Eye movements reflect comprehenders’ knowledge of syntactic structure probability

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Tily, Hemforth, Arnon, Shuval, Snider & Wasow (2008)
Expectation in comprehension

- comprehenders have expectation about upcoming material
- expectation may be central to the comprehension process (Levy, 08)

Two questions for this talk:
- what do people use to “compute” their expectations?
- can we separate “expectation about language” from “expectation about the world”?
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What information influences expectation?

• Altmann & Kamide (1999): semantic plausibility
  • visual world paradigm: subjects hear a sentence while looking at a scene filled with objects
  • comprehenders look more at cake during “the boy will eat ...” than “the boy will move ...”
  • “cake” is the most probable object of “eat” on semantic grounds
  • knowledge about the real world drives linguistic expectation
Does knowledge about language *itself* drive expectation?

- Hale (2001): comprehension difficulty is related to the probability of a syntactic structure
- Hale’s expectation is “purely linguistic” (doesn’t look at meanings)
  - (cf Konieczny (2000) and others: semantic or syntactic prediction?)
- do listeners’ expectations reflect “purely linguistic” probabilities?
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Is verb bias “purely linguistic”? 

- **verb bias** is a property of specific lexical verbs
- it is a measure of how often each construction is used with a certain verb
  - “the detective remembered the butler” *(transitive)*
  - “the detective remembered the butler was watching” *(sent. comp.)*
- different verbs have different bias toward each construction; e.g.
  - \( p(\text{trans}|\text{remember}) > p(\text{sc}|\text{remember}) \)
  - \( p(\text{trans}|\text{suspect}) < p(\text{sc}|\text{suspect}) \)
- comprehenders are sensitive to these probabilities (Trueswell et al, 1993; Garnsey et al, 1997)
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• maybe people **remember** *things* more often than they remember *propositions*
• **but suspect** *propositions* more often than *things*
• so this could be expectation about *the world*, not about language
• we need two constructions with *minimal difference in meaning*
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The dative alternation

“the pirate will send the necklace to the princess” (PP)
“the pirate will send the princess the necklace” (DO)

- dative verbs also display bias effects:
  - $p(PP|\text{send}) > p(\text{DO}|\text{send})$
  - $p(PP|\text{show}) < p(\text{DO}|\text{show})$
- this cannot be reduced to a difference in meaning
  - the two constructions mean basically the same thing
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Measuring expectation in comprehension

- different argument order
  - PP: theme-recipient
  - DO: recipient-theme

- Arai et al (2007) use eyetracking to show which construction comprehenders expect
  - a priming result: 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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Hypothesis

- **if:**
  1. comprehenders’ knowledge of language includes knowledge about verb bias; *and*
  2. this knowledge informs expectation about upcoming language

- **then:** comprehenders will expect a different argument first
  - expected: “the pirate will send the **necklace** to the princess”
  - unexpected: “the pirate will send the **princess** the necklace”
  - unexpected: “the pirate will show the **necklace** to the princess”
  - expected: “the pirate will show the **princess** the necklace”
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  unexpected: “the pirate will send the princess the necklace”

  unexpected: “the pirate will show the necklace to the princess”

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Methodology

- **visual world paradigm**
  - eyetracker monitors participants’ gaze position on a screen
  - screen displays arrays of three objects, depicting subject, recipient and theme
  - simultaneously, participants hear a sentence being spoken
Design

- 7 pairs of verbs, chosen to allow sentences to be constructed with the same recipient and theme nouns

<table>
<thead>
<tr>
<th>PP</th>
<th>DO</th>
</tr>
</thead>
<tbody>
<tr>
<td>take</td>
<td>serve</td>
</tr>
<tr>
<td>read</td>
<td>teach</td>
</tr>
<tr>
<td>hand</td>
<td>pay</td>
</tr>
<tr>
<td>offer</td>
<td>award</td>
</tr>
<tr>
<td>bring</td>
<td>feed</td>
</tr>
<tr>
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<td>promise</td>
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<tr>
<td>send</td>
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Design

• for each pair of verbs
  • choose 4 sets of subject, theme and recipient nouns
• giving 28 items in all

1. the maid + take + the wine + the prince
   the maid + serve + the wine + the prince
2. the waitress + take + the ice-cream + the cowboy
   the waitress + serve + the ice-cream + the cowboy
...

Design

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   the maid + serve + the wine + the prince
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   the waitress + serve + the ice-cream + the cowboy
...

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Materials

- we produce screens containing three clip-art pictures
  - the subject picture is at the top
  - the recipient and theme appear at the bottom, on the left and right

Eye movements reflect syntactic probability

Tily, Hemforth, Amon, Shuval, Snider & Waseso (2008)

Expectation in comprehension
Expectation about language itself
Results of the experiment
Discussion
Materials

- we record a native speaker reading each sentence in both the PP and DO constructions
  - (28 items) × (2 verbs: DO-bias/PP-bias)
  - × (2 realizations: DO/PP) = 112 recordings

  1. “the maid will take the wine to the prince” (PP-bias/PP)
  2. “the maid will take the prince the wine” (PP-bias/DO)
  3. “the maid will serve the wine to the prince” (DO-bias/PP)
  4. “the maid will serve the prince the wine” (DO-bias/DO)
  ...

Sound recordings

• to avoid subtle auditory cues, we splice and re-use the region up to and including the verb
• recall that each pair of verbs appears 4 times with different arguments
  • in 2 of these, we paste the start of the DO sentence over the start of the PP sentence
  • in the other 2 we do the reverse
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Experimental design

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Eye movements reflect syntactic probability
General timecourse

- Looking at the data as a whole,
  - Participants begin looking at the subject
    - moving to the first argument just before the second argument is spoken
    - and moving to the second only at the end of the sentence

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Overall timecourse of eye movements

Time (ms) | Log odds of fixation
---|---
0 | -2.0
500 | -1.5
1000 | -1.0
1500 | -0.5
2000 | 0.0

Looks to
- subj
- arg1
- arg2
Looks to each argument

Breaking eye-movements down by each argument,

- significantly more looks to the recipient than the theme
Looks to each argument

![Graph showing log odds of fixation over time for different arguments. The graph has a y-axis labeled 'Log odds of fixation' and an x-axis labeled 'Time (ms).']
Looks to each argument

this shows that people look more at animates
Timecourse by expectation

- We create 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
- Breaking down the data by these conditions,
  - first argument fixated *early* in the **expected** condition (soon after the verb is finished)
  - and *late* in the **unexpected** condition (only after it has been fully spoken)
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Looks to first argument

- Time (ms)
- Log odds of fixation
- verb
- arg1
- arg2
- Non-sig diff
- Expected outcome
- Unexpected outcome
- F1 n.s. p<.08 p<.01 p<.07 p<.01
- F2 p<.06 p<.06 p<.02 n.s. p<.01
Moreover, fixations to the second argument are different:
- in the unexpected condition, people “mistakenly” fixate the second argument early
- in the expected condition, they fixate it as it is spoken
Looks to second argument

Log odds of fixation

verb arg1 arg2

Non-sig diff

Expected outcome

Unexpected outcome

F1 p<.01 p<.01 p<.06 p<.01

F2 p<.001 p<.001 n.s. p<.09

Time (ms)

0 500 1000 1500 2000

−2.0 −1.5 −1.0 −0.5 0.0

Log odds of fixation

verb arg1 arg2

Expected outcome

Unexpected outcome

F1 p<.01 p<.01 p<.06 p<.01

F2 p<.001 p<.001 n.s. p<.09

Time (ms)
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 choses to speak the other argument first
Discussion

• based on their eye movements, we have established that:
  • after a DO-biased verb, comprehenders expect a DO construction
  • after a PP-biased verb, they expect a PP construction
• this suggests that:
  • comprehenders knowledge of language includes knowledge about verb bias
  • that knowledge is used to predict what will be said
Discussion

- previous work showed that comprehenders use probabilistic knowledge about the meaning of verbs to focus their attention on likely referents in context.
- our work shows that probabilistic knowledge about the idiosyncratic syntactic behaviour of verbs is used in the same way.
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- ...and supports other tuning/exposure based theories (e.g. Mitchell et al, 1995; MacDonald & Christiansen, 2002)
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• knowledge about language as well as knowledge about the world influences expectations
Future work

- verb bias is just one factor that influences this construction choice in production
  - also priming, argument definiteness, animacy, length, etc.  
    (Bresnan et al, 2007; Jaeger & Snider, 2007)
- priming is known to influence expectation (Arai et al, 2007)
- animacy seems *not* to be used (Carminati et al, in press)
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Thanks for listening!