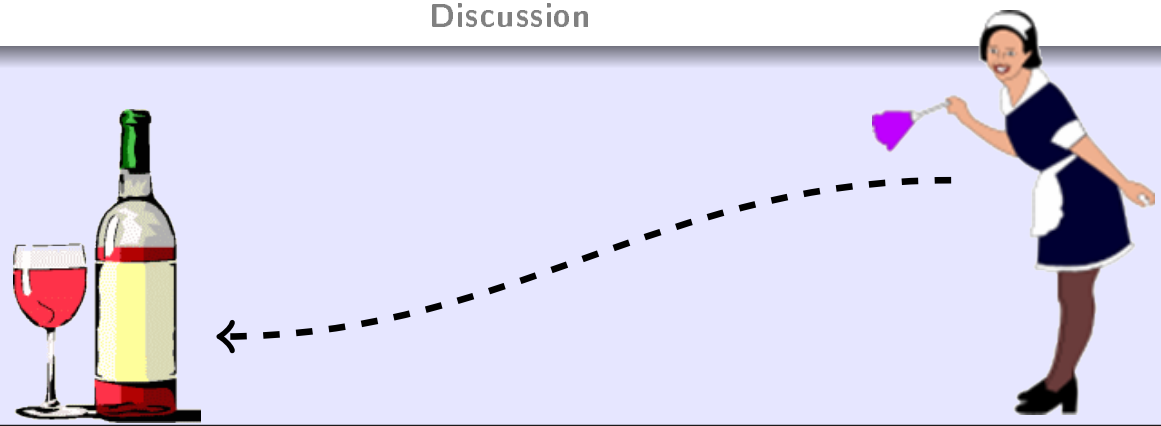


Eye movements reflect comprehenders' knowledge of syntactic structure probability

Harry Tily†, Barbara Hemforth‡, Inbal Arnon†, Noa Shuval‡, Neal Snider† & Tom Wasow†

†Stanford University, ‡Université Paris Descartes

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"?

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"?

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?

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?

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(trans|remember) > p(sc|remember)
  - p(trans|suspect) < p(sc|suspect)
- comprehenders are sensitive to these probabilities (Trueswell et al, 1993; Garnsey et al, 1997)

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(trans|remember) > p(sc|remember)
  - p(trans|suspect) < p(sc|suspect)
- comprehenders are sensitive to these probabilities (Trueswell et al, 1993; Garnsey et al, 1997)

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(trans|remember) > p(sc|remember)
  - p(trans|suspect) < p(sc|suspect)
- comprehenders are sensitive to these probabilities (Trueswell et al, 1993; Garnsey et al, 1997)

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(trans|remember) > p(sc|remember)
  - p(trans|suspect) < p(sc|suspect)
- comprehenders are sensitive to these probabilities (Trueswell et al, 1993; Garnsey et al, 1997)

Is verb bias "purely linguistic"?

- 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*

Is verb bias "purely linguistic"?

- 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*

Is verb bias "purely linguistic"?

- 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*

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|send) > p(DO|send)
  - p(PP|show) < p(DO|show)
- this *cannot* be reduced to a difference in meaning
  - the two constructions mean basically the same thing
  - controlling for semantic properties of the arguments, Bresnan et al (2007) *still* find effects of verb bias

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|send) > p(DO|send)
  - p(PP|show) < p(DO|show)
- this *cannot* be reduced to a difference in meaning
  - the two constructions mean basically the same thing
  - controlling for semantic properties of the arguments, Bresnan et al (2007) *still* find effects of verb bias

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|send) > p(DO|send)
  - p(PP|show) < p(DO|show)
- this *cannot* be reduced to a difference in meaning
  - the two constructions mean basically the same thing
  - controlling for semantic properties of the arguments, Bresnan et al (2007) *still* find effects of verb bias

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

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

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"*

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"*

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"*

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

PP	DO
take	serve
read	teach
hand	pay
offer	award
bring	feed
sell	promise
send	show

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

- 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

   ...

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

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

MAID

PRINCE

WINE

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

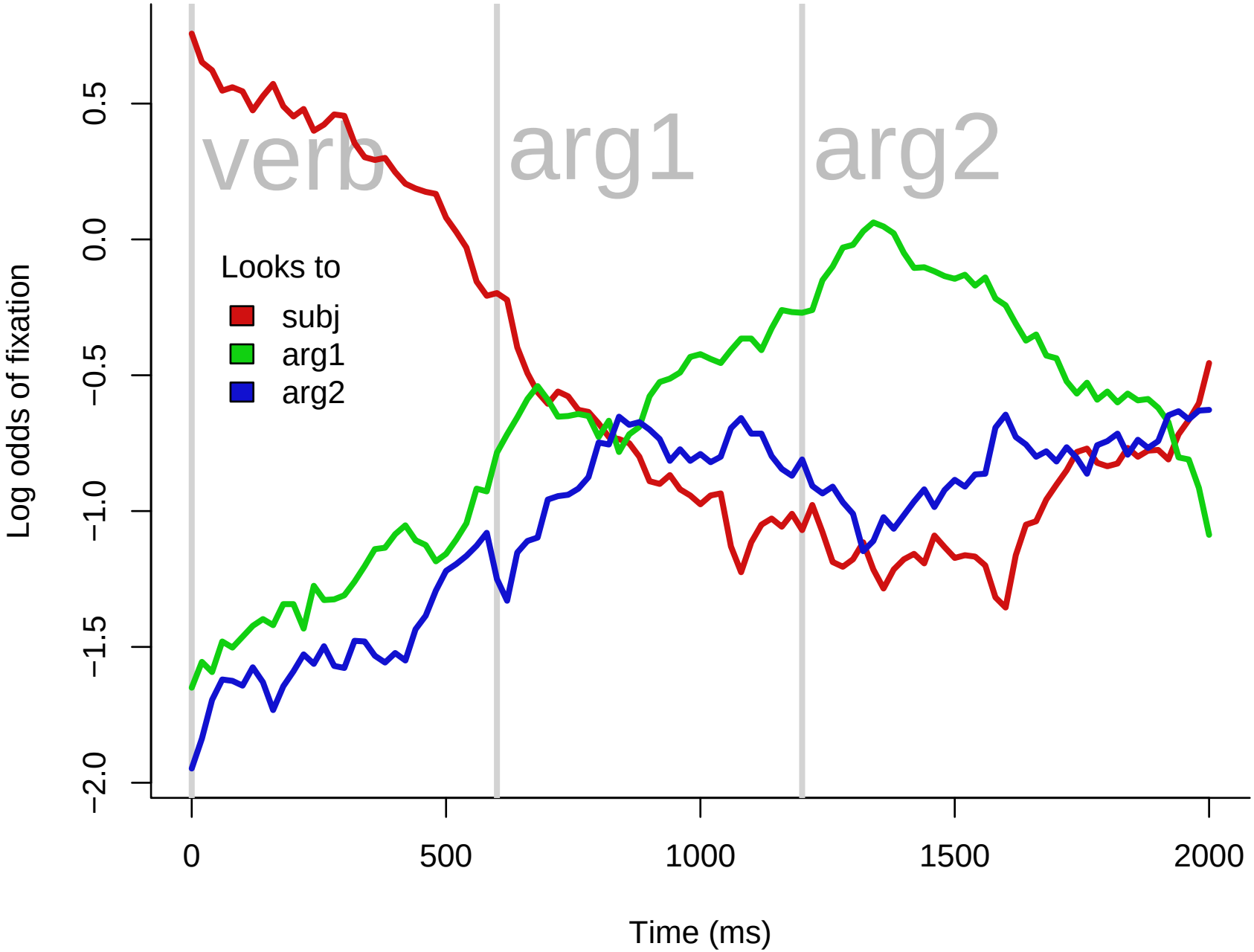
General timecourse

- 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

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

Overall timecourse of eyemovements

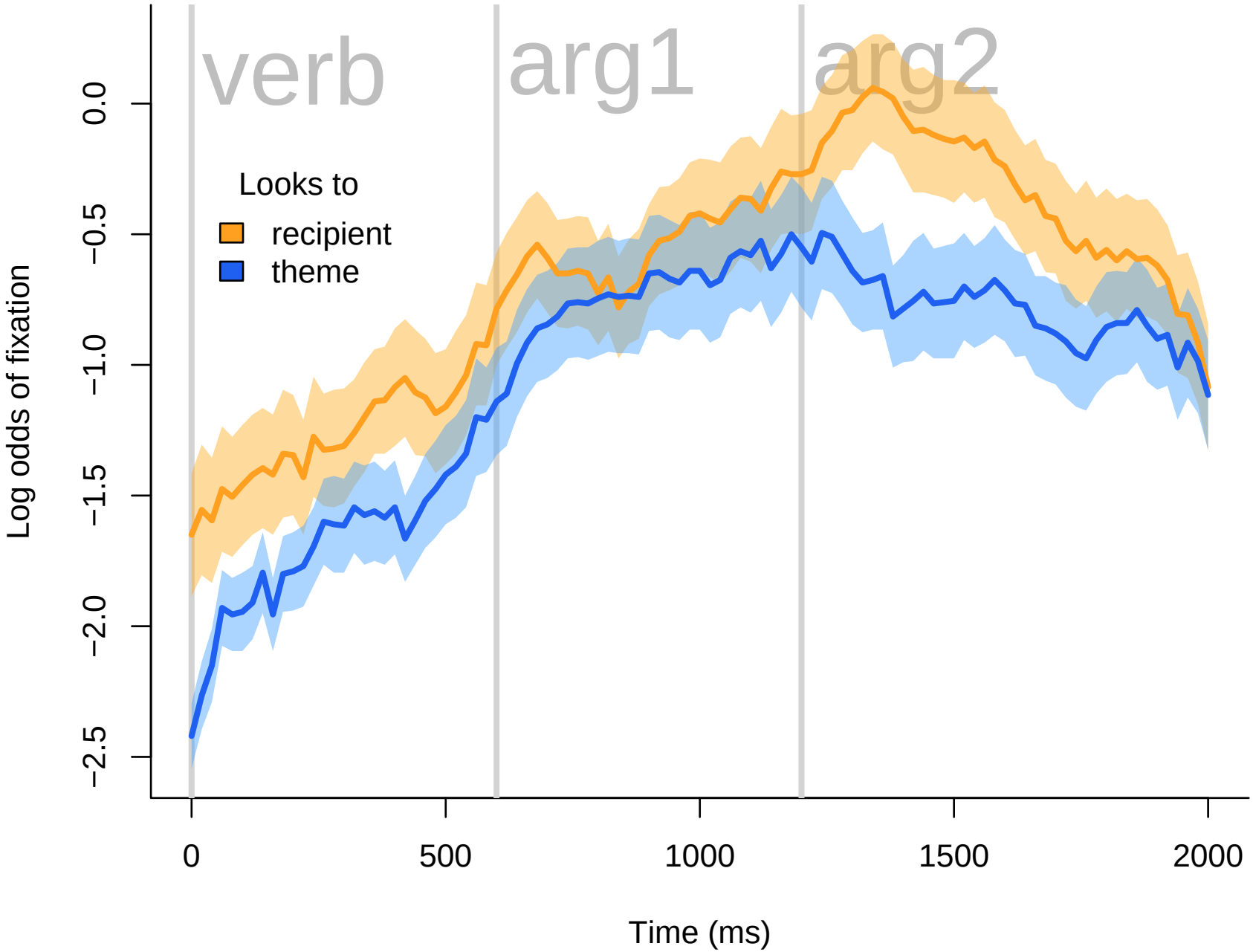


Looks to each argument

Breaking eye-movements down by each argument,

- significantly more looks to the recipient than the theme

Looks to each argument



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)

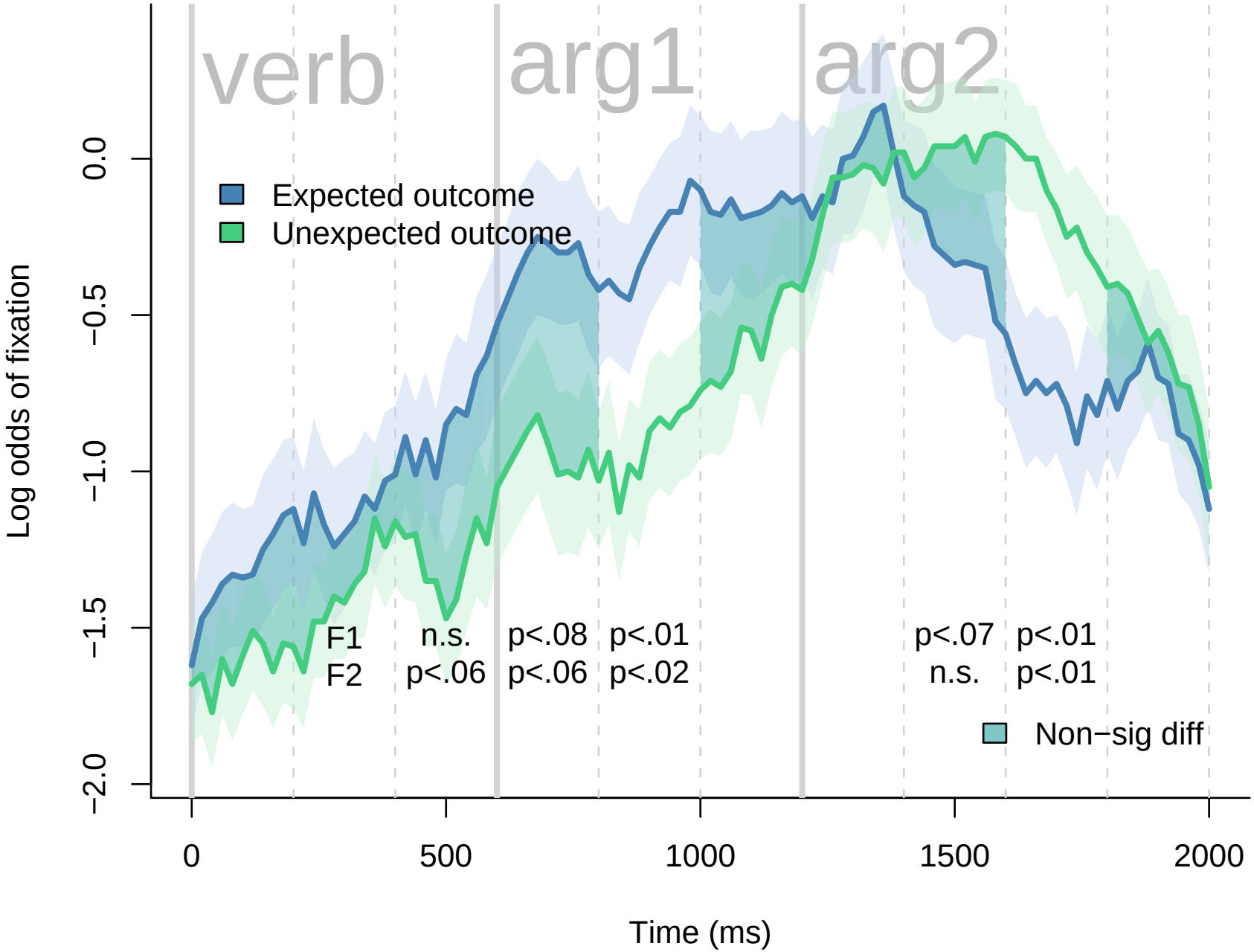
Timecourse by expectation

- 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)

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)

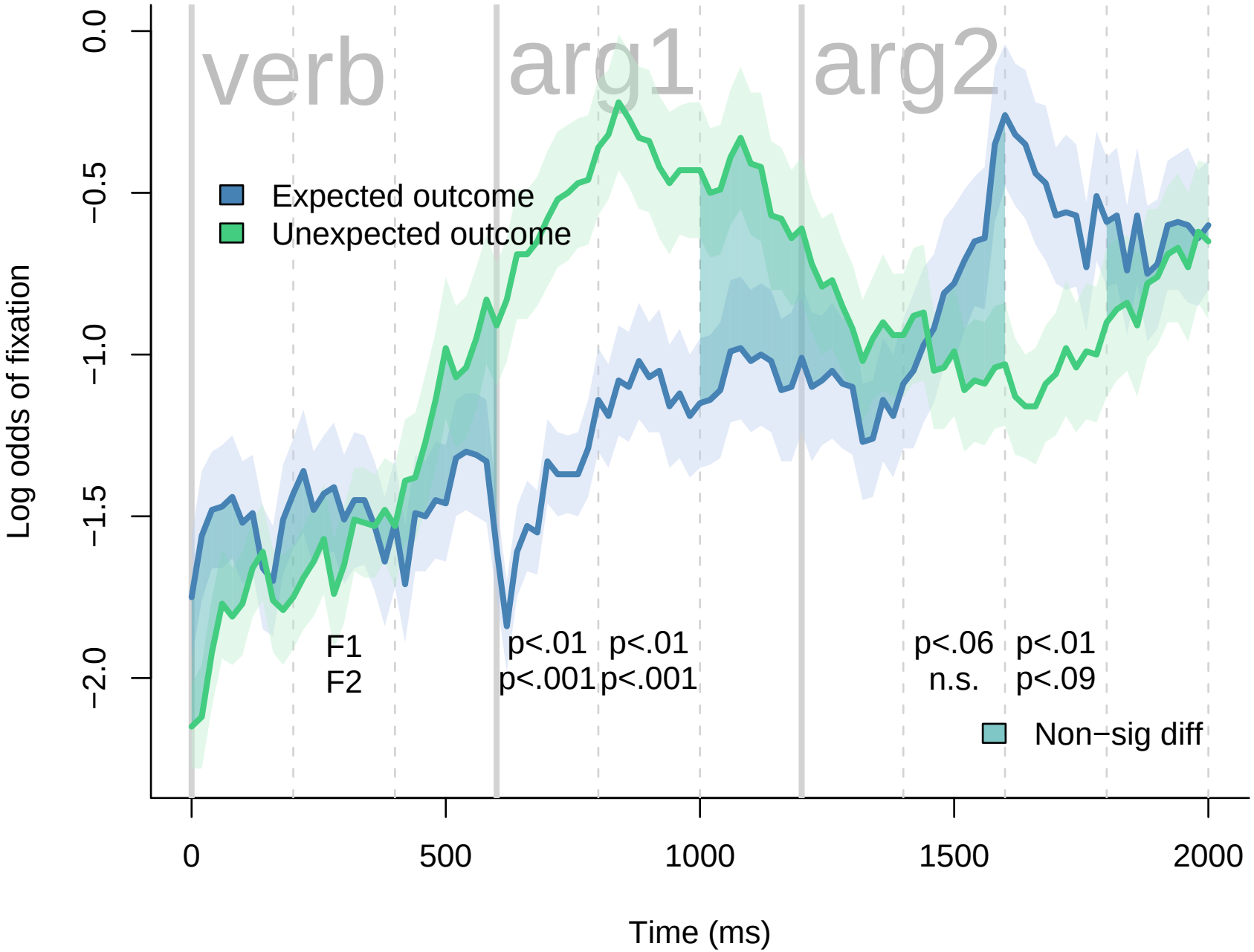
Looks to first argument



Timecourse by expectation

- 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



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

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

Discussion

- sensitivity to purely syntactic probabilities like this is a necessary condition for an expectation-based theory of syntactic comprehension (e.g. Hale, 2001)...
- ...and supports other tuning/exposure based theories (e.g. Mitchell et al, 1995; MacDonald & Christiansen, 2002)

Discussion

- sensitivity to purely syntactic probabilities like this is a necessary condition for an expectation-based theory of syntactic comprehension (e.g. Hale, 2001)...
- ...and supports other tuning/exposure based theories (e.g. Mitchell et al, 1995; MacDonald & Christiansen, 2002)

Discussion

- 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)
- it remains to be seen which other cues comprehenders use

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)
- it remains to be seen which other cues comprehenders use

Thanks for listening!