Comprehension difficulty reflects an understanding of likely production errors

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Overview

Number agreement errors are relatively common in production. How do comprehenders deal with errorful input? We suggest that reading time patterns reflect a rational solution: comprehenders know which kinds of errors are likely, and recover more easily from more probable errors.

1. Agreement errors in production

Bock & Miller (1991) find more number errors with a mismatching intervening noun:

(1) a. The keys to the cabinet ... **was** rusty

b. The keys to the cabinets ... **was** rusty

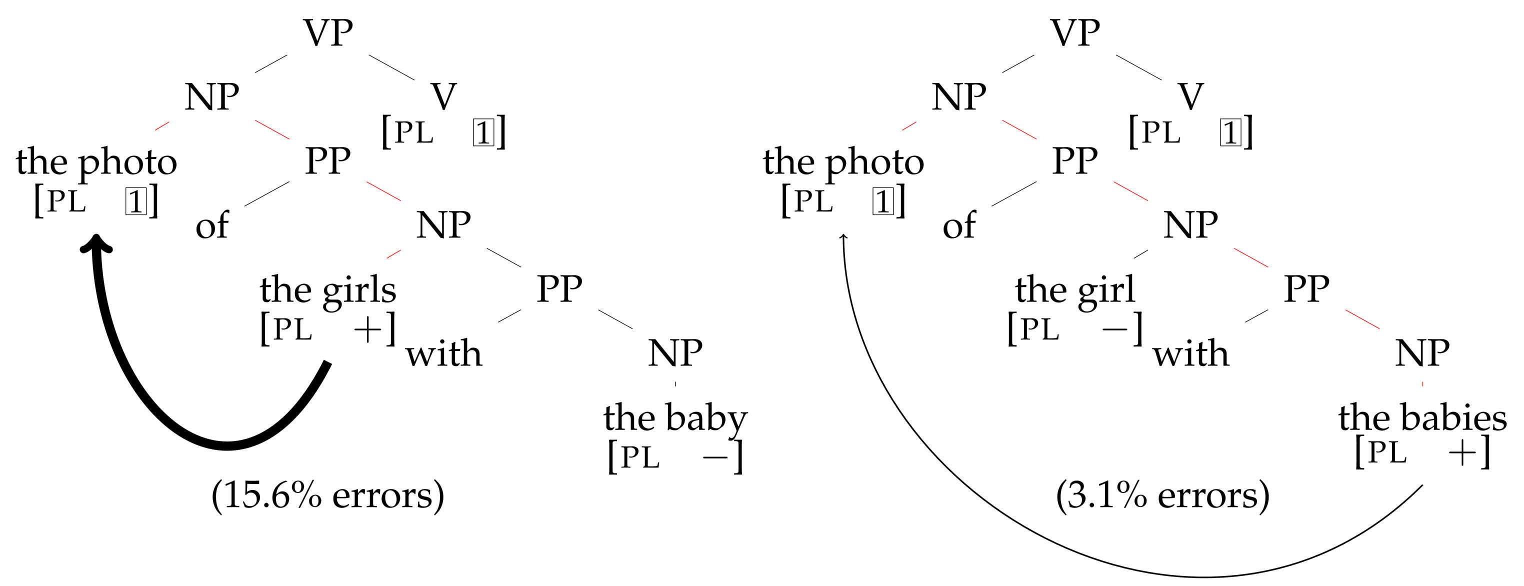
c. The key to the cabinet ... **were** rusty

d. The key to the cabinets ... **were** rusty

0 5 10 15 20

% spoken sentence completions with number errors on verb

Franck, Vigliocco & Nicol (2002): this is *not just due to adjacency*. With two embedded NPs, the first has more effect on the error rate. Errors may reflect syntactic structure: plural features are more likely to be "misplaced" by smaller tree distances.



2. Comprehension of agreement errors

Pearlmutter et al. (1999) measured reading times on sentences like (2). Correct agreement (2a,b) leads to faster reading, but this interacts with whether the intervening NP has the same (2a,d) or different (2b,c) number.

(2) a. The key to the cabinet was rusty ... *(grammatical, match)*

b. The key to the cabinets was rusty ... *(grammatical, mismatch)*

c. The key to the cabinets were rusty ... *(ungrammatical, mismatch)*

d. The key to the cabinet were rusty ... *(ungrammatical, match)*

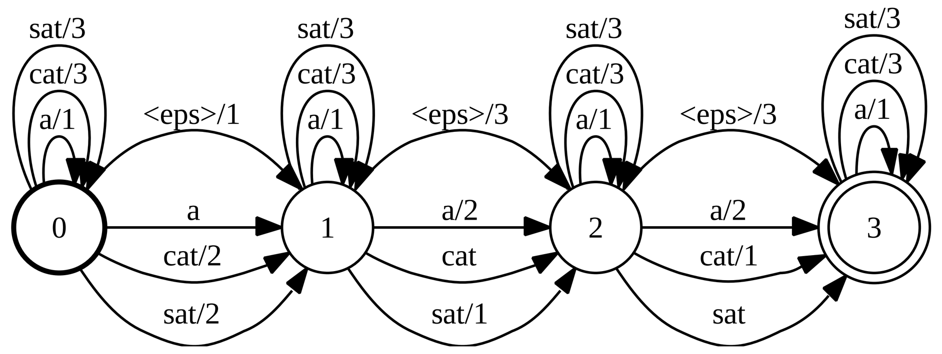
0 100 200 300 400 500 600

reading time at postverb region (ms) in replication of Pearlmutter et al.

3. Optimal comprehension under uncertainty

Efficient comprehenders should "prepare" for structures according to their probability of occurrence (Hale 2001; Levy 2008a). If the probability of errors in the input can be approximated, then an efficient comprehender should maintain "expectation" over past as well as upcoming material (Levy 2008b).

Levy (2008b) uses a string edit distance model of noisy input like production errors: e.g., what strings are probable errors if the intention is *"a cat sat"*?



Keeping track of the probability of what might have been intended accounts for comprehension patterns in "locally coherent" sentences (Tabor, Gantalucci & Richardson 2004):

(3) a. The coach smiled at the player ... tossed a frisbee

b. The coach smiled as the player ...

c. The coach smiled at the player who ...

0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

probability of intention given that (3a) is perceived

The word (*"tossed"*) is relatively probable under other similar input strings, so it may indicate an error. The comprehender re-evaluates the input, slowing reading speed.

If we replace the string-edit measure with a model of number production errors, the comprehension model represents a rational solution to dealing with these errors.

4. A computational model of production errors

Defines a probability that the speaker will produce a particular number error given the sentence they intended, with two sources of number error.
(a) each noun phrase may "flip" its plural feature with probability:

$$P\left(\overset{\text{N}}{[\text{PL} \ +]} \rightarrow \overset{\text{N}}{[\text{PL} \ -]}\right) = \phi$$

(b) a plural feature at N_a may "move" to a singular noun N_b with probability proportional to the tree distance between them:

$$P\left(\overset{\text{S}}{\overset{N_a}{[\text{PL} \ +]}\overset{N_b}{[\text{PL} \ -]}} \rightarrow \overset{\text{S}}{\overset{N_a}{[\text{PL} \ -]}\overset{N_b}{[\text{PL} \ +]}}\right) \propto \frac{1}{Distance(N_a, N_b)^{\mu}}$$

Errors at each noun are independent, and summing over all ways to derive a tree s from a tree i gives the distribution $P(Spoken = s|Intended = i)$. We estimate the two parameters, ϕ ("flip") and μ ("move") from production error rates reported by Franck et al. (2002).

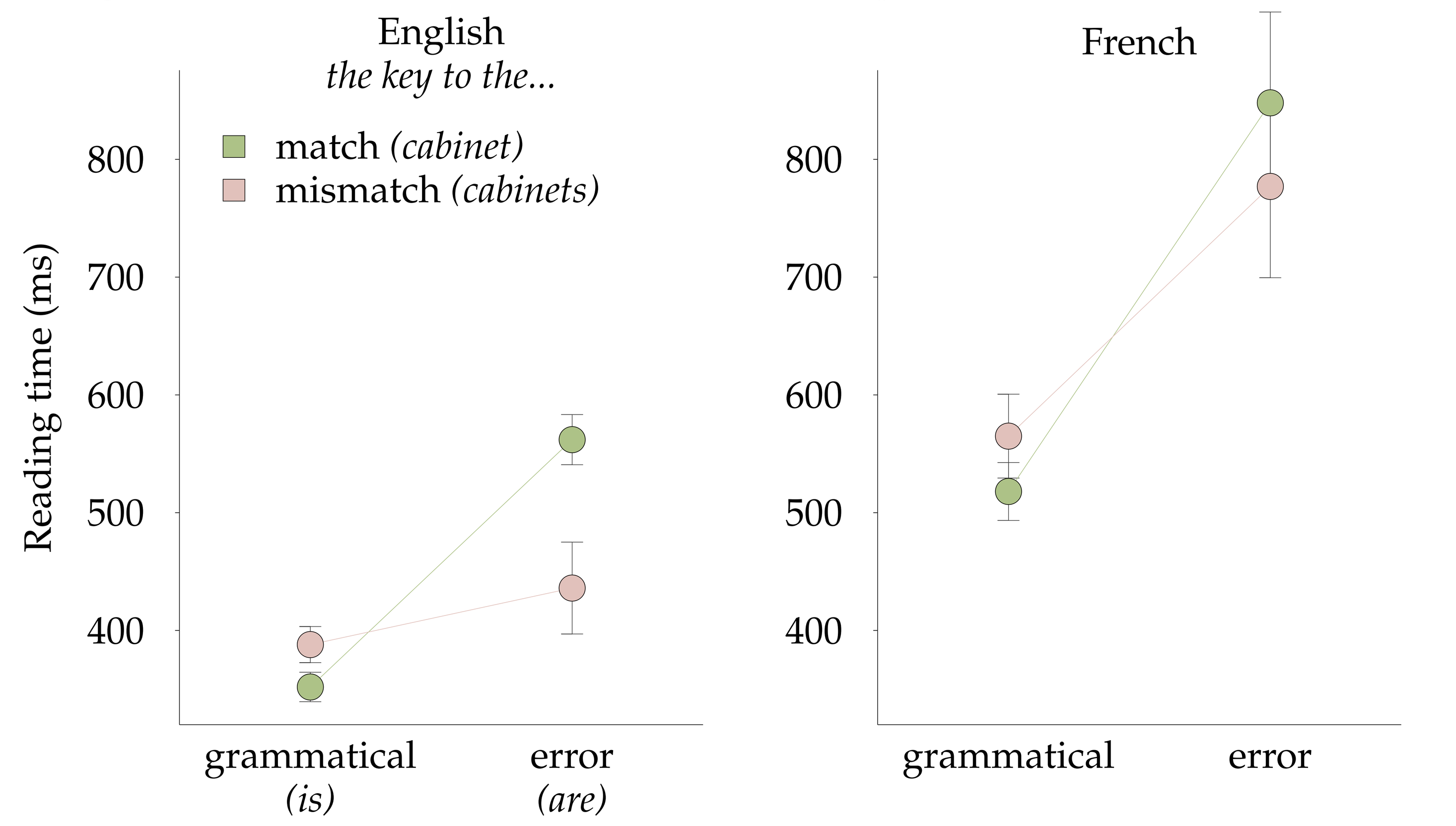
We plug this production model into the comprehension under uncertain input model:

Comprehension model predictions for reading times

(2a)	**fastest**	*grammatical* (no error) *match* (error not expected)
(2b)	**fast**	*grammatical* (no error) *mismatch* (error somewhat expected)
(2c)	**slow**	*ungrammatical* (error) *mismatch* (error somewhat expected)
(2d)	**slowest**	*ungrammatical* (error) *match* (error not expected)

5. Experimental results

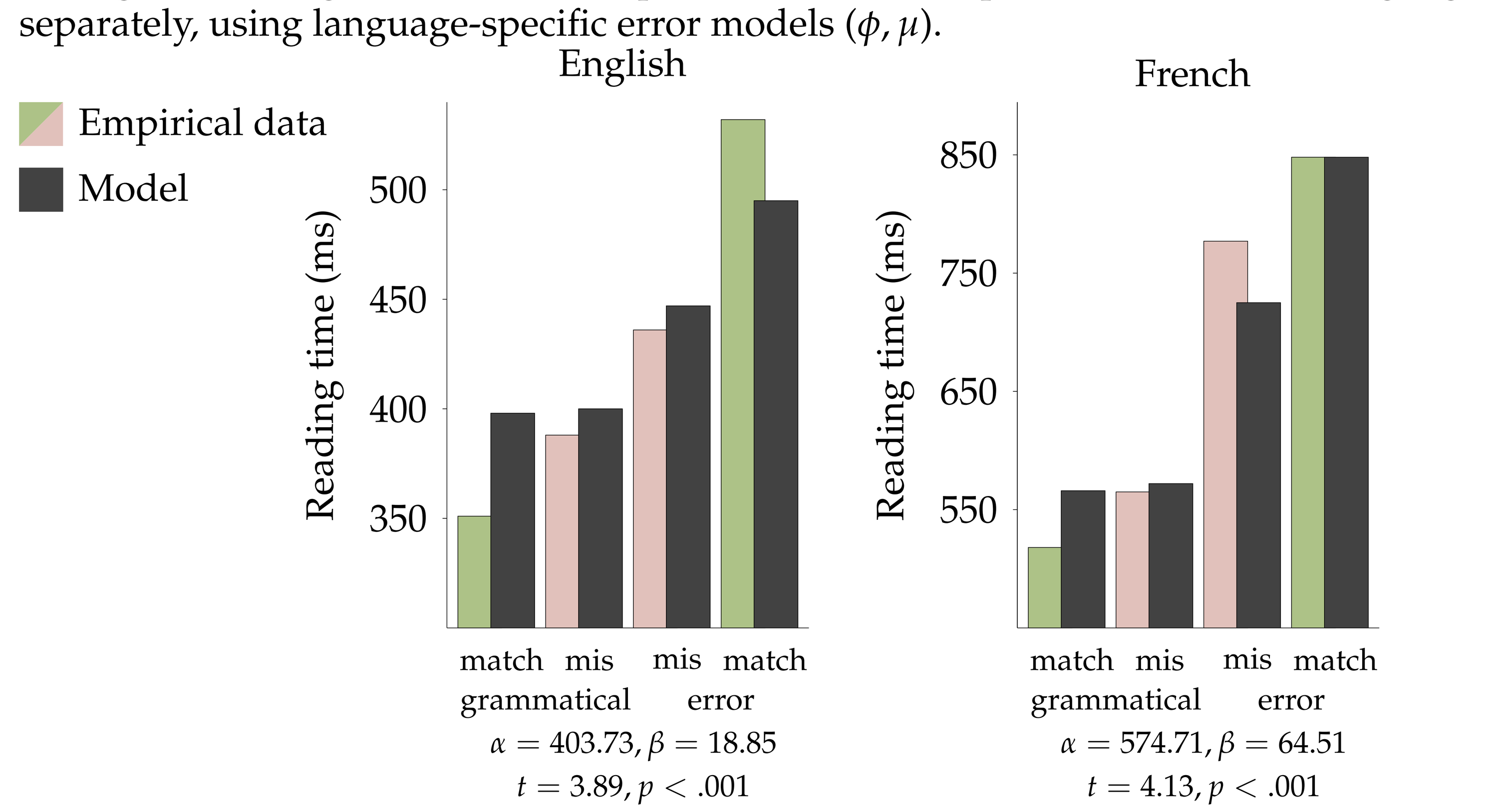
We replicate Pearlmutter et al.'s (1999) results in English, and in translation in French.



	β	s.e.	t	p	
Intercept	575.72	53.61	10.74	0.0001	
lang=En	-177.23	64.23	-2.76	0.0018	*English read faster*
error	174.52	43.55	4.01	0.0001	
match	47.02	29.47	-1.60	0.1160	*Similar to previous results*
error:match	158.86	41.82	3.80	0.0004	
lang:error	-120.37	45.79	-2.63	0.0078	*Greater error effect for French*

6. Testing the comprehension model

We regress reading times on the comprehension model's predictions for each language separately, using language-specific error models (ϕ, μ).



English data is better predicted using ϕ, μ estimated from English production error rates (log likelihood=-3301.3) than from French rates (-3303.0). French data is better predicted using error rates from French (-1662.9) than English (-1663.7).

Conclusions

A comprehension model which represents an optimal allocation of processing resources under noisy input predicts behavioral results in two domains:

- syntactically well-formed local coherences as reported by Tabor et al. (2004)
- syntactically ill-formed agreement errors as reported by Pearlmutter et al. (1999)

Our comprehension model incorporates knowledge about the probability of different kinds of production error. Language-specific estimates of these probabilities result in a better fit to comprehension data.

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