

Probabilistic syntax in production and comprehension: Converging evidence from the English ditransitive

Harry Tily

Massachusetts Institute of Technology



Is linguistic knowledge probabilistic?

- syntactic structures may be more or less likely to be used depending on contextual, structural and lexical information
- these influences are part of speakers' and comprehenders' knowledge of their language

The importance of these probabilistic influences can be observed at *all levels* of language processing

The English ditransitive

PP Yeah. I haven't **given** **much thought** to **it**. I'm kind of busy raising my kids

DO if they can test the teachers, that **gives** **them** **the full right** to **test the kids**

Influences on ditransitive choice

DO more likely

given recipient
nongiven **theme**
pronominal recipient
nonpronominal **theme**
animate recipient
inanimate **theme**
definite recipient
indefinite **theme**
short recipient
long **theme**
singular theme

PP more likely

nongiven **recipient**
given theme
nonpronominal **recipient**
pronominal theme
inanimate **recipient**
animate theme
indefinite **recipient**
definite theme
long **recipient**
short theme
plural **theme**

A rich model of syntactic probability

Bresnan, Cueni, Nikitina, & Baayen (2007): logistic regression model predicting ditransitive choice

- Outputs a number from 0.0 (DO) to 1.0 (PP)
- Correctly classifies 94% of unseen data (baseline: 79%)

Model probability: $P(\textit{Construction} = pp | \textit{Predictors})$

The English ditransitive

- PP Yeah. I haven't **given** much thought to **it**. I'm kind of busy raising my kids $P(pp) = 0.01$
- DO if they can test the teachers, that **gives** **them** the full right to test the kids $P(do) = 0.99$

Verifying Bresnan et al.'s model

Bresnan (2006):

- speakers' judgements agree with the model
- speakers are uncertain in the same cases that the model is uncertain

The model is a good estimate of speakers' knowledge of the probability of construction choice.

Is this knowledge involved in online language processing?

Probabilities influence phonetic realization

This section published as Tily, Gahl, Arnon, Snider, Kothari & Bresnan (2009)

Words and syllables are **phonetically reduced** when:

- high frequency
(Zipf, 1929; Bybee, 2000; Aylett and Turk, 2004)
- predictable given adjacent words and syllables
(Gregory et al., 1999; Jurafsky et al., 2001; Bell et al., 2003; Aylett and Turk, 2004; Pluymaekers et al., 2005)
- repeated, or topical
(Fowler and Housum, 1987; Aylett and Turk, 2004)

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The probability of a construction

Does the probability of a construction influence its pronunciation?

- Gahl and Garnsey (2004): **verb bias** affects the duration of words and pauses

Verb Bias: $P(\textit{Construction}|\textit{Verb})$

Data

2349 annotated spoken ditransitives from Switchboard

Only use duration of initial “to” in the PP constructions

We remove:

- utterances without time alignments
- outliers 2.5 sd from mean speech rate
- disfluent utterances

446 cases remain

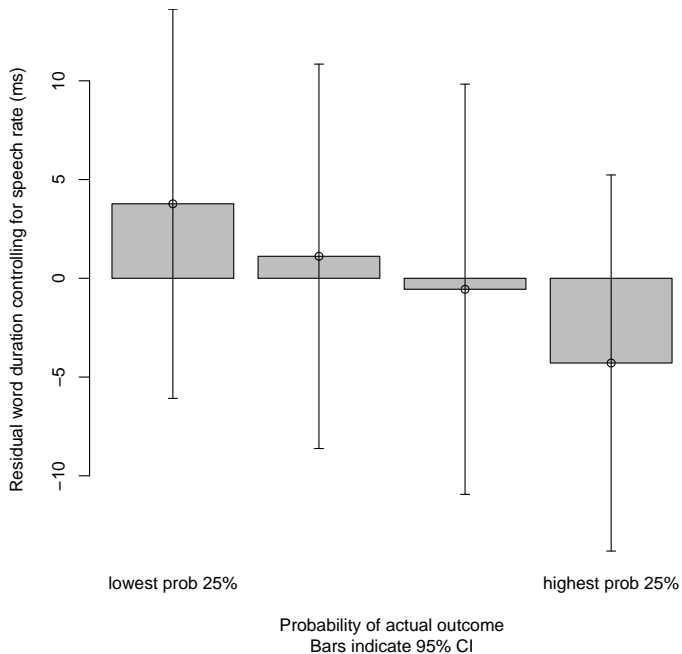
Model results

Linear regression predicting word duration in seconds:

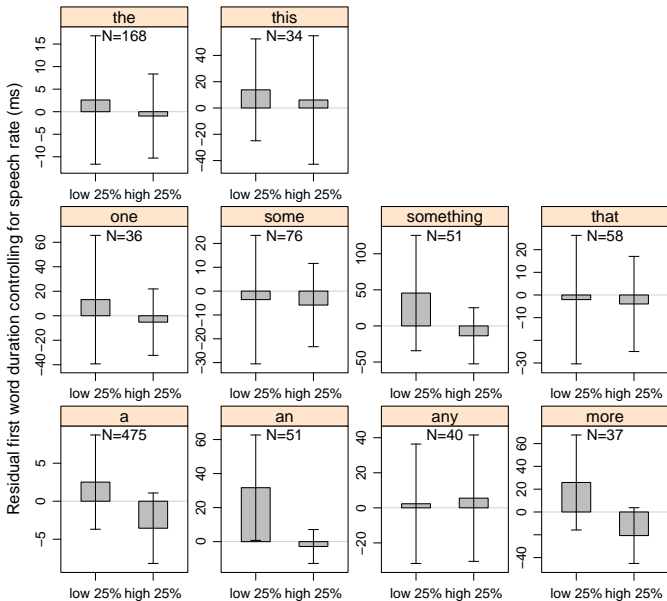
	β	p
Intercept	0.17557	0.000000
PP probability	-0.34147	0.013603
Backward bigram	-6.92303	0.001235
Previous vowel	0.02486	0.017001

No effect of: forward bigram, speech rate, verb bias.

Word duration as a function of outcome probability in the NP PP



Word duration as a function of outcome probability in the NP NP



Probability of NP NP outcome

Bars indicate 95% CI

Probabilities influence fluency

Words are less likely to be disfluent when:

- they are part of a less complex NP
(Clark and Wasow, 1998)
- they signify a previously mentioned referent
(Arnold et al., 2003)
- they are more likely given the preceding words
(Stolcke and Shriberg, 1996)

Data

Same dataset, using all constructions (DO and PP)

Disfluency: repetition, repair, restart or filled pause in IP containing verb

We remove:

- outliers 2.5 sd from mean speech rate

2061 cases remain (594 disfluent)

Model results

Logistic regression predicting log odds of disfluency:

	β	p
Intercept	0.6782	0.0146
Speech rate	-0.8168	0.0000
Outcome probability	-0.2020	0.0317

No effect of: verb bias.

Discussion

The probability of a construction influences the way it is spoken
More probable outcomes...

- ... are realised with shorter words
- ... are spoken more fluently

Probabilistic influences may affect the **availability** of a construction to the speaker during online production

Expectation in comprehension

For more discussion of results in this section, see Tily, Hemforth, Arnon, Snider & Wasow (2008); Hemforth, Tily, Arnon, Snider & Wasow (prep)

Comprehenders have some idea what might be said before they hear it

Does this expectation reflect knowledge about probabilistic influences on construction choice?

Expectation in comprehension

For more discussion of results in this section, see Tily, Hemforth, Arnon, Snider & Wasow (2008); Hemforth, Tily, Arnon, Snider & Wasow (prep)

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Expectation about referent choice

Altmann and Kamide (1999): **semantic plausibility**

- visual world paradigm
- comprehenders look more at **cake** during “*the boy will eat ...*” than “*the boy will **move** ...*”
- “eat” restricts reference probability more than “move”
- **knowledge about the world** drives linguistic expectation

Expectation about constructions in variation

Ditransitive constructions have different order of mention

- PP: theme-recipient
- DO: recipient-theme

Arai et al. (2007): **priming** influences expectation for order

- *“the pirate sent... the necklace to the princess”*
- *“the pirate sent... the princess the necklace”*
- when hearing “send”,
 - look at **necklace** if “send” was last heard in the PP
 - look at **princess** if it was in the DO

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Question

Do probabilistic influences on syntactic choice influence expectation?

Materials

Vary verb bias and DO/PP outcome:

- *“the maid gave/brought the wine to the prince”*
- *“the maid gave/brought the prince the wine”*

Participants hear sentences while looking at clip-art pictures

- the subject picture is at the top
- recipient and theme at bottom left and right (counterbalanced)

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MAID



PRINCE

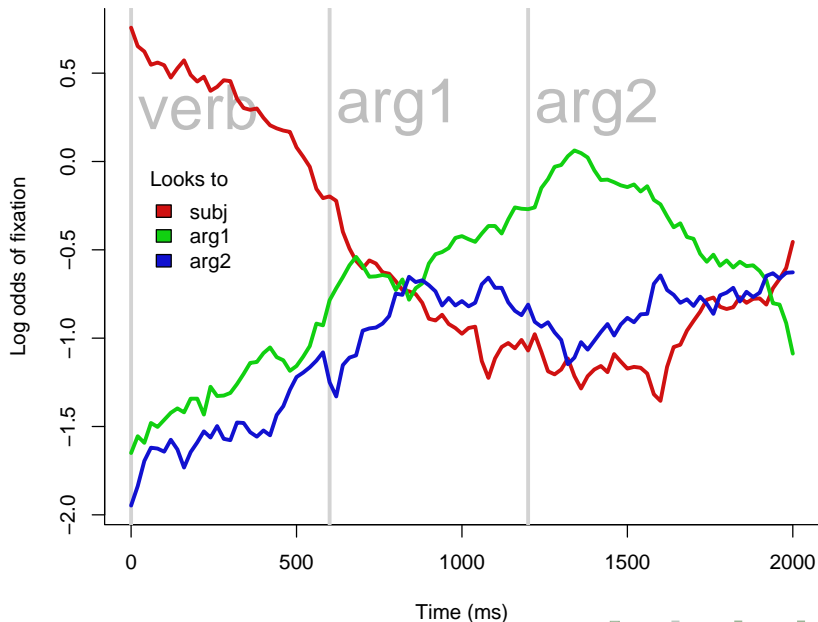


WINE





Overall timecourse of eyemovements

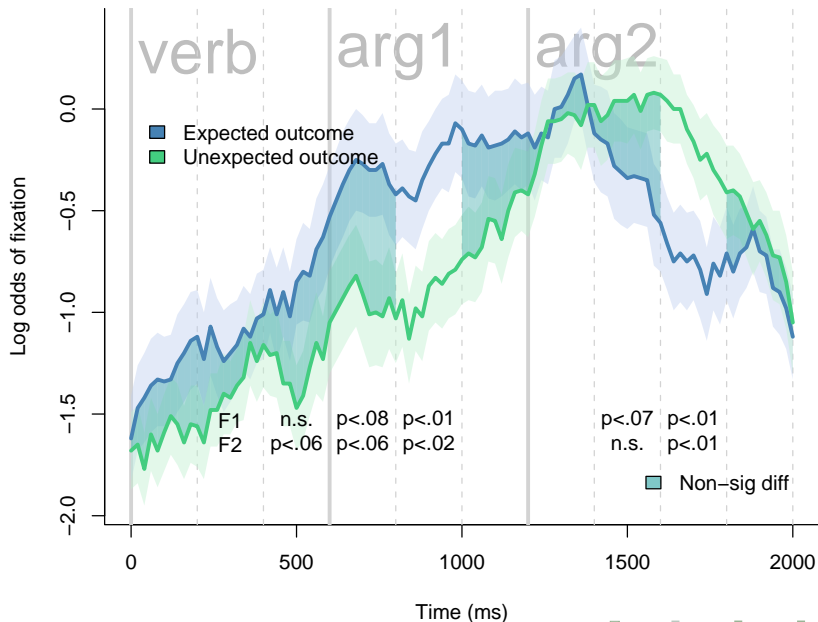


Timecourse by expectation

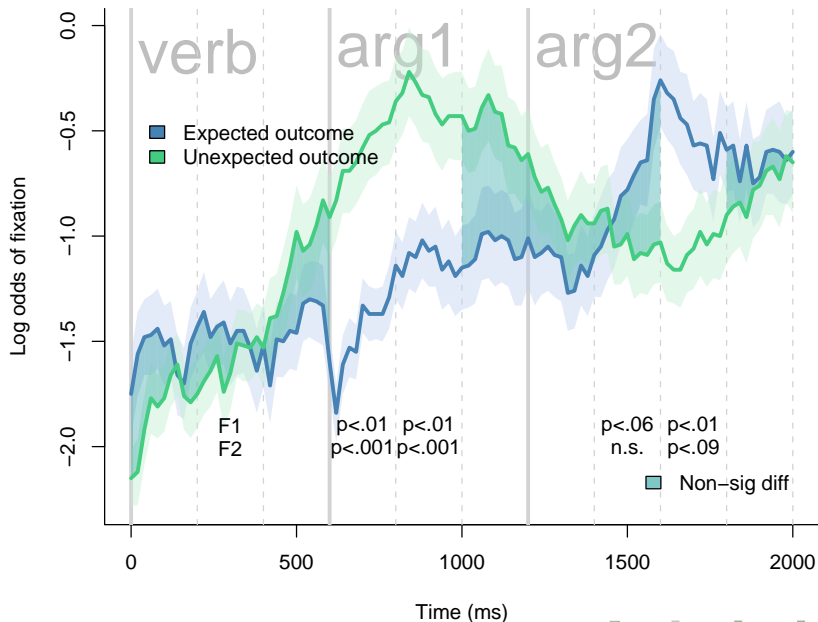
Two “meta-conditions”

- **expected**: DO-bias verbs in DO / PP-bias verbs in PP
- **unexpected**: PP-bias verbs in DO / DO-bias verbs in PP

Looks to first argument



Looks to second argument



Summary of results

- people fixate the arguments in the order of mention
- they fixate the argument they expect *given verb bias* before it is fully spoken
- they fixate the argument they expect *given verb bias* even if the speaker chooses to speak the other argument first

Expectation in comprehension

Expectation is central to comprehension (Levy, 2008)

- the more expected something is, the easier it is processed
- expectation **drives** comprehension

Does comprehension difficulty reflect construction probability?

Constraint-based processing

Trueswell, Tanenhaus & Kello (1993): Verb bias influences comprehension:

- The student hoped the solution **was** ...
- The student forgot the solution **was** ...

Is this knowledge about the probability of a construction or the probability of an event in the world?

Does verb bias affect comprehension of meaning-equivalent constructions?

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Methodology

Self-paced reading

Critical sentences are PP ditransitives

I vary (a) animacy of the theme, and (b) verb bias

DO The nurse gave the baby/pills to the doctor

PP The nurse brought the baby/pills to the doctor

Methodology

Self-paced reading

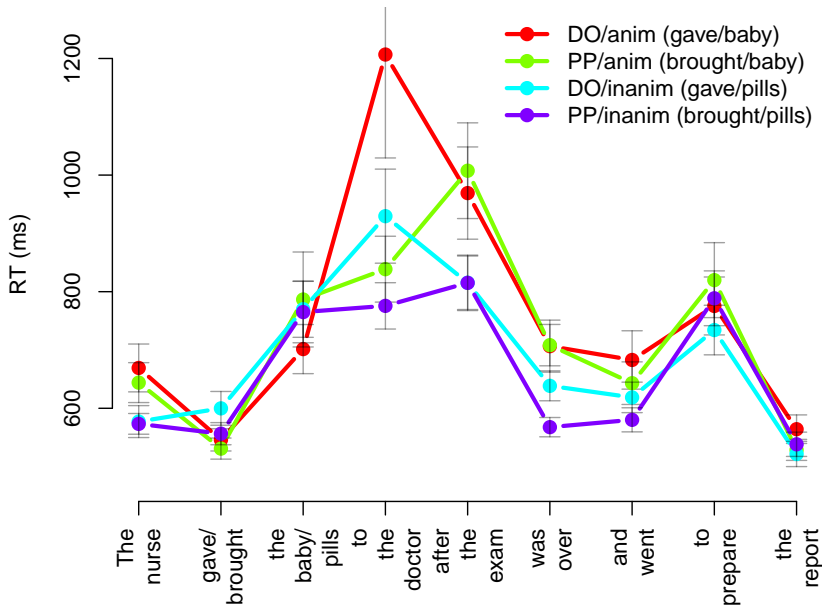
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Reading times by region



Conclusions

The mistaken anticipation in eyetracking translates into difficulty in comprehension

- severe slowdown when verb bias is not followed
- comprehenders use linguistic cues (verb bias, animacy) to guide interpretation

Discussion

Multiple factors convene to make a construction more or less likely; this likelihood influences

- phonetic realization
- fluency
- expectation and attention
- comprehension difficulty

Do probabilistic effects reflect the probability of **world events** or **linguistic events**?

- verb bias, at least, is semantically vacuous
- comprehenders know about **specifically linguistic probabilities**

Discussion

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Conclusion

Probabilistic influences on syntactic choice are fundamental parts of our knowledge of language in both comprehension and production

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