Back and forth: real-time computation of linguistic dependencies

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Real-time language comprehension involves both *forward*- and *backward*-looking processes.

Altmann & Kamide (1999); Federmeier & Kutas (1999); Aoshima et al. (2003); DeLong et al. (2005); Van Berkum et al. (2005); Gordon et al. (2006); Lau et al. (2006); Lewis et al. (2006); Staub & Clifton (2006); Kazanina et al. (2007); Wagers et al. (2009); Van Dyke & McElree (2011); Yoshida et al. (2012); Dillon et al. (2014); Omaki et al. (2015)
Prediction involves retrieving stored representations from memory.

Chow, Momma, Smith, Lau, & Phillips (2016)
Let’s make some predictions

The gardener talked as the barber trimmed the __________ ...

The barber talked as the gardener trimmed the __________ ...
Outline

Background

– A surprising case of N400 blindness

From “semantic illusions” to unfolding verb predictions

– Evidence from English, Mandarin Chinese and Japanese

Proposal

– A “bag-of-arguments” mechanism for verb predictions

Discussion

– Prediction as memory retrieval: timing and mechanisms
Event-related Potentials (ERP)

- The brain’s electrical responses time-locked to stimuli of interest
- Serial visual presentation
The N400 and Predictability

- The N400 is a negative-going ERP response that is largest at around 400ms following stimulus onset.
  - has been linked to lexical semantic processing.
  - Its amplitude is *inversely* related to a word’s cloze probability (offline predictability).

“The children went outside to **play** / **eat** / **read**.”

- low cloze probability
- medium cloze probability
- high cloze probability

Kutas & Hillyard (1984); Kutas (1993); Federmeier & Kutas (1999)
Gunter et al. (2000); Deacon et al. (2000); DeLong et al. (2005)
Dambacher & Kluegl (2007); Federmeier et al. (2007); Lau et al. (2008)
The N400 may seem very “smart”…

young child / adult:
“Every evening I drink some wine before I go to sleep.”

van Berkum, van den Brink, Tesink, Kos & Hagoort (2008)
But not always…

- Argument role reversals

John wondered which **thief** the **cop** arrested.

John wondered which **cop** the **thief** arrested.

- result in an *implausible* thematic relation
- also affect the verb’s cloze probability
- elicit a late positivity (P600 effect)
- **do not modulate the N400**.
A surprising case of N400 blindness

Example: SOV $ba$-construction in Mandarin Chinese

Canonical: jingcha $ba$ xiaotou zhua-le
cop_{SUBJ} BA thief_{OBJ} arrest

Role-reversed: xiaotou $ba$ jingcha zhua-le
thief_{SBJ} BA cop_{OBJ} arrest

Chow & Phillips (2013)
The N400’s insensitivity to role-reversals

- English: Kim & Osterhout (2005); Kuperberg et al. (2003; 2007)
- Dutch: Kolk et al. (2003); Van Herten et al. (2005; 2006)
Competing Accounts

Semantic Illusions

- The N400 is modulated by the **plausibility** of the interpretation being built.

- Its insensitivity to role-reversals reflects a **temporary failure to detect the implausibility** (e.g., Kolk et al, 2003; Kim & Osterhout, 2005).

Unfolding Predictions

- The N400 is modulated by the **online predictability** of a word’s meaning (e.g., Federmeier & Kutas, 1999).

- Its insensitivity to role-reversals suggests that **verb predictions are not immediately sensitive to the arguments’ roles**.
Semantic illusions

“Child abuse cases are being reported much more frequently these days. In a recent trial, a 10-year sentence was given to the victim, but this was subsequently appealed.”

→ Undetected semantic anomalies do not elicit any ERP effect.

Sanford, Leuthold, Bohan & Sanford (2010)
Non-immediate use of argument roles in predictive processing

“Toby arrests the crook.”

Kukona, Fang, Aicher, Chen & Magnuson (2011)
I. Semantic illusion vs. Unfolding prediction?

- Why do argument role reversals fail to modulate the N400 response?
Experiment 1

• Unfolding Predictions Hypothesis:
  Argument role information *does* impact comprehenders’ verb predictions, but its impact is delayed.

• Paradigm:
  – To increase the linear distance (and effectively the amount of time elapsed) between the arguments and the verb.
Long distance

Short distance

上星期，last week
警方，police
把，BA

把，BA
警方，police

疑犯，suspect
在，ZAI

上星期，last week
抓住了，arrest

1800ms
600ms
# Experiment 1 – Predictions

<table>
<thead>
<tr>
<th>Short-distance</th>
<th>Long-distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>___ Canonical</td>
<td>___ Canonical</td>
</tr>
<tr>
<td>Last week police BA suspect arrest...</td>
<td>Police BA suspect ZAl last week arrest...</td>
</tr>
<tr>
<td>___ Role-reversed</td>
<td>___ Role-reversed</td>
</tr>
<tr>
<td>Last week suspect BA police arrest...</td>
<td>Suspect BA police ZAl last week arrest...</td>
</tr>
</tbody>
</table>

*If the arguments’ structural roles can impact verb predictions within the lengthened time window…*
Experiment 1 – Results (n=24)

**Short-distance**

- **Canonical**
  - Last week police BA suspect **arrest**...
- **Role-reversed**
  - Last week suspect BA police **arrest**...

**Long-distance**

- **Canonical**
  - Police BA suspect ZAI last week **arrest**...
- **Role-reversed**
  - Suspect BA police ZAI last week **arrest**...
Argument role reversals elicited an N400 effect when the verb was further away from its arguments.
Experiment 2

• *Are we really looking at prediction?*
  – Do these results simply show that people can detect the implausibility more quickly when they have more time?
Experiment 2 – Predictions

Low-predictability
--- Canonical
Mr. Liu BA parrot ZAI that summer train ...
--- Role-reversed
Parrot BA Mr. Liu ZAI that summer train ...

High-predictability
--- Canonical
Cop BA thief ZAI that evening arrest ...
--- Role-reversed
Thief BA cop ZAI that evening arrest ...

• Unfolding Prediction hypothesis:
  – The N400 is modulated by a word’s **online** predictability.
  – *If argument role information can impact verb predictions by the time the verb appears*…
Experiment 2 – Predictions

- **Semantic Illusion hypothesis:**
  - Role-reversed sentences are equally implausible in both conditions.
  - An N400 effect should be present in both cases.

<table>
<thead>
<tr>
<th>Low-predictability</th>
<th>High-predictability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Canonical</strong></td>
<td><strong>Canonical</strong></td>
</tr>
<tr>
<td>Mr. Liu BA parrot ZAI that summer <strong>train</strong> ...</td>
<td>Cop BA thief ZAI that evening <strong>arrest</strong> ...</td>
</tr>
<tr>
<td><strong>Role-reversed</strong></td>
<td><strong>Role-reversed</strong></td>
</tr>
<tr>
<td>Parrot BA Mr. Liu ZAI that summer <strong>train</strong> ...</td>
<td>Thief BA cop ZAI that evening <strong>arrest</strong> ...</td>
</tr>
</tbody>
</table>
Experiment 2 – Results (n=24)

**Low-predictability**

- **Canonical**
  - Mr. Liu BA parrot ZAI that summer train ...
- **Role-reversed**
  - Parrot BA Mr. Liu ZAI that summer train ...

![Graphs showing P600 effect](image)

**High-predictability**

- **Canonical**
  - Cop BA thief ZAI that evening arrest ...
- **Role-reversed**
  - Thief BA cop ZAI that evening arrest ...

![Graphs showing P600 effect and N400 effect](image)
Experiment 2 – Results (n=24)

Low-predictability
___ Canonical
   Mr. Liu BA parrot ZAI that summer train ...
___ Role-reversed
   Parrot BA Mr. Liu ZAI that summer train ...

High-predictability
___ Canonical
   Cop BA thief ZAI that evening arrest ...
___ Role-reversed
   Thief BA cop ZAI that evening arrest ...

When the verb was further away from its arguments, the N400 became sensitive to the offline predictability of the verb (and not plausibility per se).
Interim Summary

• Argument role reversals were readily detected and elicited a P600 effect in all cases.

• Argument role reversals modulated the N400 only
  – when the presentation of the verb was delayed, and
  – when they have a clear impact on the verb’s cloze probability.
Implications

• The N400’s insensitivity to argument role reversals is not attributable to semantic illusions.

• Instead, these results suggest information about the arguments’ roles has a delayed impact on verb predictions.
Convergent findings from Japanese (Momma, Sakai & Phillips, 2015)

Role-reversal in 2-word sentences (SV or OV)
• Canonical: bee\text{\textsubscript{NOM}} sting
• Role-reversed: bee\text{\textsubscript{ACC}} sting

SOA manipulation
• Short (800ms) vs. Long (1200ms)
Momma, Sakai & Phillips (2015)

Short SOA (800ms)

Long SOA (1200ms)

300-500ms
Snapshots of verb predictions

N400 insensitive to the roles of the arguments

cop BA thief cop

arrest...

[ZAI that evening] arrest...

N400 sensitivity emerged

t = 0ms t = 600ms t = 1800ms
Snapshots of verb predictions

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

Verb prediction sensitive to the arguments’ roles

cop   BA  thief
thief  BA  cop

[ZAI that evening]  arrest...

What’s happening here?

The business man knew which customer the secretary called…
The business man knew which article the secretary called…

Some information about the arguments can impact verb predictions rather quickly.

N400 effect
II. Initial stages of verb predictions

• Are initial verb predictions sensitive to other information about the arguments (e.g., their lexical meaning)?
Experiment 3

- **Hypothesis:**
  - The lexical meaning of the arguments can impact verb predictions more quickly than their structural roles.

<table>
<thead>
<tr>
<th>Argument role reversal</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High cloze (25%)</strong></td>
<td>The restaurant owner forgot which customer the waitress had <strong>served</strong> during dinner yesterday.</td>
</tr>
<tr>
<td><strong>Low cloze (0%)</strong></td>
<td>The restaurant owner forgot which waitress the customer had <strong>served</strong> during dinner yesterday.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Argument substitution</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High cloze (28%)</strong></td>
<td>The superintendent overheard which <strong>tenant</strong> the landlord had <strong>evicted</strong> at the end of May.</td>
</tr>
<tr>
<td><strong>Low cloze (0%)</strong></td>
<td>The superintendent overheard which <strong>realtor</strong> the landlord had <strong>evicted</strong> at the end of May.</td>
</tr>
</tbody>
</table>
Experiment 3 – Predictions

**Argument role reversal**

_____ High cloze - The restaurant owner forgot which customer the waitress had served ...

____ Low cloze - The restaurant owner forgot which waitress the customer had served ...

**Argument substitution**

_____ High cloze - The superintendent overheard which tenant the landlord had evicted ...

_____ Low cloze - The superintendent overheard which realtor the landlord had evicted ...

*If the arguments’ lexical meaning has a more immediate impact on verb predictions than their structural roles…*
Experiment 3 – Results (n=24)

**Argument role reversal**

- **High cloze** - The restaurant owner forgot which customer the waitress had served ...  
- **Low cloze** - The restaurant owner forgot which waitress the customer had served ...

**Argument substitution**

- **High cloze** - The superintendent overheard which tenant the landlord had evicted ...  
- **Low cloze** - The superintendent overheard which realtor the landlord had evicted ...
Experiment 3 – Results (n=24)

**Argument role reversal**

- High cloze - The restaurant owner forgot which customer the waitress had served ...
- Low cloze - The restaurant owner forgot which waitress the customer had served ...

**Argument substitution**

- High cloze - The superintendent overheard which tenant the landlord had evicted ...
- Low cloze - The superintendent overheard which realtor the landlord had evicted ...

→ Despite similar cloze probability differences, only argument substitution elicited an N400 effect.

→ Verb predictions are sensitive to the arguments’ lexical meaning rather early on.
• What is *initially* involved in predicting a verb?

“The exterminator inquired which neighbour the landlord had …”

Bag-of-arguments Hypothesis

Bag-of-words Hypothesis
Experiment 4

“Different words” argument substitution (same as Exp 4)

<table>
<thead>
<tr>
<th>High cloze</th>
<th>The tenant inquired which neighbor the landlord had evicted …</th>
</tr>
</thead>
<tbody>
<tr>
<td>(22%)</td>
<td></td>
</tr>
<tr>
<td>Low cloze</td>
<td>The tenant inquired which exterminator the landlord had evicted …</td>
</tr>
<tr>
<td>(&lt;1%)</td>
<td></td>
</tr>
</tbody>
</table>

“Same words” argument substitution

<table>
<thead>
<tr>
<th>High cloze</th>
<th>The exterminator inquired which neighbor the landlord had evicted …</th>
</tr>
</thead>
<tbody>
<tr>
<td>(22%)</td>
<td></td>
</tr>
<tr>
<td>Low cloze</td>
<td>The neighbor inquired which exterminator the landlord had evicted …</td>
</tr>
<tr>
<td>(&lt;1%)</td>
<td></td>
</tr>
</tbody>
</table>
Experiment 4 – Predictions

Different words

- High cloze - The tenant inquired which neighbor the landlord had **evicted**...
- Low cloze - The tenant inquired which exterminator the landlord had **evicted**...

Same words

- High cloze - The exterminator inquired which neighbor the landlord had **evicted**...
- Low cloze - The neighbor inquired which exterminator the landlord had **evicted**...

*If comprehenders initially use a bag-of-words mechanism…*
Experiment 4 – Predictions (cont’d)

<table>
<thead>
<tr>
<th>Different words</th>
<th>Same words</th>
</tr>
</thead>
<tbody>
<tr>
<td>___ High cloze  - The tenant inquired which neighbor the landlord had evicted...</td>
<td>___ High cloze  - The exterminator inquired which neighbor the landlord had evicted...</td>
</tr>
<tr>
<td>___ Low cloze   - The tenant inquired which exterminator the landlord had evicted...</td>
<td>___ Low cloze   - The neighbor inquired which exterminator the landlord had evicted...</td>
</tr>
</tbody>
</table>

If comprehenders initially use a bag-of-arguments mechanism…
Experiment 4 – Results (n=24)

Different words

_____ **High cloze** - The tenant inquired which neighbor the landlord had **evicted**...

_____ **Low cloze** - The tenant inquired which exterminator the landlord had **evicted**...

Same words

_____ **High cloze** - The exterminator inquired which neighbor the landlord had **evicted**...

_____ **Low cloze** - The neighbor inquired which exterminator the landlord had **evicted**...
Implications

• The meaning of the arguments, not just any words in the context, is immediately used for verb predictions.

• The impact of argument roles on verb predictions is delayed relative to their lexical meaning.
Experiment 5

• Can we find independent evidence for a “bag-of-arguments” mechanism?

• Online cloze production
  – Sentence frames taken from Experiment 3
    “The exterminator inquired which neighbour the landlord had ___”
  – Manipulate response deadline
Online cloze paradigm

Adapted from Staub et al. (2015) JML
# Experiment 5 – Results (n=40)

Online cloze of the ERP target words

## Argument Reversals

<table>
<thead>
<tr>
<th>ERP target</th>
<th>Short</th>
<th>Long</th>
<th>Offline</th>
</tr>
</thead>
<tbody>
<tr>
<td>The restaurant owner forgot…</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) which customer the waitress had …</td>
<td>11.4%</td>
<td>15.1%</td>
<td>25.4%</td>
</tr>
<tr>
<td>(b) which waitress the customer had …</td>
<td>3.6%</td>
<td>1.2%</td>
<td>0%</td>
</tr>
</tbody>
</table>

## Argument Substitution

<table>
<thead>
<tr>
<th>Cloze Probability</th>
<th>Short</th>
<th>Long</th>
<th>Offline</th>
</tr>
</thead>
<tbody>
<tr>
<td>The secretary confirmed…</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c) which illustrator the author had …</td>
<td>16%</td>
<td>19.7%</td>
<td>27.7%</td>
</tr>
<tr>
<td>(d) which readers the author had …</td>
<td>1.5%</td>
<td>0.2%</td>
<td>0%</td>
</tr>
</tbody>
</table>
Comprehenders’ verb predictions are immediately sensitive to the lexical meaning of the arguments, but the impact of the arguments’ roles is delayed.
Why is the impact of argument role delayed?

Prediction involves memory retrieval.

Verb prediction
• What’s being retrieved?
  – Memory of events
• Retrieval cues?
  – Arguments + their roles
    [customer] [customer-as-agent]
    [waitress] [waitress-as-patient]

Chow, Momma, Smith, Lau, & Phillips (2016)
Why is the impact of argument role delayed?

Some potential causes:
1. Delayed cue availability ← unlikely?
2. Similarity-based Interference
3. Format mismatch between retrieval cues and target memories
Similarity-based Interference

Delay due to interference from events that match only some of the retrieval cues

“The manager forgot which waitress the customer had … “

– a serving event matches the [customer] [waitress] cues but not the [customer-as-agent] [waitress-as-patient] cues
Format mismatch between retrieval cues and target memories

• Role information may be encoded differently in retrieval cues than in event memory.
  – Relevant information in event memory may not be directly accessible.

• This may necessitate the use of an indirect (or additional) process for retrieval.
  – e.g., a process that aligns the different role encodings, a search-like process that evaluates candidate events serially, etc.
Summing up

• The N400’s insensitivity to role reversals is not due to semantic illusions.
  – It presents a case of slow prediction.

• The roles of arguments have a delayed impact on verb predictions relative to their lexical meaning.
  – Conceptualising prediction as memory retrieval can help us think more clearly about potential underlying mechanisms.
Thank you!

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