Using eye movements to study spoken sentence processing

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Can we use eye movements to study sentence-level processes?

*Put the frog that’s on the napkin into the box.*

Tanenhaus et al. (1995); Trueswell et al. (1999)
Point 1. The presence & absence of competitor effects can be used to study parsing decisions.

Put the frog that’s on the napkin into the box.

Tanenhaus et al. (1995); Trueswell et al. (1999)
Point 2. **Anticipatory effects** can be used to study parsing and interpretation as well.

Put the frog that’s on the napkin into the box.

*No...*

Tanenhaus et al. (1995); Trueswell et al. (1999)
Outline

• Using **competitor effects** to study parsing and interpretation in spoken sentence processing
  – Referential constraints
  – Lexico-syntactic and lexico-semantic constraints
  – Prosody
  – Pragmatic/real-world constraints

• Using **anticipatory effects** to study parsing and interpretation in spoken sentence processing
  – Lexical representations & contextual sensitivity
    • Spatial prepositions
    • Verbs
  – Discourse implications of structure
    • Finnish word order
Real-time Sentence Processing

• Sentence interpretation is rapid and unfolds over course of perceiving each sentence.
  – Semantic Anomaly Effects
  – Garden-Path Sentences

• Requires rapid structure building
  – Phonological
  – Syntactic
  – Semantic
  – Referential
Real-Time Sentence Processing
Classic Distinctions / Debates

Modular (Encapsulation) vs. Interactive
Principle-Based Decisions vs. Probabilistic
Phrase-Structure-Like Representations vs. Lexicalist
Syntactic Ambiguity Resolution
(30 years of research on a single slide)

• Early reading studies found general structural biases (e.g., Frazier & Rayner, 1982; Rayner et al., 1983)
  – Minimal Attachment: Prefer the simplest structure
    • Ann hit the thief with the stick. Ann hit the thief with the scar.

• Better controlled studies found a highly-tuned linguistic processor that is sensitive to context
  – Lexical Effects (e.g., Taraban & McClelland, 1988; Trueswell et al., 1994; Garnsey et al., 1998)
    • Ann hit/recognized the thief with the stick…
  – Referential Effects (e.g., Crain & Steedman, 1983; Altmann & Steedman, 1988)
    • Story about two thieves, one holding a stick….
  – Interactive Combination (Britt, 1994; Spivey-Knowlton & Sedivy, 1998)
    • Referential and Lexical Evidence show simultaneous effects
Levels of Representation and Interface Issues

Phonological structure

Prosodic structure
Syllabic structure
Segmental structure
Morphophonology

Syntactic structure

Semantic/conceptual structure

Spatial structure

Fig. 1.1. Structure of The little star's beside a big star

Jackendoff (2002)
Effects of visual world on parsing decisions
(Tanenhaus et al., 1995; Spivey et al., 2002; Trueswell et al., 1999)

1-Referent Context
Supports
Destination Interp.
(VP-Attach)

2-Referent Context
Supports
Modifier Interp.
(NP-Attach)
Fig. 3. Percentage of trials in which there was a look to the Incorrect Destination, e.g. the empty napkin, as measured for the onset of ambiguous phrase, e.g. “on the napkin”
Which information sources drive parsing decisions? And how do they combine?

• *Put the frog on the napkin*…
  – Parsing Principles (Minimal Attachment)?
  – Lexico-syntactic tendencies?
  – Lexico-semantic tendencies?
  – Prosody?
  – Referential/pragmatic constraints?

Constraint-Based Lexicalist (CBL)
Lexical constraints
(Snedeker & Trueswell, 2004)

• Adults in Eye-Gaze Listening
• Global Syntactic Ambiguity, Manipulate V-bias:
  – *Tickle the pig with the fan.* (Instrument Bias)
  – *Feel the frog with the feather.* (Equi Bias)
  – *Choose the cow with the stick.* (Modifier Bias)
• Crossed with Referential Scene...
Adults show Referential and Verb-bias effects

Actions:
Use of Instrument

Eye Movements:
Looks to Instrument

Proportion of Trials

(Tickle...)
Instrument-Bias

(Feel...)
Equi-Bias

(Choose...)
Modifier-Bias

50% Acted on Other Frog

50% acted on Target Frog

1-Referent
2-Referent
Tracking without an eye tracker
(see Snedeker & Trueswell, 2004)

Stimulus speakers from laptop. Also connected to audio-in of camera.

Great for young children, as well as for field work w/ adults or children.

Digital Video Camera (Audio-locked)
Role of Prosody
(Snedeker & Trueswell, 2003)

• Pairs of participants
  – ‘Speaker’
  – ‘Listener’

• (Highly constrained) referential communication task…
Exp. demonstrates either instrument or modifier action to speaker.

Tap the frog with the feather.
Speaker had seen Modifier Demo.

Speaker had seen Instrument Demo.
Pour the egg in the bowl onto the flower.

Compatible competitor

Incompatible competitor

Percent Looks to False Goal

- Ambiguous Phrase
- Unambiguous Phrase

Referential Competitor

Compatible

Incompatible

Percent time spent fixating false goal
Which information sources drive parsing decisions?

- **Put the frog on the napkin…**
  - Parsing Principles (Minimal Attachment)? **No.**
  - Lexico-syntactic tendencies? **Yes.**
  - Lexico-semantic tendencies?
  - Prosody? **Yes.**
  - Referential/pragmatic constraints? **Yes.**

Constraint-Based Lexicalist (CBL)
Constraint-based lexicalist theory
(Trueswell & Tanenhaus, 1994; MacDonald et al., 1994)

- Comprehension process is inherently a perceptual guessing game
- Multiple probabilistic cues to recover detailed linguistic structure
- Parsing is a recognition process, with temporary parallelism
Anticipatory Effects
(e.g. Chambers, Tanenhaus, Eberhard, Filip & Carlson, 2002)

*Put the duck inside the can.*

**FIG. 1.** Examples of experimental displays (Experiment 1).
Verb Semantic Restrictions
(Altmann & Kamide, 1999)

Boland (2004): Only arguments are predicted, not adjuncts.

*The boy will move the cake.*  *The boy will eat the cake.*
Listeners can compute semantics in real time and use this information to anticipate properties of upcoming constituents.

Can people compute the discourse status of upcoming constituents as well?
Sentence processing in Finnish
Kaiser & Trueswell (2004)

• Finnish
  – Case Marking
  – Flexible word order
  – No articles (the, a)
  – SVO canonical order
  – OVS order:
    • Object is discourse old
    • Subject is discourse new
  – Prediction: When Finnish listeners hear OV… they should expect a discourse NEW subject.
At the hospital, behind a desk, are a doctor and a nurse. ....
And it’s almost two o’clock.
Target sentence (OVS):

Then doctor-obj greets …
Target sentence (OVS):

Then doctor-obj greets…

Anticipatory looks to new ref after hearing OV….
Then doctor-obj greets patient-subj.
Then doctor-subj greets…
Target sentence (SVO):

Then doctor-subj greets…

Delay looks to new referent until hear the noun?
Target sentence (SVO):

Then doctor-subj greets patient-obj
Then doctor-obj greets ....
Then *doctor-obj* greets ....

Anticipatory looks to new nurse after hearing OV....
Then doctor-obj greets nurse-subj
Then doctor-subj greets nurse-obj

Less looks to new nurse?
Summary of Design and Predictions

- OVS unambiguous
  - Early looks to New Referent upon hearing [OV…]
- SVO unambiguous
  - Looks to New Referent delayed until hearing N2
- OVS ambiguous
  - Early looks to New Referent upon hearing [OV…]
  - Prefer New Referent, though ambiguous
- SVO ambiguous
  - Few looks to New Referent? (Prefer Old Referent?)
Looks to discourse-new referent from onset of 2nd Noun
Main effect of structure (first 400 ms, p<0.05)

% of trials w/ look to new ref

Frames (1/30th of a second)
Effects of Phonological Content of Noun

Effects of Ambig. And Structure (400 ms and onward, p<0.05)

% of trials w/ look to new ref

Frames (1/30th of a second)
Summary of Parsing

• Two tricks of the trade:
  – Competitor effects
  – Anticipation effects

• Results show listeners dynamically structure input into semantic + referential characterization of input.
  – Done in real-time
  – Done at multiple levels simultaneously
  – Highly interactive
Open questions

• Importance of lexical generated structure building vs. contextual dependencies

• Interface Issues
  – What are the limitations (if any) on interactions across levels of representation
  – Are complete linguistic characterizations computed & operated on?
Language Development (next Thurs.)

• The two tricks of the trade, competitor effects and anticipatory effects, are being used to study:
  – Phonological & Lexical development
    • Fernald, Swingley, Aslin and colleagues
  – Syntax & Semantics
    • Trueswell, Snedeker, Gleitman, Lidz, Musolino and colleagues
  – Discourse & Conversation
    • Sedivy, Eply, Keysar and colleagues