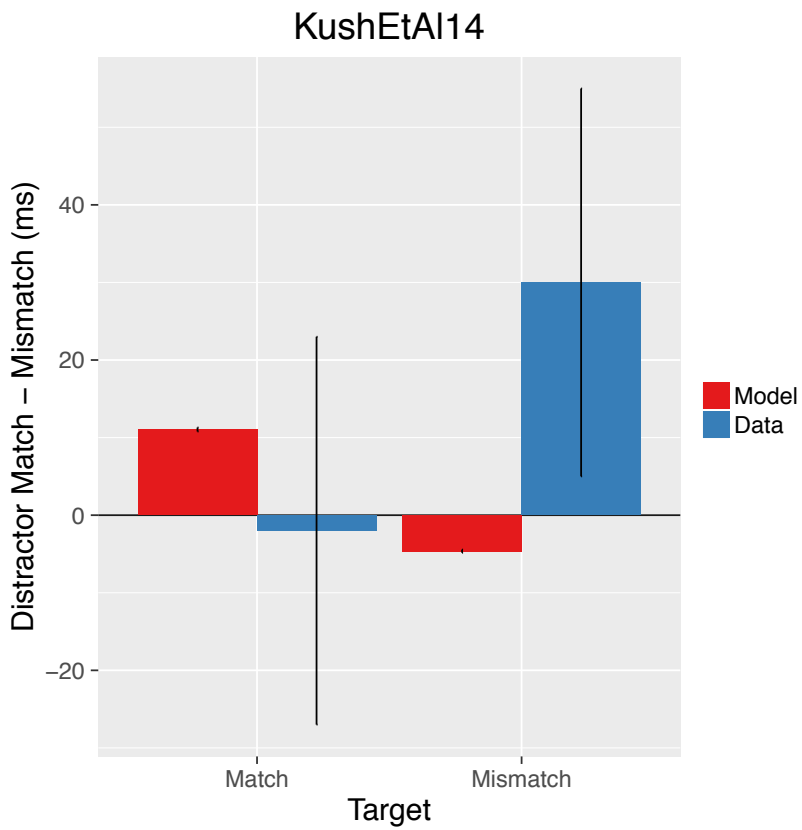
1. Stronger inhibitory effect in target-match with subject OR topicalized distractor.
   Cunnings and Felser (2013); Patil et al. (2012); Van Dyke and McElree (2011)

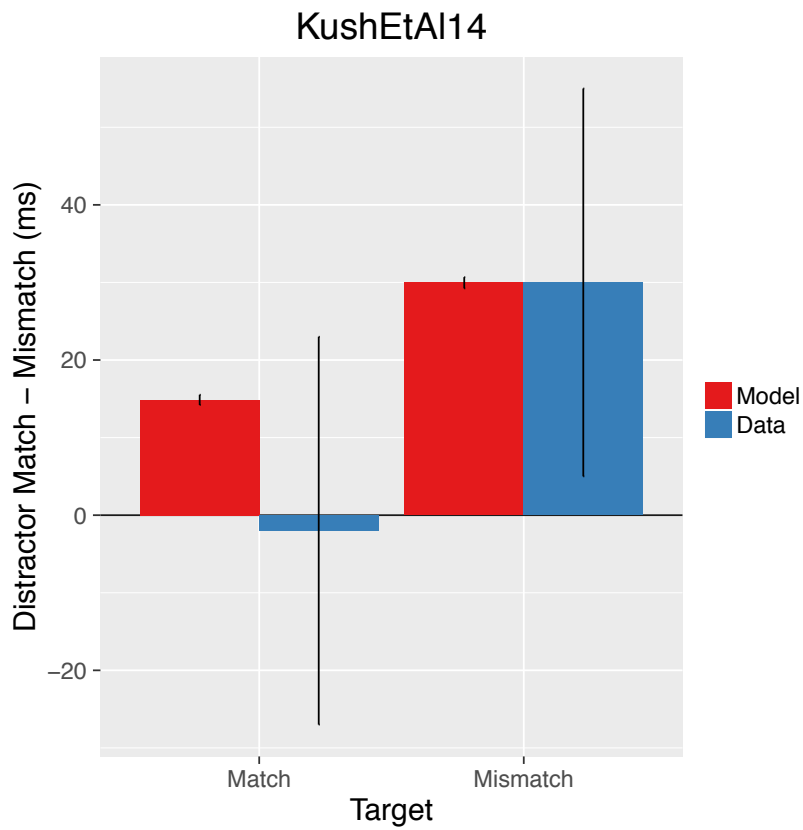
2. Facilitatory effect in target-match with subject AND topicalized distractor.
   Cunnings and Felser (2013); Sturt (2003)

Simulations

Cue confusion in Hindi reciprocals



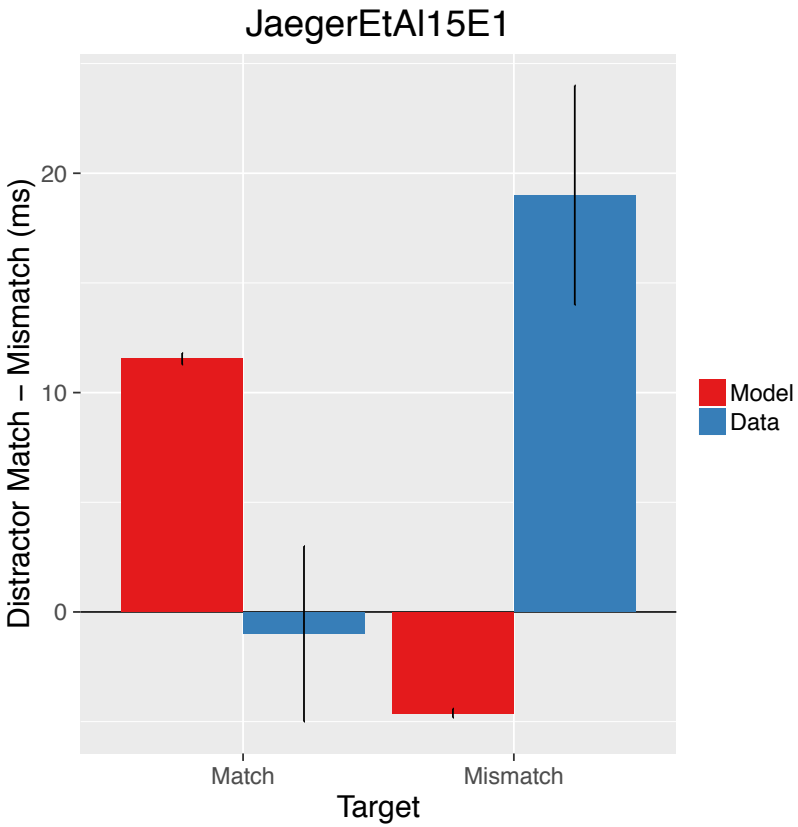
Classic model



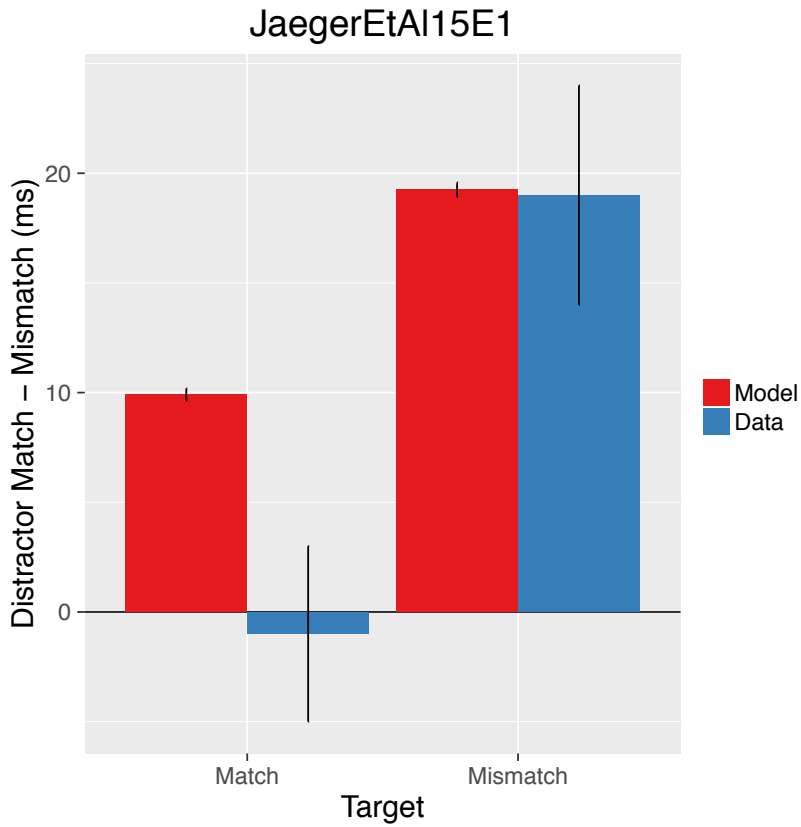
New model

Simulations

Cue confusion in Mandarin reflexives



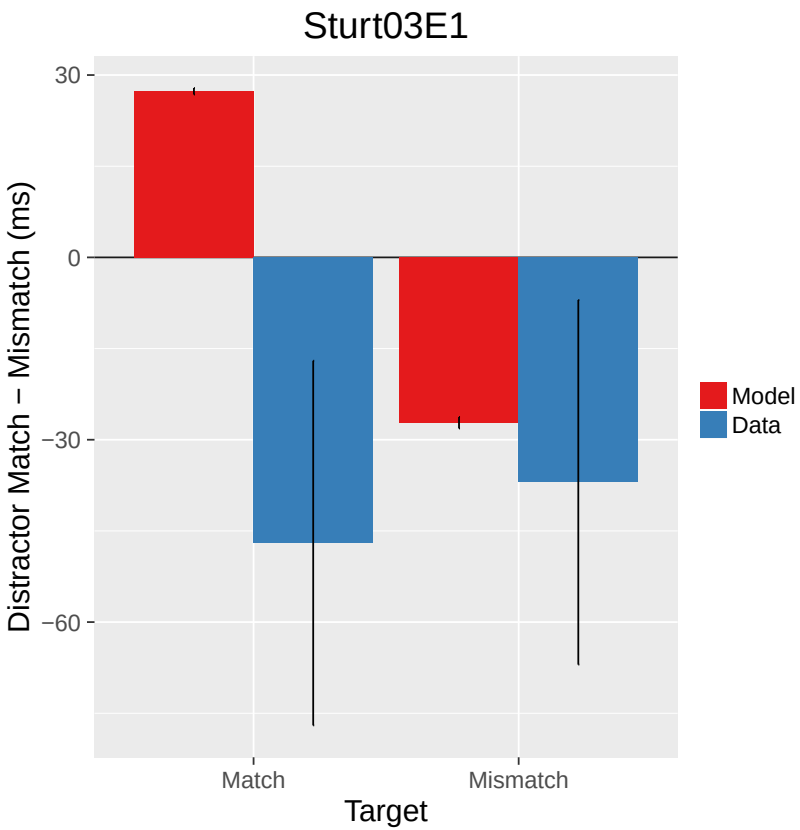
Classic model



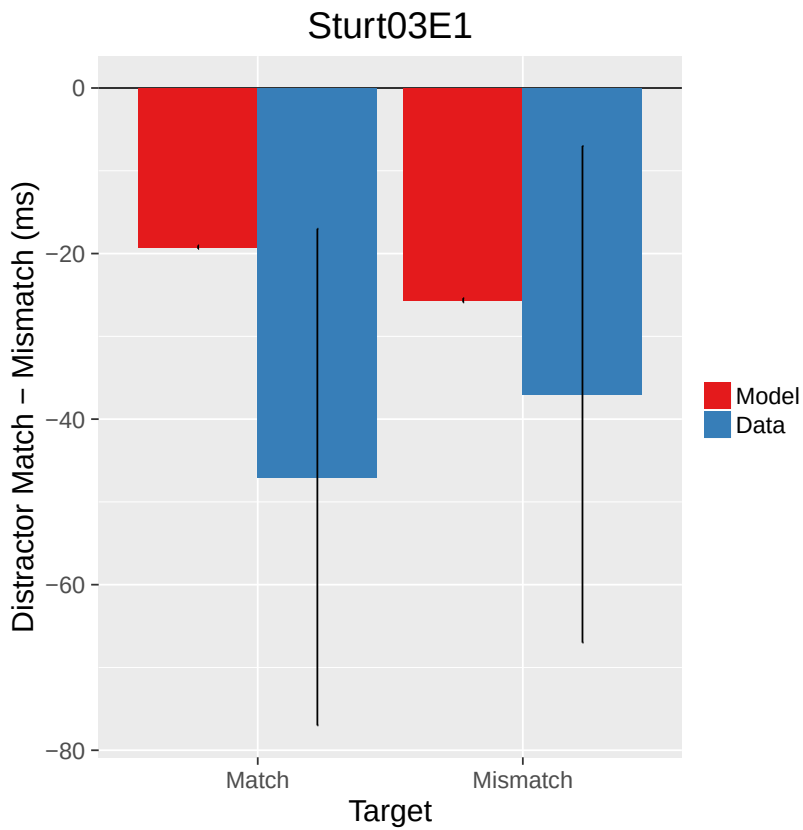
New model

Simulations

Distractor prominence



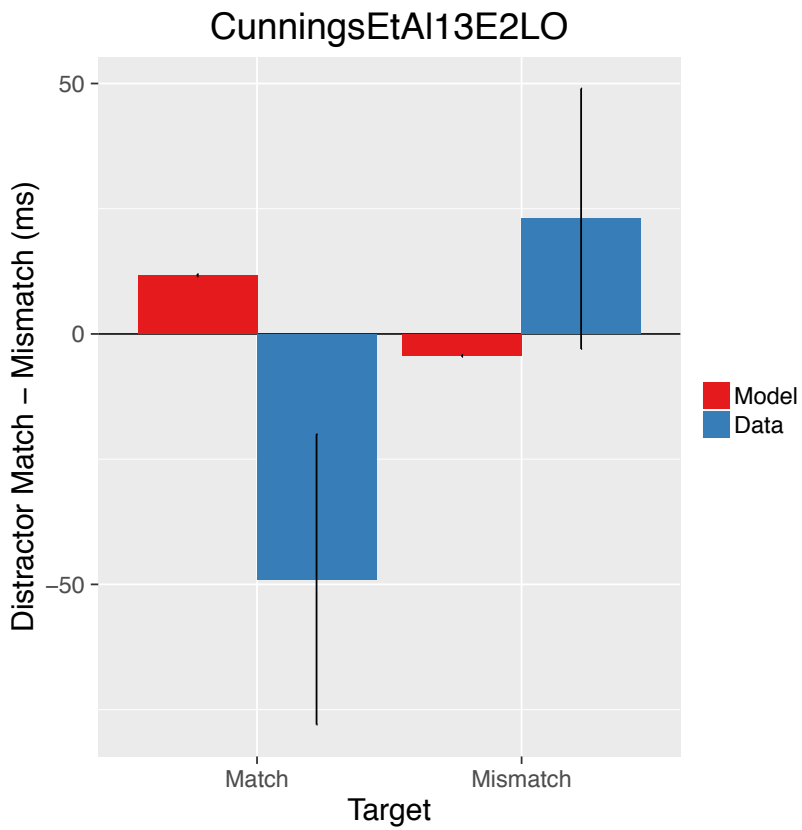
Classic model



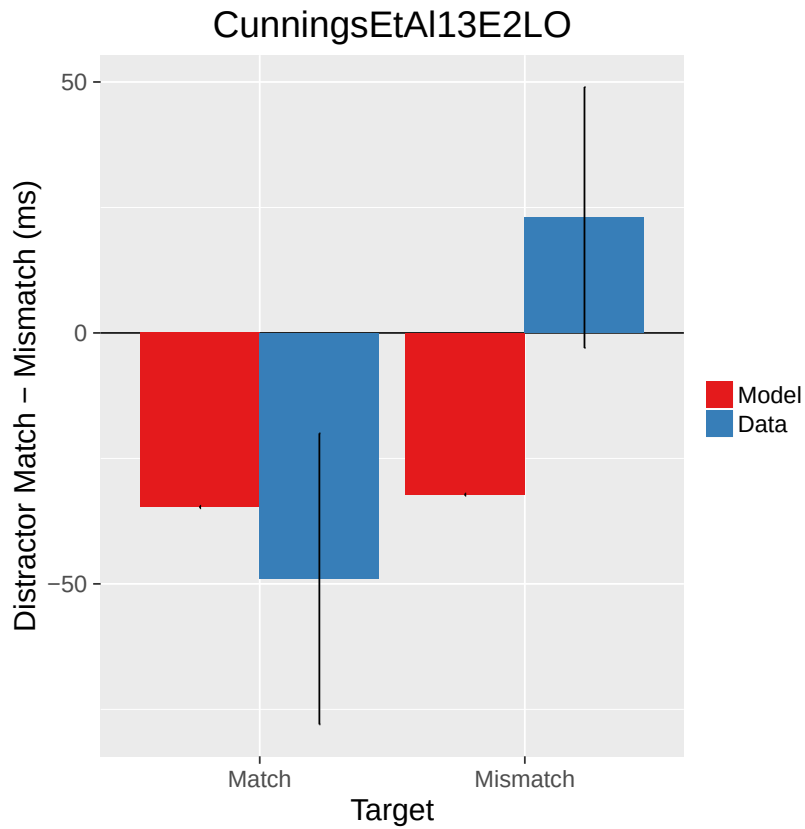
New model

Simulations

Distractor prominence



Classic model



New model

Summary

An extended model of cue-based retrieval accounts for experimental design and task-specific adaptation:

1. Distractor prominence and associative cues extend models of cue-based retrieval.
2. Distractor Prominence explains facilitatory interference in target-match conditions.
3. Cue Confusion explains inhibitory interference in target-mismatch conditions.
4. Simple mechanisms (associative cues, interruption through regression) generate adaptive behaviour:
   Associative cues $\times$ dependency context $\rightarrow$ speed-up / slow-down.

Software

The inter-act model of cue-based retrieval in sentence processing:
`https://engelmann.shinyapps.io/inter-act`

Open issues

1. Experimental investigation of distractor prominence and cue confusion.
2. Acquisition of cue-feature associations.

Cue Confusion experiment

a. *Reflexive; distractor-match*
The *nurse* who cared for the *children* had pricked *themselves* . . .

b. *Reflexive; distractor-mismatch*
The *nurse* who cared for the *child* had pricked *themselves* . . .

c. *Reciprocal; distractor-match*
The *nurse* who cared for the *children* had pricked *each other* . . .

d. *Reciprocal; distractor-mismatch*
The *nurse* who cared for the *child* had pricked *each other* . . .

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