Phonetic Production
Reflects Syntactic Probability:
Evidence from Duration and Disfluency

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Is linguistic knowledge probabilistic?

A growing body of evidence suggests that:

• speakers have knowledge about the probabilities of linguistic events

• those probabilities influence speakers’ choices between constructions, and their phonetic realization

Resnik (1996); Jurafsky et al. (2001); Gahl and Garnsey (2004); Jaeger et al. (2005); Gahl et al. (2006); Pluymaekers et al. (2005); Bresnan (2006); Jaeger (2006); Jaeger et al. (2006); Levy and Jaeger (2006); Levy (2006); Bresnan et al. (2007); Wasow et al. (2007), etc
Probabilities influence phonetic realization

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)
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)
Different probability estimates for different effects

- Studies on construction choice have looked at “rich” probability measures
  (How likely is the construction given all/much of the information available to the speaker?)

- But most studies reporting phonetic effects look at local or single-cue probability measures
  (bigrams, frequency, etc)

- As do models of disfluency developed for speech recognition (Stolcke and Shriberg, 1996)
The current study

Phonetic realization and speech fluency reflect the probability of the linguistic structures being produced

Therefore:

- speakers use multiple, varied sources of information to estimate probabilities
- **syntactic** probabilities affect the **phonetic realization** and **fluency** of speech

The probability of a syntactic construction affects its phonetics

This is not a novel idea:

Gahl and Garnsey (2004): the probability of some argument structure given the verb *does* correlate with phonetic effects

**Verb Bias:** \[ P(\text{Construction}|\text{Verb}) \]
The probability of a syntactic construction affects its phonetics

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**Verb Bias:** $P(Construction|Verb)$

Verb bias is an estimate of the probability of a construction — but not a very accurate one
The probability of a syntactic construction affects its phonetics

Do more accurate estimates of the probability of a construction that incorporate rich information sources correlate with phonetic effects?
The probability of a syntactic construction affects its phonetics

Do more accurate estimates of the probability of a construction that incorporate rich information sources correlate with phonetic effects?

We extend the Gahl and Garnsey finding:

• with a more accurate probability measure that incorporates semantic and contextual information

• with a novel construction

• using naturalistic data
A rich model of syntactic probability

Bresnan et al. (2007): a regression model predicts the construction choice in the dative alternation:

(1)a. Yeah, I haven’t *given much thought to it*, I’m kind of busy raising my kids  
   *prepositional phrase*

b. Yeah, I haven’t *given it much thought*, I’m kind of busy raising my kids  
   *double object*
A rich model of syntactic probability

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\[
Predictors = \left\{ \begin{array}{l}
\text{verbal meaning, discourse accessibility,} \\
\text{relative argument length, structural parallelism,} \\
\text{definiteness, animacy, pronominality, …}
\end{array} \right\}
\]
A rich model of syntactic probability

This model correctly predicts the choice on 94% of unseen data.

Compare this to simple verb bias on a corpus of 2349 spoken dative sentences:

<table>
<thead>
<tr>
<th>Model</th>
<th>Accuracy</th>
<th>Odds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline (always choose DO)</td>
<td>79%</td>
<td>3.8</td>
</tr>
<tr>
<td>Verb bias</td>
<td>83%</td>
<td>4.9</td>
</tr>
<tr>
<td>Bresnan et al model</td>
<td>94%</td>
<td>15.7</td>
</tr>
</tbody>
</table>

Verb bias is 1.3 times improvement over the baseline, while the rich model is a 4.9 times improvement.
A rich model of syntactic probability

The model outputs a number from 0.0 (meaning double object) to 1.0 (prepositional)

**Model probability:** $P(Construction = pp|Predictors)$
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Bresnan (2006):

• speakers’ judgements agree with the model
• speakers are uncertain in the same cases that the model is uncertain
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So we can use the output of the model as an estimate of speakers’ knowledge of syntactic probability.
Study 1: Does syntactic probability affect word duration?

More predictable words tend to be phonetically reduced
(Gregory et al., 1999; Jurafsky et al., 2001; Bell et al., 2003)

**Hypothesis:**
- words within a construction will be **shorter** when it is assigned a **higher** probability

\[ P(Cxt|predictors) \]

Study 1: Words of interest

Duration of an initial “to” in the PP outcome, and “the” in the NP outcome:

(2)a. ... they gave all that money to the people ...

b. ... if you’re going to pay teachers the salary they’re paid...

These words were chosen because

• reduction effects have been found on these words (Bell et al., 2001, 2003)

• they can be kept constant across all cases

• they are very rarely prosodically marked
Study 1: Data

The Spoken Dative Database (Recchia, 2006) : a heavily annotated dataset of 2349 spontaneous, spoken dative constructions extracted from Switchboard

We remove:

- utterances without time alignments (1.7%)
- outliers three s.d. from mean speech rate (5.5%)
- disfluent utterances (3%)
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| total dataset: | 2114 |
| PPs (which all begin with *to*): | 488 |
| NPs beginning with *the*: | 260 |

Tily, Snider, Kothari, Arnon & Bresnan (2007)  *Phonetic Production reflects Syntactic Probability*
Study 1: Linear regression model

- **Dependent variable:** duration of critical word
- **Independent variable:** syntactic probability
- **Controls:**
  - verb bias
  - **forward** and **backwards bigram probabilities**
  - **speech rate** (syllables per second within the fluent region that contains the critical word)
  - **phonological context** (whether the previous and following segments are consonants or vowels, for the four levels $C_C$, $C_V$, $V_C$, $V_V$)
Study 1: Results

We model PP and DO outcomes separately, because they show prosodic differences.
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**Syntactic probability** is a significant predictor of the duration of *to* in the PP ($p < .05$):

- as $P(pp|predictors)$ increases, duration decreases
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**Syntactic probability** is a significant predictor of the duration of *to* in the PP ($p < .05$):
- as $P(pp|predictors)$ increases, duration **decreases**

**Syntactic probability** is a marginally significant predictor of the duration of *the* in the NP ($p = .07$):
- as $P(pp|predictors)$ increases, duration **increases**
Study 1: Results

• For both data sets, there are significant effects of bigram probability

• but no effect of verb bias
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- but no effect of verb bias

There is no significant collinearity between any predictors:

- all vifs < 1.2 (variance inflation factors)
Study 1: Summary

• syntactic probabilities estimated from rich information affect articulation

• word durations are shorter in more predictable constructions

• this effect is significant beyond previously reported probability estimates
  ○ verb bias does not predict duration in this dataset
What is the relationship between fluency and probability?

- Words that are more likely given previous words are less likely to be disfluent (Stolcke and Shriberg, 1996)

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  - and more complex phrases are more often disfluent (Clark and Wasow, 1998)
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So several probability estimates have been (indirectly) shown to correlate with fluency
Study 2: Are less probable constructions less fluent?

Hypothesis:

- there will be less disfluency in a construction that is assigned a higher probability

\[ P(Cxt|predictors) \]
Study 2: Operationalizing disfluency

- binary outcome: fluent or disfluent

- we code disfluency adjacent to the first word of the second argument (as in Study 1)

- disfluencies can be:
  - a pause of 500ms or more
  - a filled pause ("uh", "um")
  - repetition of a word
  - a “stumble” or restart
    ("give them ano- another trial")
Study 2: Logistic regression model

- **Dependent variable:** disfluency at the critical word

- **Independent variable:** syntactic probability

- **Controls:**
  - *speech rate at that point* (this time, including the duration of the critical word)
  - *the length of the second argument in words* (to control for planning effects associated with the complexity of the phrase)

Again, we model PP and DO outcomes differently
Study 2: Results

- within the PP dataset, syntactic probability is a significant predictor of disfluency at the start of the second argument ($p < .01$)
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• within the DO dataset, syntactic probability is a significant predictor of disfluency at the start of the second argument ($p < .05$)
  ○ as $P(pp|predictors)$ goes up, disfluency is more likely
Study 2: Results

Figure 2: Estimated disfluency probabilities

Discussion

Previous work has shown that:

- speakers’ choice between constructions is conditioned on many sources of semantic and contextual information
- temporal reduction is correlated with probability
- disfluency is correlated with probability
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Previous work has shown that:

- speakers’ choice between constructions is conditioned on many sources of semantic and contextual information
- temporal reduction is correlated with probability
- disfluency is correlated with probability

We combine these findings:

- the probability of a construction conditioned on semantic and contextual information correlates with temporal reduction and fluency
Discussion

This strengthens the findings that:

- speakers estimate the probability of a construction based on rich information (Bresnan, 2006; Bresnan et al., 2007)

- syntactic probability affects phonetic realization (Gahl and Garnsey, 2004)
Implications for models of speech production

- The probability (or activation level) of a syntactic construction and/or the information on which it is conditioned is available during the time-course of sentence production
  - and this influences articulatory planning
Further work

• Are the effects of construction probability in production mirrored by similar effects in comprehension?
  ○ Further work will test this possibility

• We are working on a controlled lab experiment to confirm these findings
  ○ Participants will produce more or less probable structures (à la Gahl and Garnsey (2004))
The End

Thanks for listening!

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References


