Prediction, learning, and the development of conversation

Hugh Rabagliati

github.com/hughrabagliati/

@hugh_rab
Chiara Gambi
Laura Lindsay
Alex Robertson
Jarek Lelonkiewicz

The Leverhulme Trust

The Carnegie Trust

The University of Edinburgh
School of Philosophy, Psychology & Language Sciences
Most frequent pattern: perfect timing (across 10 different languages)

Data from Stivers et al., 2009; Howes et al., 2011
Coordinating these components requires prediction

What do you think of Trump’s…

I love it!  I hate it!

Levinson (2016); Pickering & Garrod (2015)
The developing role of prediction in conversation

Interesting in a few ways:

1. As a basic psycholinguistic question

2. Understanding timely turn taking for Social Communication Disorder

3. Prediction facilitates learning
   • Via processing
   • As a learning mechanism
I don’t want the blue tray, I want the chromium one
Prediction as a learning mechanism

Reinforcement Learning
Schulz et al (1997), Rescorla & Wagner (1972), Daw et al (2006), etc etc etc...

Predictive Coding
Friston (2005), Rao & Ballard (1999), Clark (2012), etc etc etc...

Recurrent Neural Networks
Jordan (1986), Elman (1990), Hochreiter & Schmidhuber (1997), etc etc etc...
Prediction as a learning mechanism

1. **Initial generative model of form**
   - Predicted probabilities over possible sounds
   - Acoustic input
   - Prediction error (input – predictions)

2. **Updated generative model of form**
   - Updated predictions

3. **Updated generative model of form**
   - Updated predictions
   - Prediction error (input – predictions)

**Generative model of the lexicon**
Two babies learned a language

Meaning of baby.
Meaning of two.
etc.

Subject Verb Object
baby+s = plural
learn+ed = past tense

compositional semantic analysis
lexical analysis

syntactic + morphological analysis
phonological analysis
acoustic analysis

Freq Time

Two babies learned a language
Predictions based on linguistic knowledge

Predictions based on associations

*Mary will eat the…*

Mani & Huettig (2012)

Predictions based on syntax-semantics

*John arrested the…*
Predictions based on linguistic knowledge

PREDICTIVE VERB: …Pingu will arrest the …
NON-PREDICTIVE VERB: …Pingu will touch the …

predictive gaze around the scene

Visual World Paradigm
Adults (n: 24)

* mixed-effects growth curve models with quadratic terms and maximal random structure; $|t| > 2$ means $p<.05$
...Pingu will **arrest** the ...
...Pingu will **touch** the ...

...show me **arresting**?
...show me **touching**?
Parallel, weighted predictions

Bert will take a nap on the…

The hairdresser will cut the long…

Freddie is touching the…
Adults, n = 48

Fixations to Object vs. Time (ms)

Order 1

Order 2

No Order

- Nap on the...
- Cut the long...
- Touching the...

Time (ms)

Fixations to Object

-750 -500 -250 0

-750 -500 -250 0

-750 -500 -250 0
78 4-year-olds
77 3-year-olds
60 2-year-olds

* mixed-effects logistic regressions with maximal random structure; $|z| > 2$ means $p<.05$
Prediction *errors* in children’s language

...*hairdresser will cut the*...
Prediction errors in children’s language

touching the...

...grass!

cut the long...
The role of prediction skills in later language development

The role of prediction in learning (e.g., of distorted speech)

The role of prediction in the development of conversation skills
Most frequent pattern: perfect timing (across 10 different languages)

Smooth turn-taking

Early preparation

Prediction of turn ends

Density

Inter-turn Interval (ms)
• What the speaker will say.
• When the speaker will say it (i.e., when they will finish speaking)
Exploring conversation under tightly-controlled conditions

Predictions about timing

24 adults
30 5-year-olds (one participant excluded, N=29)
47 3-year-olds (13 participants excluded, N=34)
Different, Unpredictable
Same, Predictable
Same, Unpredictable
Different, Predictable

Should we go past Po?
Should we go past Boots?
Should we go past Po?
Should we go past Boots?

Po
Boots

Skye
Boots

Belle
Curious George

Belle
Boots

Fireman Sam
Po

Note: Thought Bubble = participants’ thoughts
Different, Unpredictable

Same, Predictable

Should we go past Po?

Boots

Should we go past Boots?

Boots

Predictable

Unpredictable

Should we go past Po?

Skye

Belle

Curious George

Should we go past Po?

Fireman Sam

Po

Skye
No evidence that adults or children predict timing

* Gaps < 2 sec; Linear mixed-effects models with maximal random structure; |t| > 2 means p<.05
Prior Preparation Preventing Poor Performance

Should we go past Fireman Sam?....Yes!
Children prepare their response as their partner speaks.
Children predict the content of turns.

Neither adults nor children predict the timing of turns.

Children prepare their responses as they listen.

So, why are children slow at conversation?
Coordinating perception and action through prediction

Putting the two pieces together

Early Preparation

Prediction of Turn Ends
48 adults; 48 5-year-olds; 58 3-year-olds
4 mazes, 24 trials each
ONE ANIMAL, EARLY

Is Doc McStuffins hiding the Parrot?

ONE ANIMAL, LATE

Is the parrot behind Doc McStuffins?

TWO ANIMALS, EARLY

Is Doc McStuffins hiding the Parrot?

TWO ANIMALS, LATE

Is the parrot behind Doc McStuffins?
Early Preparation

Predictable, Early
Is Doc McStuffins hiding the Parrot?

Predictable, Late
Is the parrot behind Doc McStuffins?

Is Doc McStuffins hiding the parrot?

Is the parrot behind Doc McStuffins?
Is Doc McStuffins hiding the parrot?

Inter-turn Interval

Predictability * Early Preparation

ONE ANIMAL, EARLY

TWO ANIMALS, EARLY

ONE ANIMAL, LATE

TWO ANIMALS, LATE
Adults use their predictions to prepare their responses. Children do not (or at least not to the same degree).
Children are remarkably good at generating linguistic predictions, and these may play a causal role in language acquisition.

Key developmental hurdle: learning to coordinate production with comprehension processes.