Back and forth: real-time computation of linguistic dependencies

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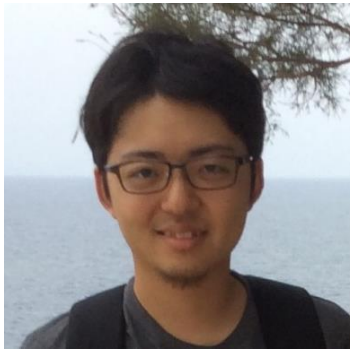

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prediction

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

memory retrieval

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 ___mustache___ *…*

The barber talked as the gardener trimmed the ___hedge___ *…*

Outline

Background

- A surprising case of N400 blindness

From “semantic illusions” to unfolding verb predictions

- Evidence from English, Mandarin Chinese and Japanese

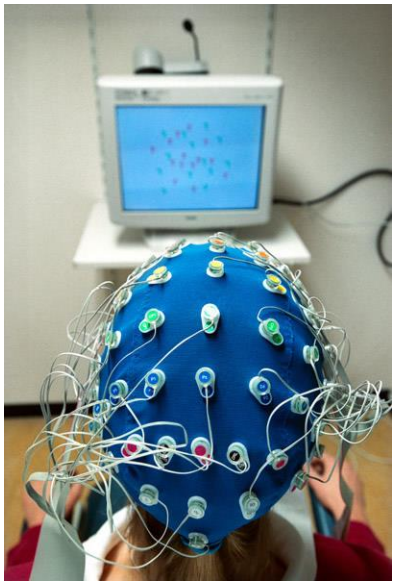
Proposal

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

Discussion

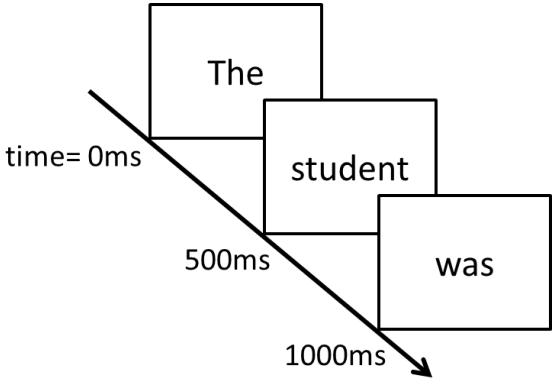
- Prediction as memory retrieval: timing and mechanisms

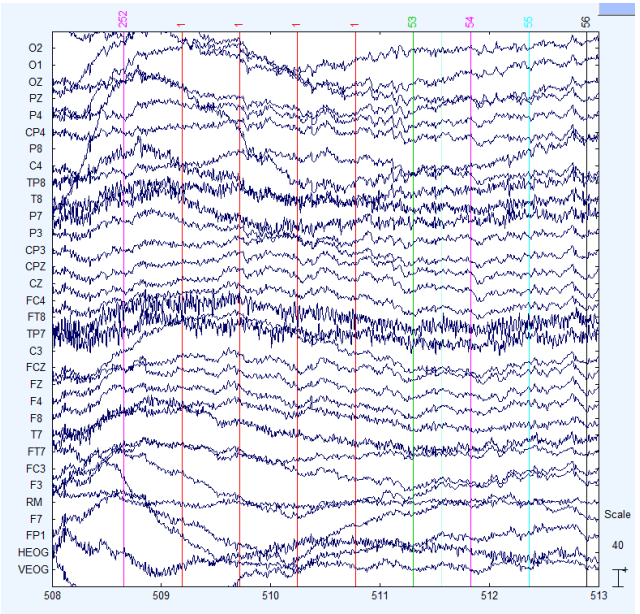
Event-related Potentials (ERP)



- The brain's electrical responses time-locked to stimuli of interest

- Serial visual presentation

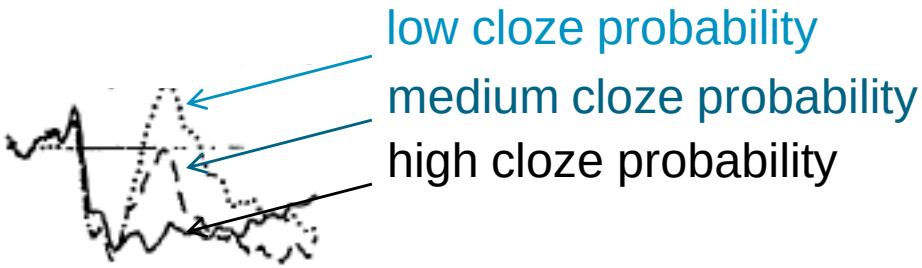




The N400 and Predictability

- 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).

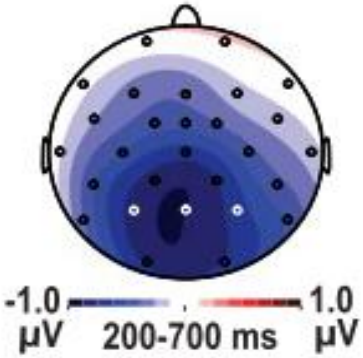
"The children went outside to play / eat / read."

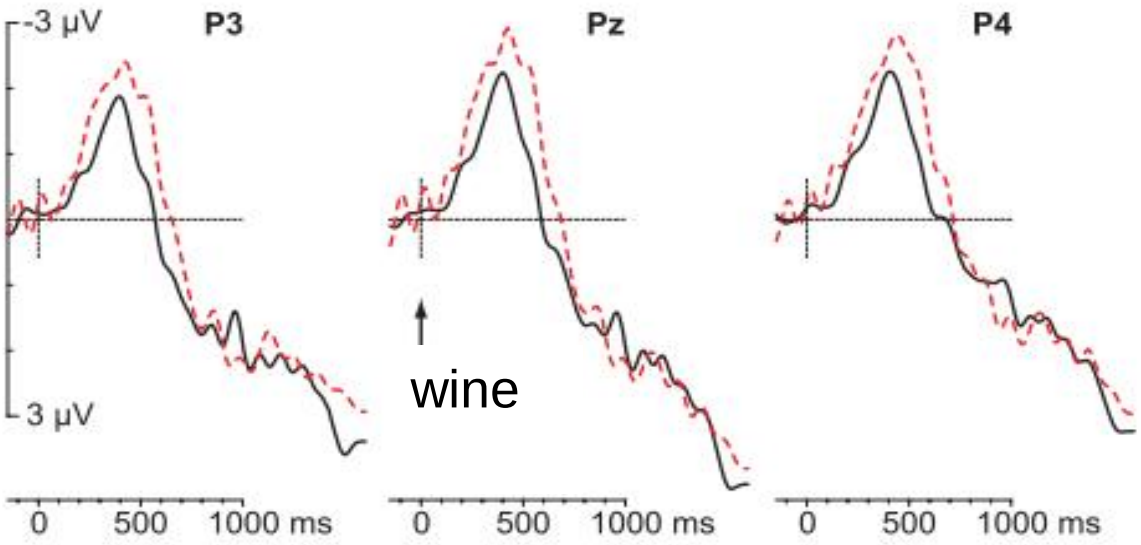


Kutas & Hillyard (1984); Kutas (1993); Federmeier & Kutas (1999)
Gunter et al. (2000); Deacon et al. (2000); DeLong et al. (2005)
Dambacher & Kliegl (2007); Federmeier et al. (2007); Lau et al. (2008)

The N400 may seem very "smart"…

young child / adult:
"Every evening I drink some <u>wine</u> before I go to sleep."





van Berkum, van den Brink, Tesink, Kos & Hagoort (2008)

But not always…

- Argument role reversals

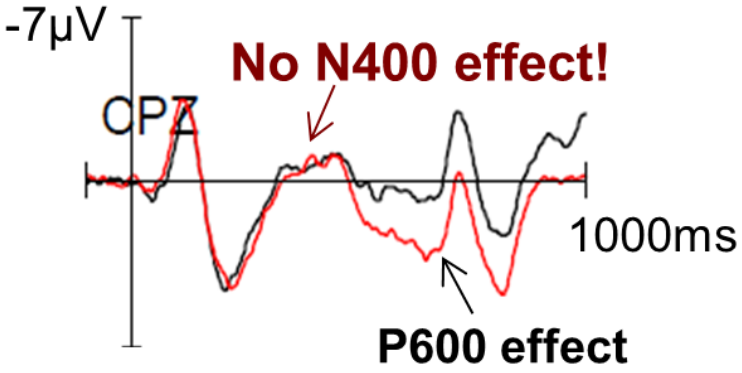
John wondered which **thief** the **cop** arrested.
John wondered which **cop** the **thief** arrested.

  - 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

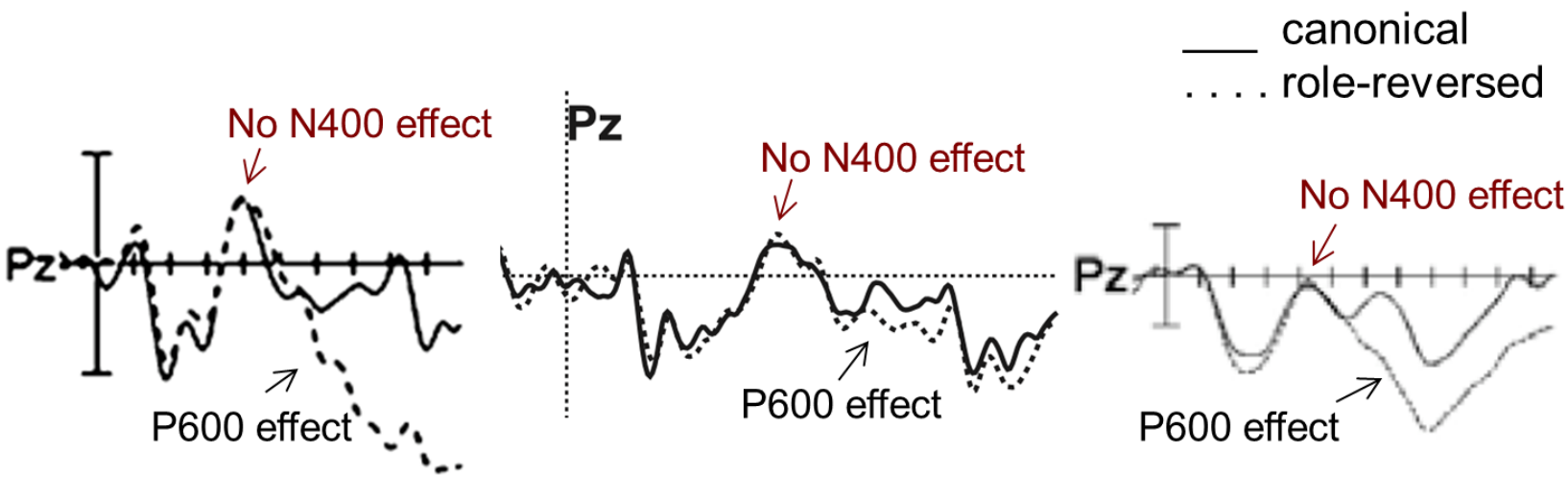
Canonical:	*jingcha*	*ba*	*xiaotou*	***zhua-le***
	cop_{SUBJ}	BA	$thief_{OBJ}$	arrest
Role-reversed:	*xiaotou*	*ba*	*jingcha*	***zhua-le***
	$thief_{SBJ}$	BA	cop_{OBJ}	arrest



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)
- Mandarin Chinese: Ye & Zhou (2008); Chow & Phillips (2013)
- Japanese: Oishi & Sakamoto (2010)



Kim & Osterhout (2005) Van Herten et al. (2005) Kuperberg et al. (2007)

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).

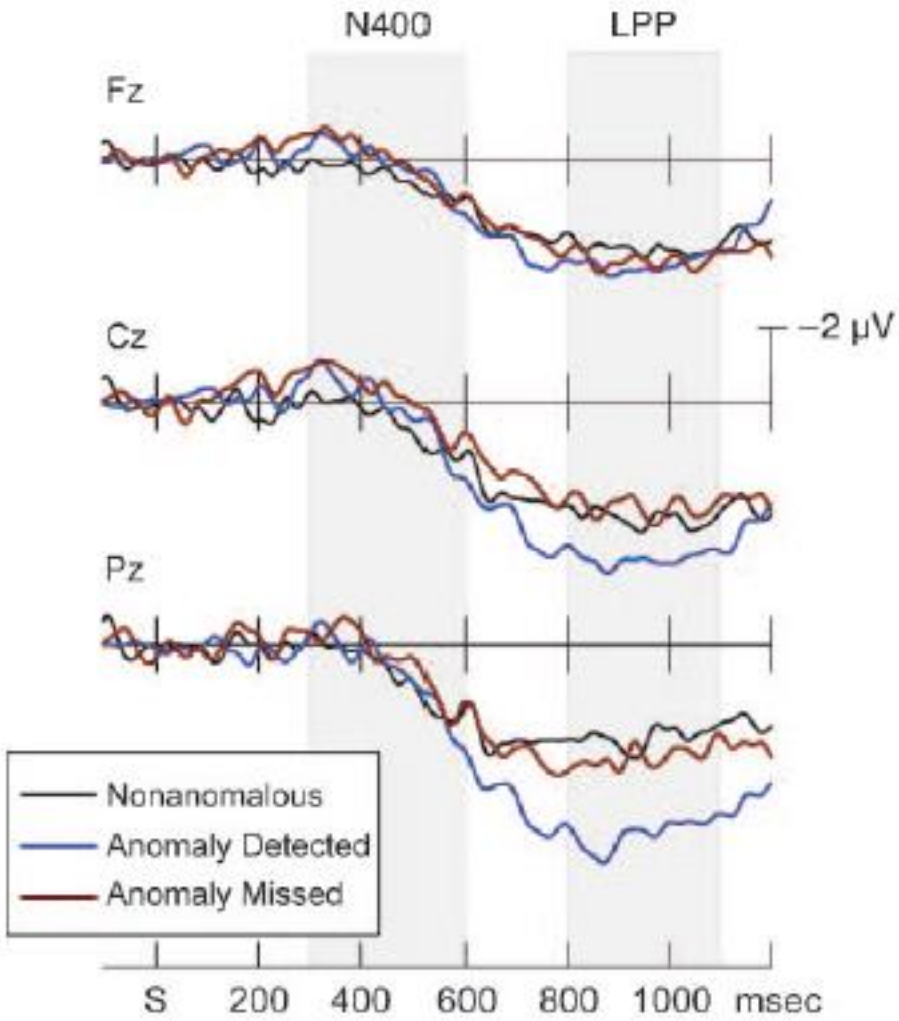
Unfolding Predictions

- 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."

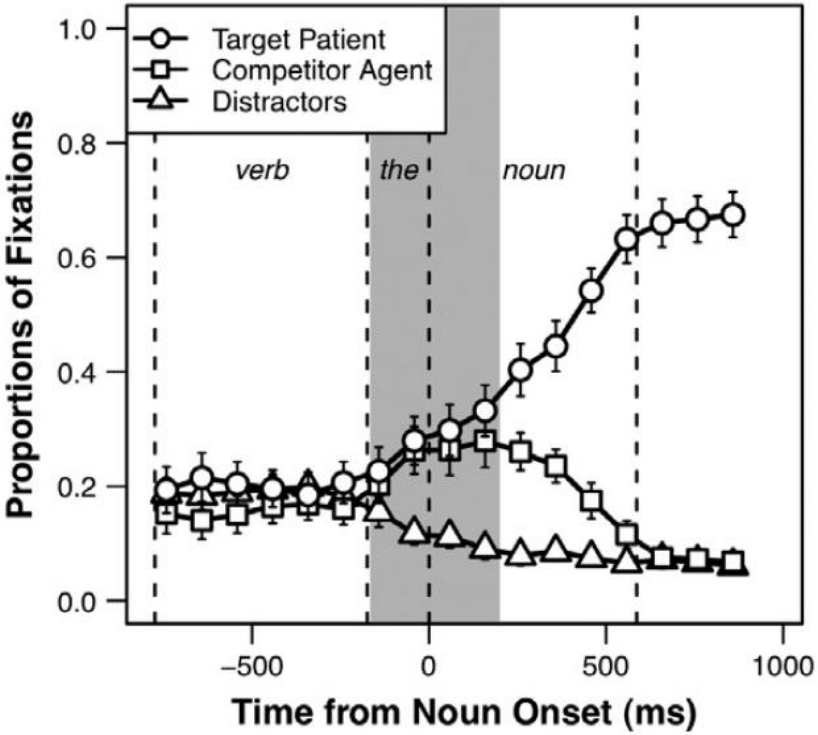
→ Undetected semantic anomalies do not elicit any ERP effect.



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?

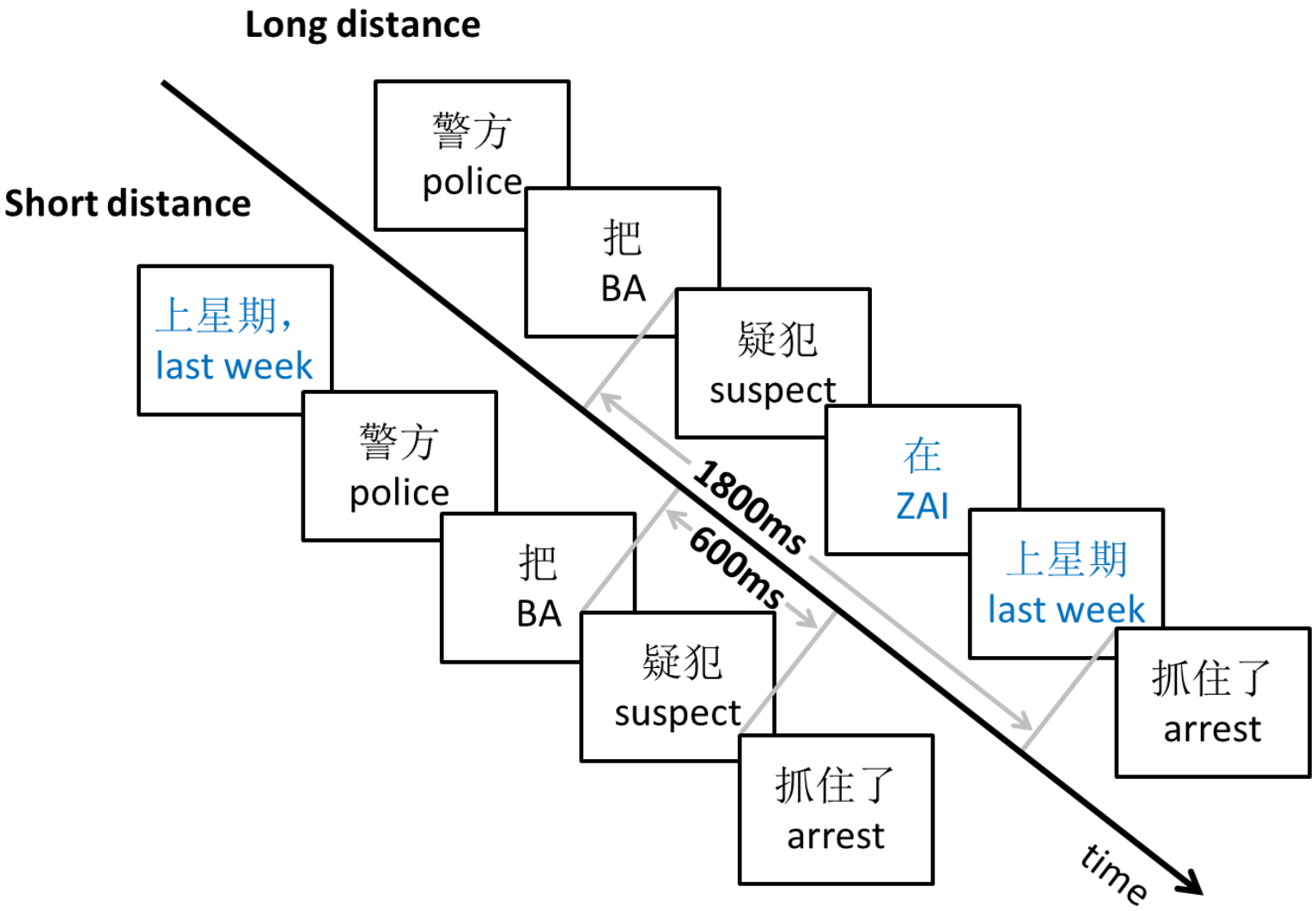
Chow, Lau, Wang & Phillips (under revision)

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
警方
police
把
BA
疑犯
suspect
在
ZAI
上星期
last week
抓住了
arrest
上星期，
last week
警方
police
把
BA
疑犯
suspect
抓住了
arrest
1800ms
600ms
time

Experiment 1 – Predictions

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 …

If the arguments' structural roles can impact verb predictions within the lengthened time window…

Experiment 1 – Results (n=24)

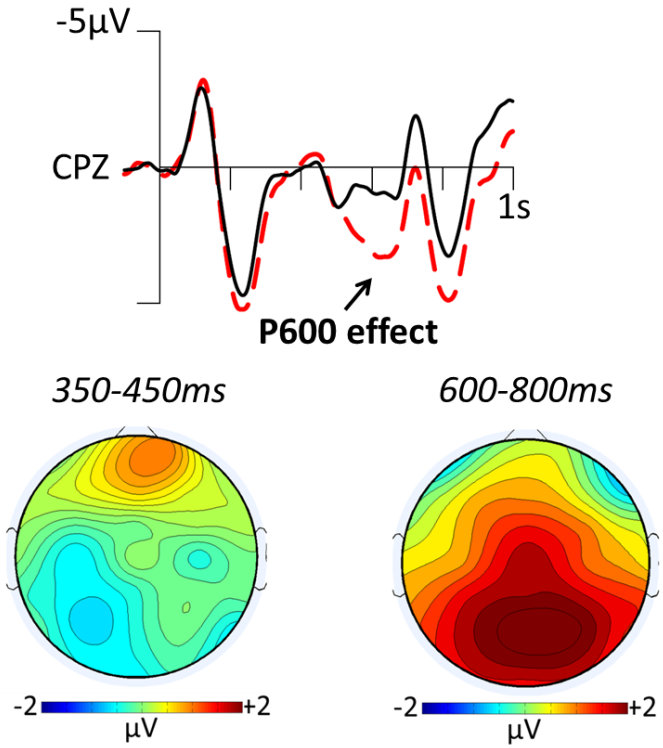
Short-distance

____ **Canonical**

Last week police BA suspect arrest…

_ _ _ **Role-reversed**

Last week suspect BA police arrest…



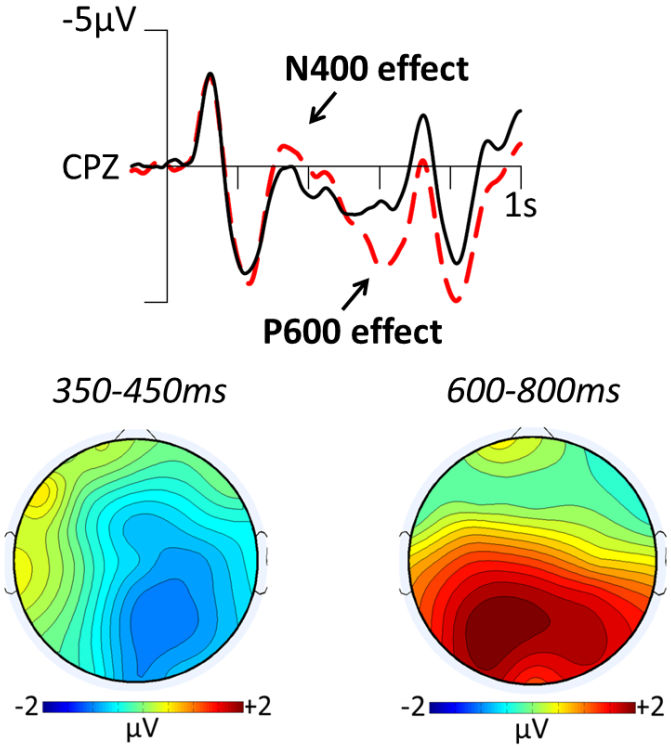
Long-distance

____ **Canonical**

Police BA suspect ZAI last week arrest…

_ _ _ **Role-reversed**

Suspect BA police ZAI last week arrest …



Experiment 1 – Results (n=24)

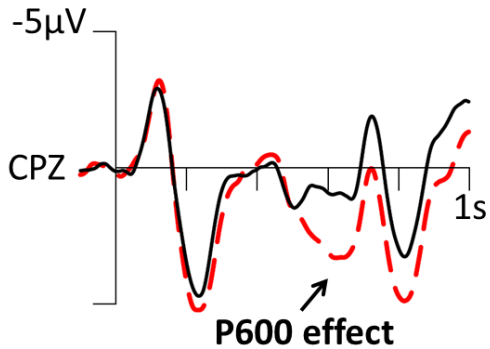
Short-distance

____ **Canonical**

Last week police BA suspect arrest…

_ _ _ **Role-reversed**

Last week suspect BA police arrest…



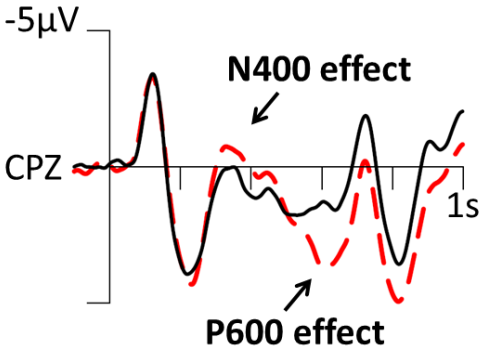
Long-distance

____ **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

7% cloze

____ **Canonical**

Mr. Liu BA parrot ZAI that summer train …

_ _ _ **Role-reversed**

Parrot BA Mr. Liu ZAI that summer train …

0% cloze

High-predictability

64% cloze

____ **Canonical**

Cop BA thief ZAI that evening arrest …

_ _ _ **Role-reversed**

Thief BA cop ZAI that evening arrest …

0% cloze

- 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

Low-predictability	High-predictability
____ **Canonical**	____ **Canonical**
Mr. Liu BA parrot ZAI that summer train …	Cop BA thief ZAI that evening arrest …
_ _ _ **Role-reversed**	_ _ _ **Role-reversed**
Parrot BA Mr. Liu ZAI that summer train …	Thief BA cop ZAI that evening arrest …

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

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 …

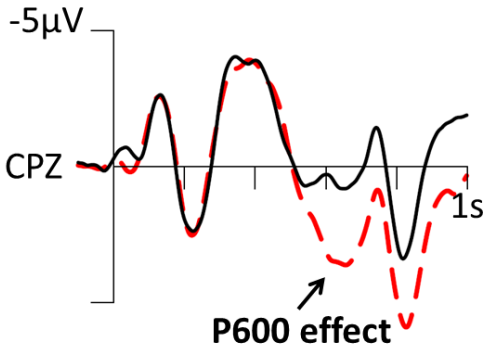
High-predictability

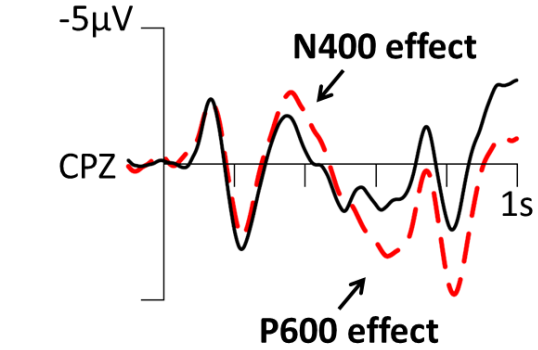
____ **Canonical**

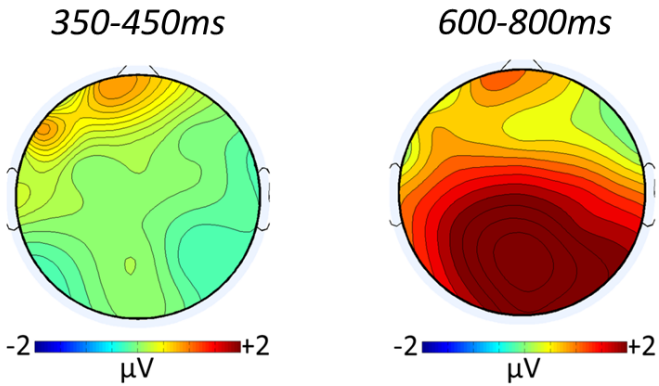
Cop BA thief ZAI that evening arrest …

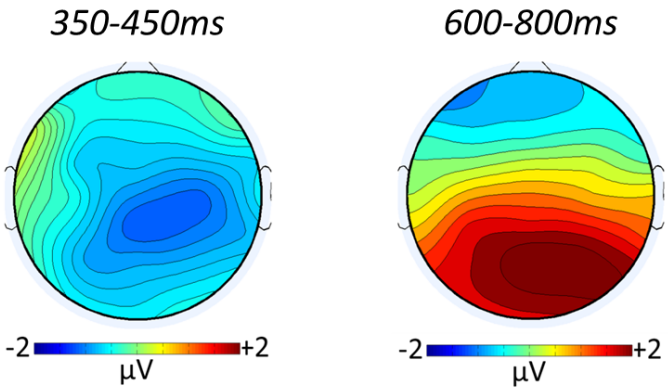
_ _ _ **Role-reversed**

Thief BA cop ZAI that evening arrest …









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 …

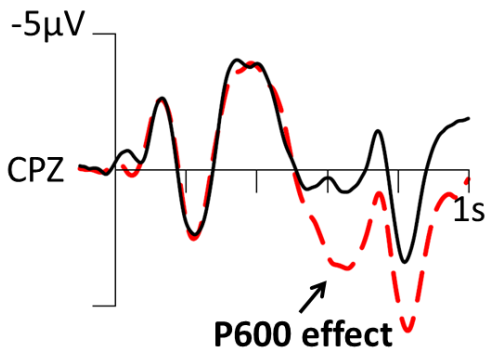
High-predictability

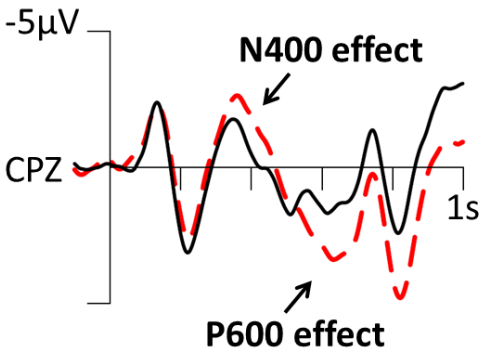
____ **Canonical**

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 <u>not</u> attributable to semantic illusions.

- Instead, these results suggest **information about the arguments' roles has a delayed impact on verb predictions.**

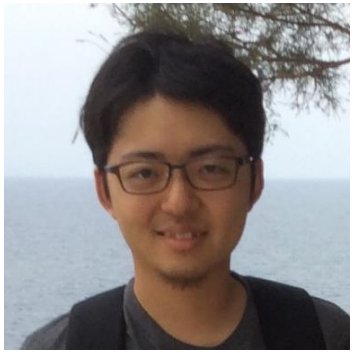
Convergent findings from Japanese (Momma, Sakai & Phillips, 2015)

Role-reversal in 2-word sentences (SV or OV)

- Canonical: bee$_{NOM}$ sting
- Role-reversed: bee$_{ACC}$ sting

SOA manipulation

- Short (800ms) vs. Long (1200ms)

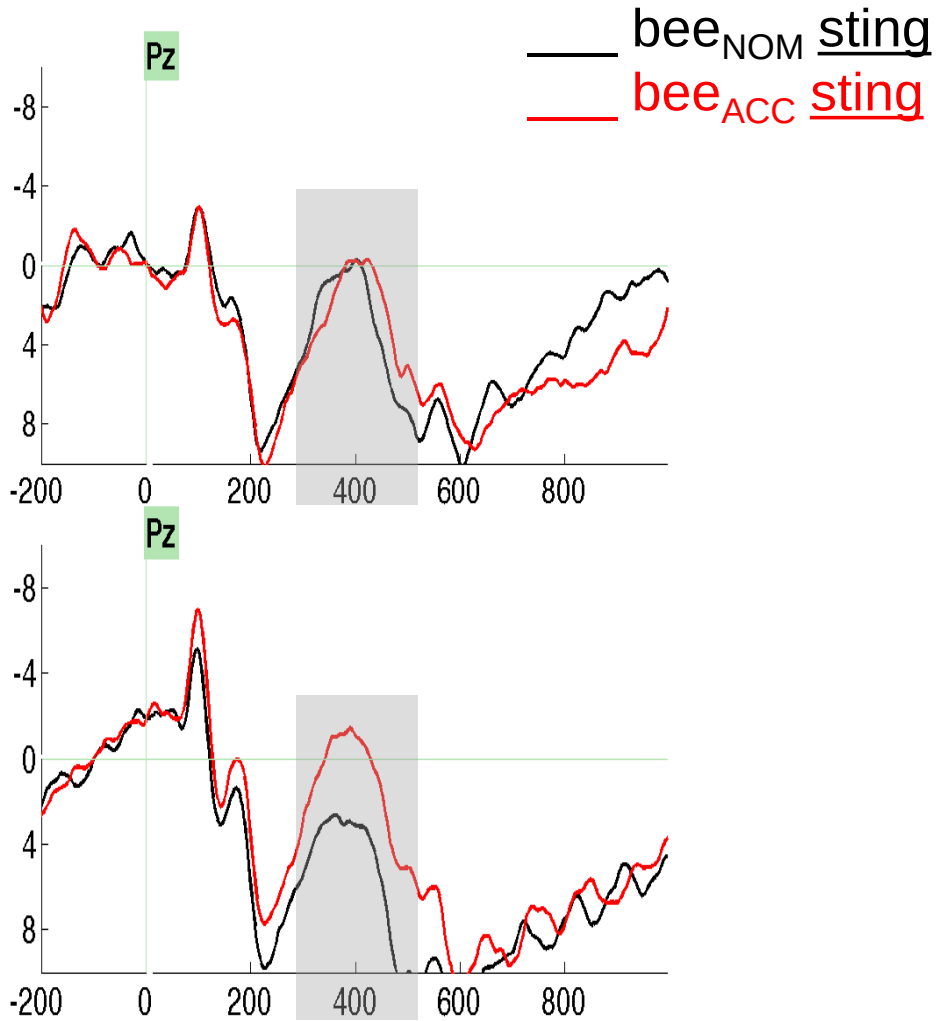


Shota Momma

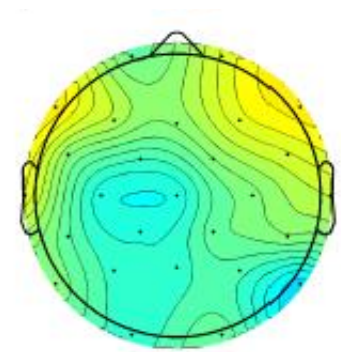
Momma, Sakai & Phillips (2015)

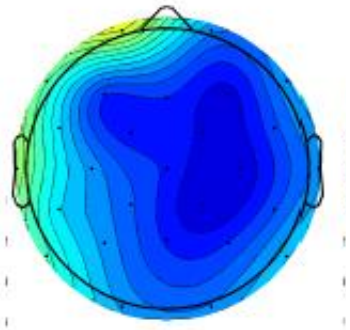
Short SOA
(800ms)

Long SOA
(1200ms)

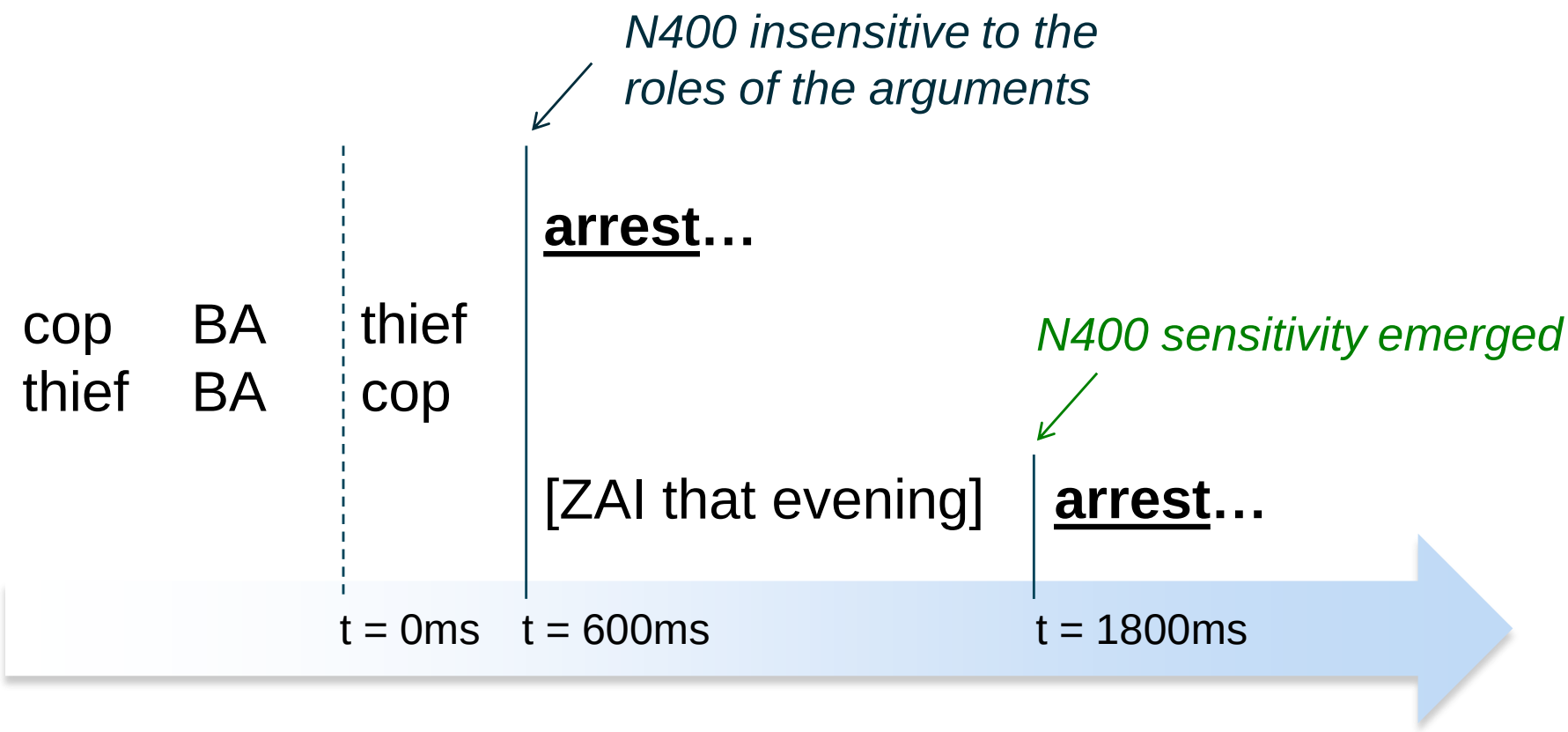


300-500ms

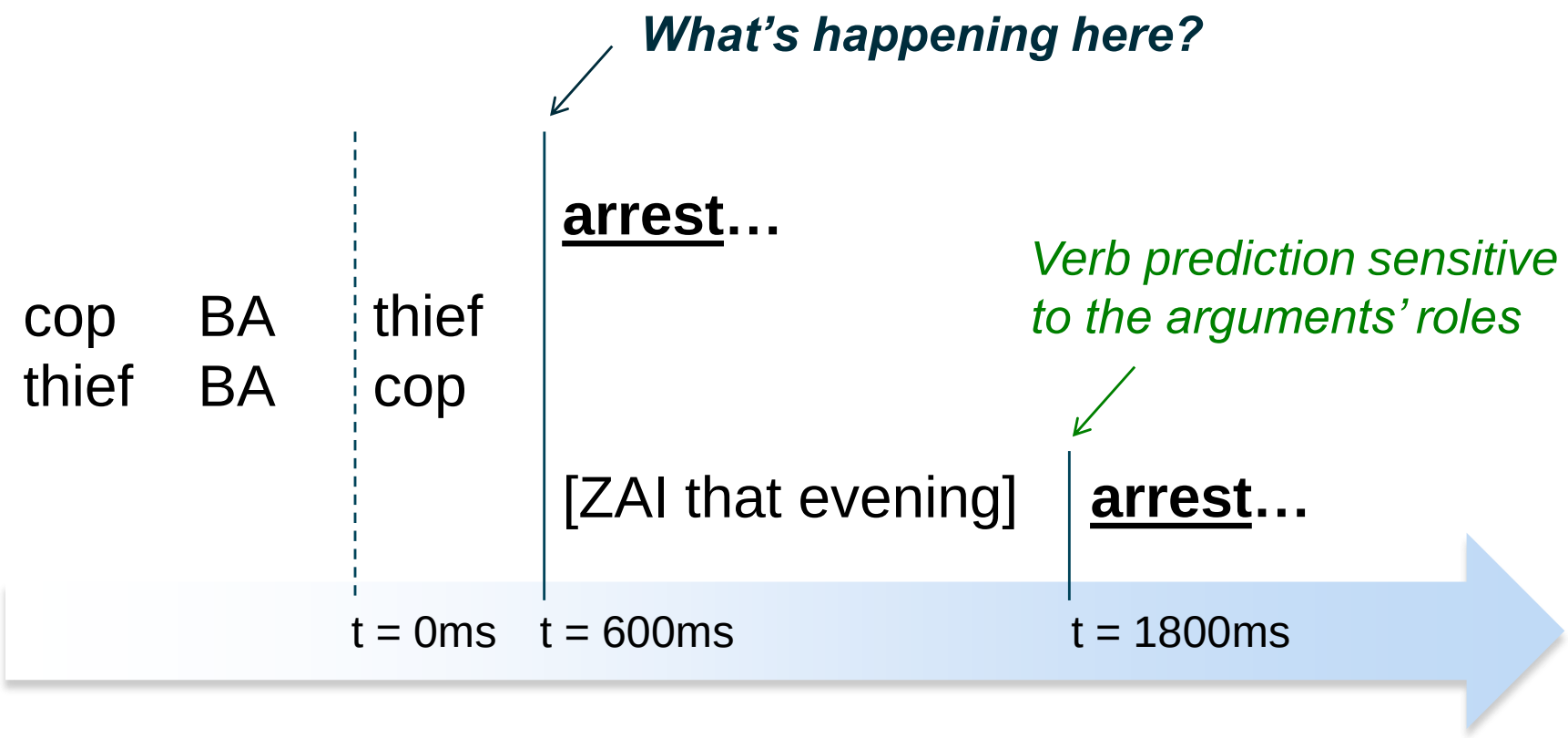




Snapshots of verb predictions



Snapshots of verb predictions



Garnsey, Tanenhaus & Chapman (1989)

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

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

N400 effect

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

II. Initial stages of verb predictions

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

Chow, Smith, Lau, & Phillips (2016)

Experiment 3

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

Argument role reversal	
High cloze (25%)	The restaurant owner forgot which customer the waitress had **served** during dinner yesterday.
Low cloze (0%)	The restaurant owner forgot which waitress the customer had **served** during dinner yesterday.

Argument substitution	
High cloze (28%)	The superintendent overheard which tenant the landlord had **evicted** at the end of May.
Low cloze (0%)	The superintendent overheard which realtor the landlord had **evicted** at the end of May.

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 …*

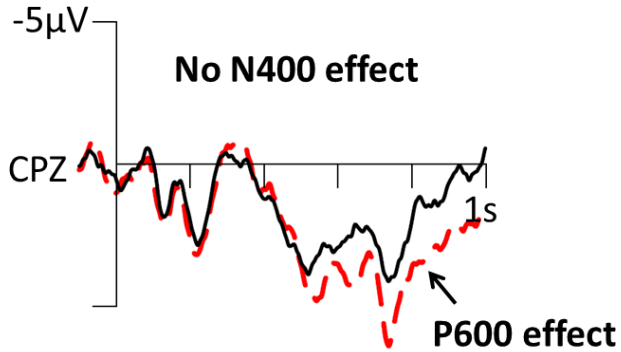
If the arguments' lexical meaning has a more immediate impact on verb predictions than their structural roles…

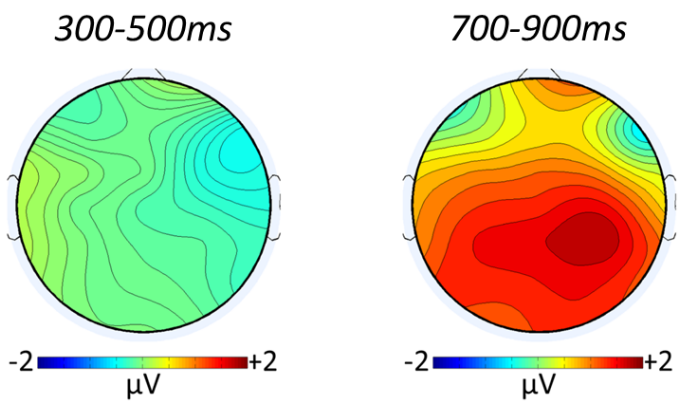
Experiment 3 – Results (n=24)

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 …*

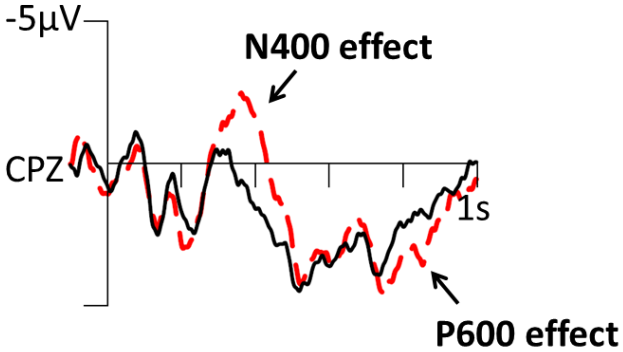


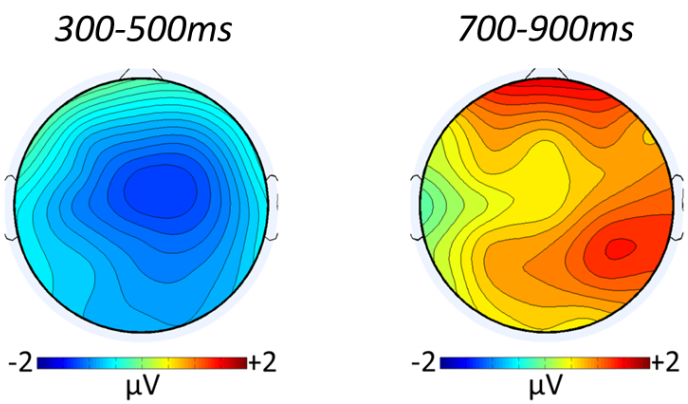


Argument substitution

____ **High cloze** - *The superintendent overheard which tenant the landlord had evicted …*

_ _ _ **Low cloze** - *The superintendent overheard which realtor the landlord had evicted …*



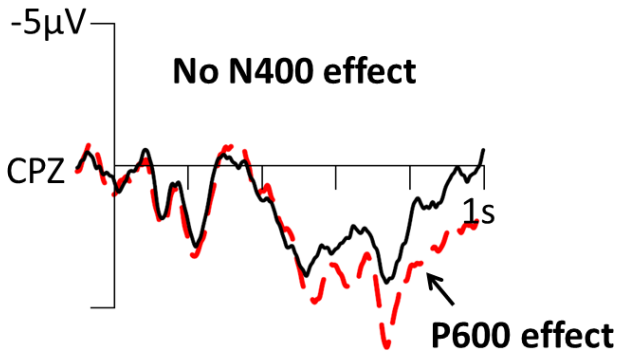


Experiment 3 – Results (n=24)

Argument role reversal

____ **High cloze** - *The restaurant owner forgot which customer the waitress had served …*

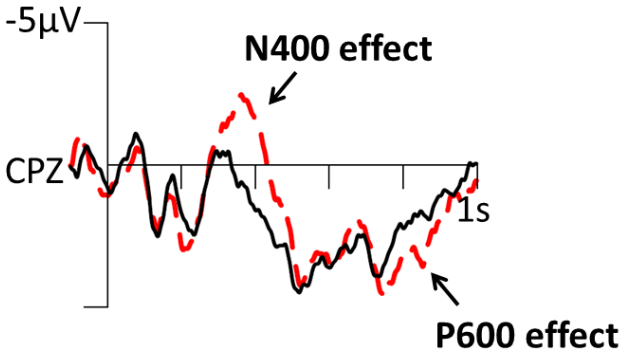
_ _ _ **Low cloze** - *The restaurant owner forgot which waitress the customer had served …*



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)	
High cloze (22%)	The tenant inquired which neighbor the landlord had **evicted** …
Low cloze (<1%)	The tenant inquired which exterminator the landlord had **evicted** …

"Same words" argument substitution	
High cloze (22%)	The exterminator inquired which neighbor the landlord had **evicted** …
Low cloze (<1%)	The neighbor inquired which exterminator the landlord had **evicted** …

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)

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 …*

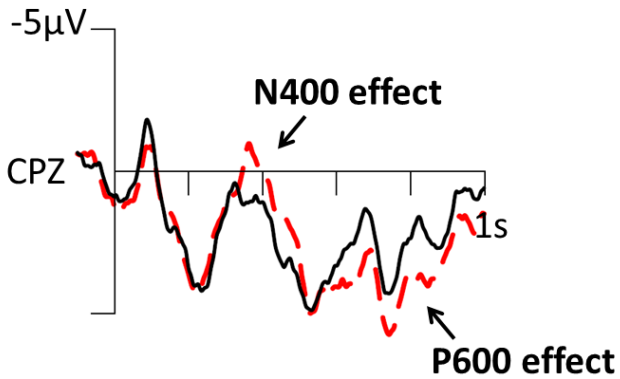
If comprehenders initially use a bag-of-arguments mechanism…

Experiment 4 – Results (n=24)

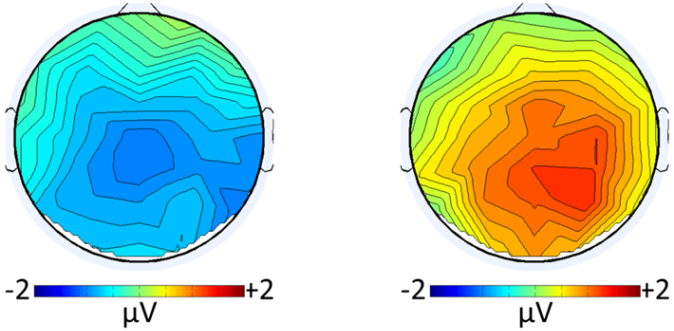
Different words

____ **High cloze** - *The tenant inquired which neighbor the landlord had evicted …*

_ _ _ **Low cloze** - *The tenant inquired which exterminator the landlord had evicted…*



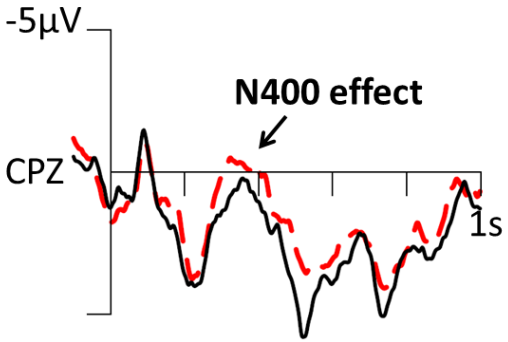
300-500ms *700-900ms*



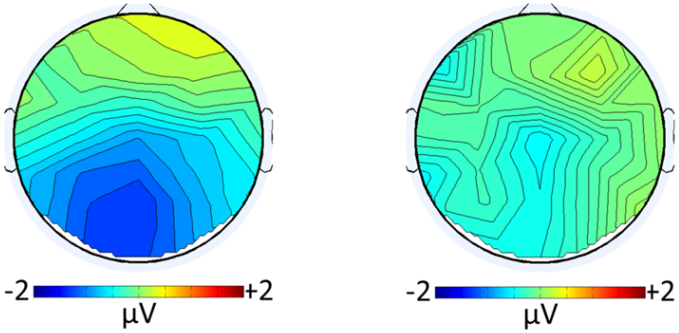
Same words

____ **High cloze** - *The exterminator inquired which neighbor the landlord had evicted …*

_ _ _ **Low cloze** - *The neighbor inquired which exterminator the landlord had evicted …*



300-500ms *700-900ms*



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.

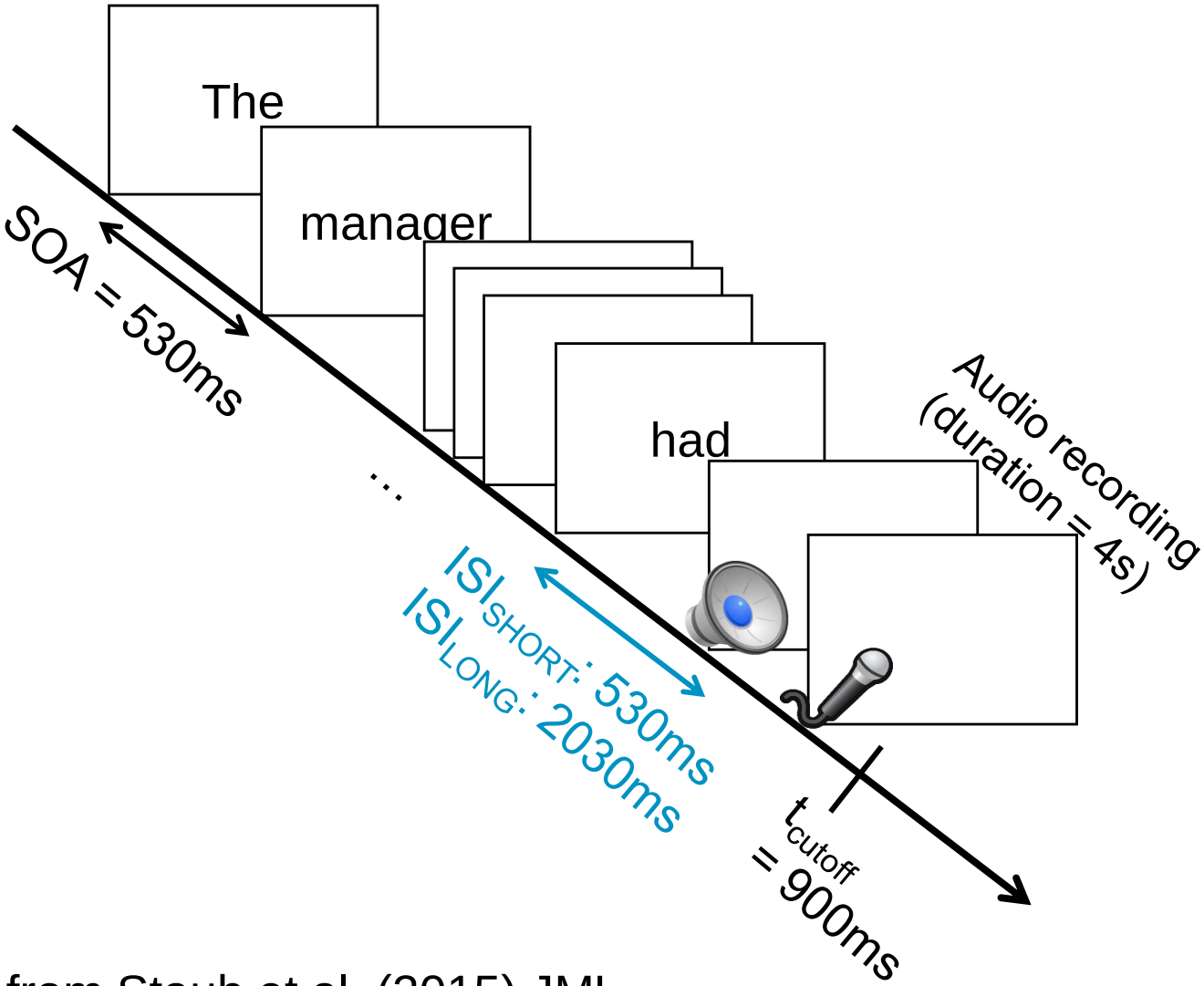
Experiment 5

- 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)

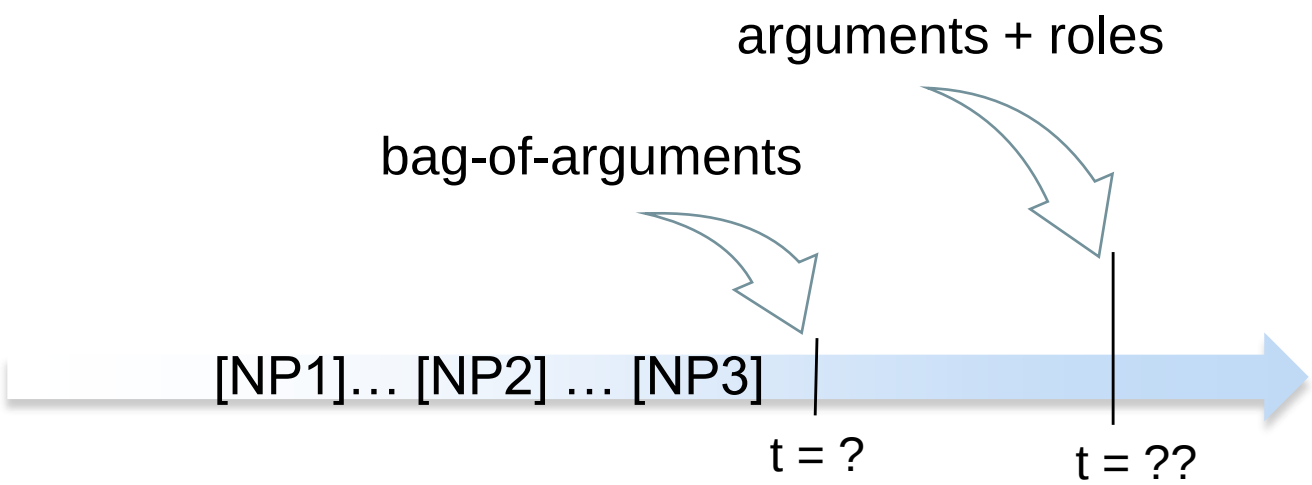
Online cloze of the ERP target words

Argument Reversals	ERP target	Cloze Probability Short	Long	Offline
The restaurant owner forgot…				
(a) which customer the waitress had …	*served*	11.4%	15.1%	25.4%
(b) which waitress the customer had …		3.6%	1.2%	0%

Argument Substitution		Short	Long	Offline
The secretary confirmed…				
(c) which illustrator the author had …	*hired*	16%	19.7%	27.7%
(d) which readers the author had …		1.5%	0.2%	0%

Proposal:

Comprehenders' verb predictions are immediately sensitive to the lexical meaning of the arguments, <u>but the impact of the arguments' roles is delayed</u>.



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 <u>not</u> 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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