



Quantified Sentences as a Window into Prediction and Priming: An ERP Study

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The Elevator Pitch

Previously on This Topic

- ▶ N400 insensitive to truth-value (Fischler et al. 1983);
- ▶ N400 modulated by truth-value when controlling for pragmatically unnatural uses of negation (Nieuwland & Kuperberg 2008).

In This Talk We (Aim To) ...

... unequivocally disambiguate truth-value and priming by examining the processing of simple quantified sentences.

We Also Discuss ...

- ▶ Early prediction effects tied to the truth-conditional properties of quantifiers;
- ▶ ERP markers of quantifier complexity.

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- ▶ ERP markers of quantifier complexity.

Outline

1 N400 & Truth-value

2 Experimental Design

3 N400&Priming

4 Prediction Effects

5 Conclusions

Truth-value/Negation and the N400

Fischler et al. (1983)

Is the N400 modulated by falseness, or by semantic mismatches?

(B)

- (1) True, Affirmative (TA): A robin / is / a bird.
- (2) True, Negative (TN): A robin / is not / a tree.
- (3) False, Affirmative(FA): A robin / is / a tree.
- (4) False, Negative (FN) A robin / is not / a bird.

Truth-value/Negation and the N400

Fischler et al. (1983)

Is the N400 modulated by **falseness**, or by conceptual mismatches?

(B)

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Truth-value/Negation and the N400

Fischler et al. (1983)

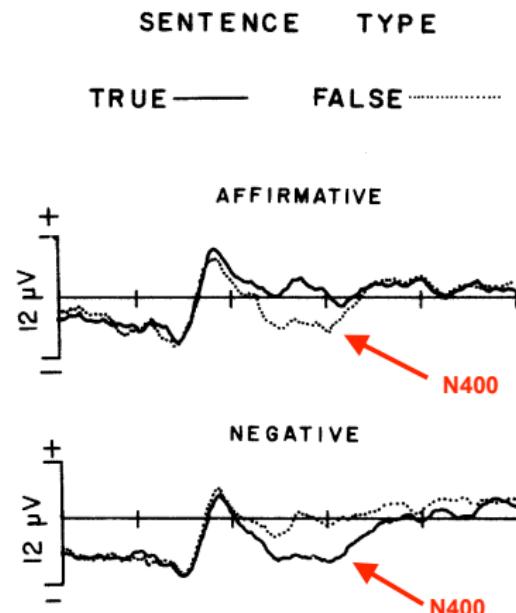
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Fischler et al. (1983)

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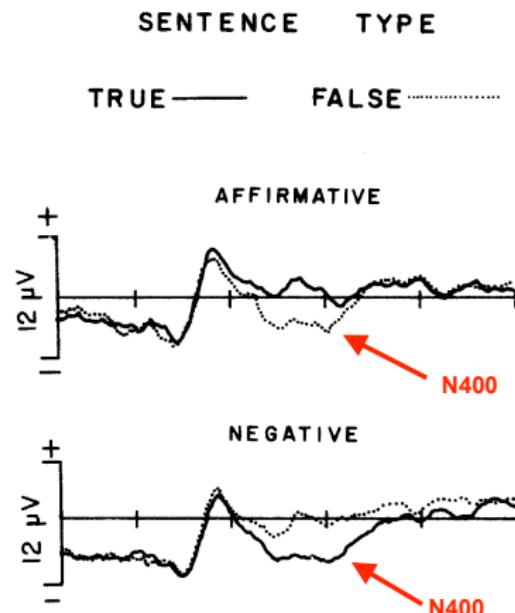
⇒ N400 modulated by subject/predicate relatedness.

→ cf. Kounios & Holcomb (1992), Lüdtke et al. (2008) a.o.

Fischler et al. (1983)

(B)

- (1) True, Affirmative (TA): A robin / is / a bird.
- (2) True, Negative (TN): A robin / is not / a tree.
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⇒ **N400 modulated by subject/predicate relatedness.**

→ cf. Kounios & Holcomb (1992), Lüdtke et al. (2008) a.o.

Nieuwland & Kuperberg (2008)

Aim

Disentangle effects of truth-value and pragmatic licensing.

Nieuwland & Kuperberg (2008)

Aim

Disentangle effects of truth-value and pragmatic licensing.

1a

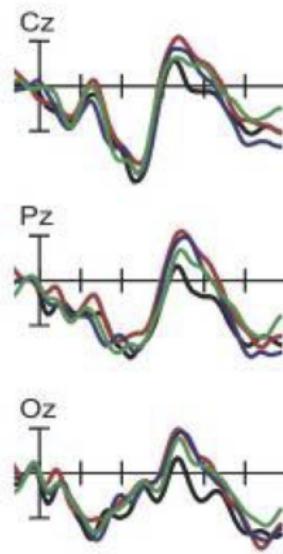
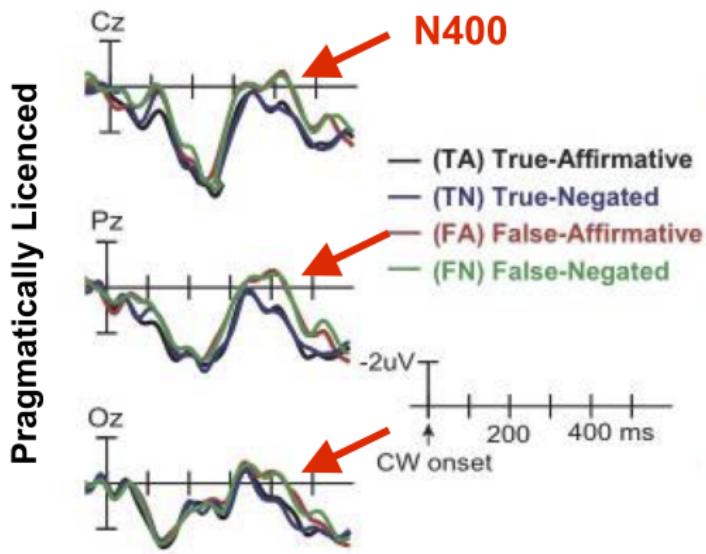
Pragmatically licensed negation

True	{	Affirmative	<i>With proper equipment, scuba-diving is very safe...</i>
		Negated	<i>With proper equipment, scuba-diving isn't very dangerous...</i>
False	{	Affirmative	<i>With proper equipment, scuba-diving is very dangerous...</i>
		Negated	<i>With proper equipment, scuba-diving isn't very safe...</i>

Pragmatically unlicensed negation

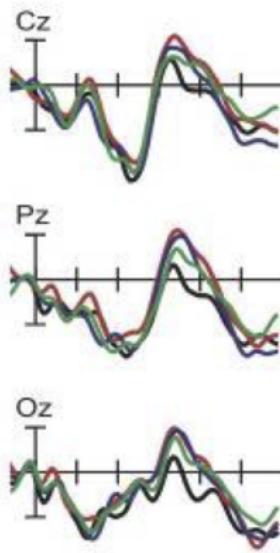
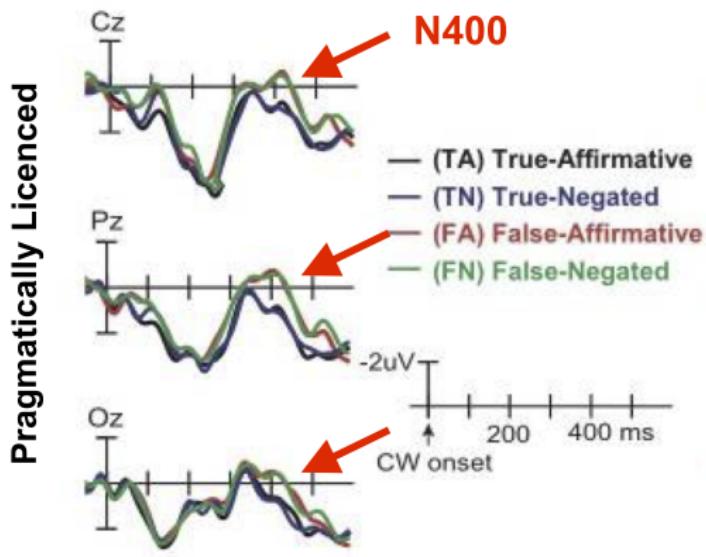
<i>Bulletproof vests are very safe...</i>
<i>Bulletproof vests aren't very dangerous...</i>
<i>Bulletproof vests are very dangerous...</i>
<i>Bulletproof vests aren't very safe...</i>

Nieuwland & Kuperberg (2008)



Pragmatically Unlicenced

Nieuwland & Kuperberg (2008)



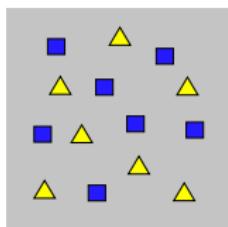
Pragmatically Unlicenced

⇒ N400 modulated by truth-value in pragmatically natural contexts.

In This Study

Aim

We want to disambiguate N400 effects of truth-value and priming.

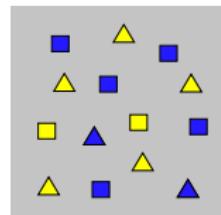


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

Most of the squares are blues
Most of the squares are reds

SOME

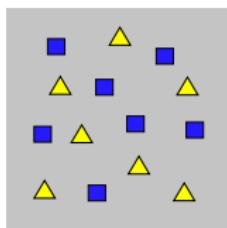
Some of the squares are yellows
Some of the squares are reds

- ▶ Shape/color combinations yield 8 conditions;
- ▶ Contrast ratio 7 : 7 (ALL/NONE) or 5 : 2 (MOST/SOME);
- ▶ False conditions: **unprimed** color/shape-predicates (i.e. red)
- ▶ Adult native English speakers ($N = 10$) asked for (mis)match judgments after each trial.

In This Study

Aim

We want to disambiguate N400 effects of truth-value and priming.

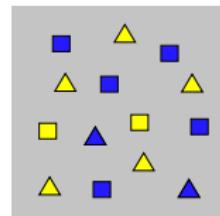


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

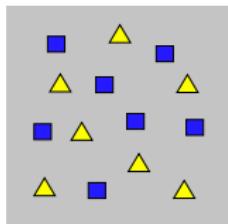
Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

- ▶ Shape/color combinations yield 8 conditions;
- ▶ Contrast ratio 7 : 7 (ALL/NONE) or 5 : 2 (MOST/SOME);
- ▶ False conditions: **unprimed** color/shape-predicates (i.e. red)
- ▶ Adult native English speakers ($N = 10$) asked for (mis)match judgments after each trial.

Hypothesis Table

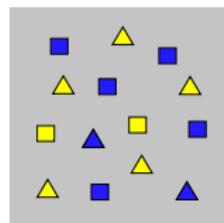


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

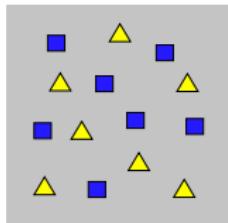
N400 modulated by truth-value

- ▶ All ... Red (F>T)
- ▶ Some ... Red (F>T)
- ▶ Most ... Red (F>T)
- ▶ None ... Blue(F>T)

Mean modulation by control prime

- ▶
- ▶
- ▶
- ▶

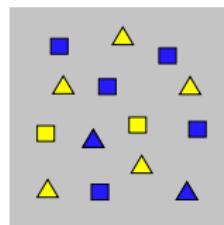
Hypothesis Table

**ALL**

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds

**MOST**

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

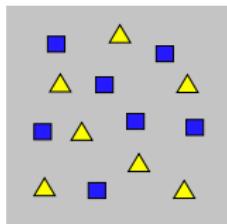
N400 modulated by truth-value

- ▶ All ... Red (F>T)
- ▶ Some ... Red (F>T)
- ▶ Most ... Red (F>T)
- ▶ None ... Blue(F>T)

N400 modulated by visual prime

- ▶ All ... Red (UP>P)
- ▶ Some... Red (UP>P)
- ▶ Most ... Red (UP>P)
- ▶ None... Red (UP>P)

Hypothesis Table

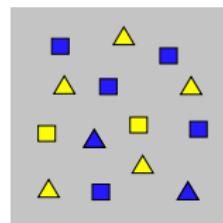


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

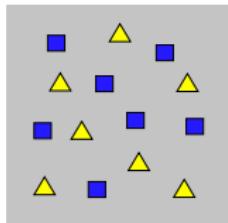
N400 modulated by truth-value

- ▶ All ... Red (F>T)
- ▶ Some ... Red (F>T)
- ▶ Most ... Red (F>T)
- ▶ None ... Blue(F>T)

N400 modulated by visual prime

- ▶ All ... Red (UP>P)
- ▶ Some... Red (UP>P)
- ▶ Most ... Red (UP>P)
- ▶ None... Red (UP>P)

Hypothesis Table

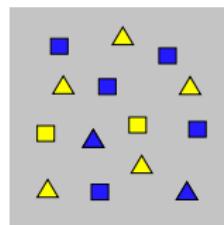


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

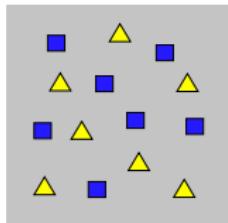
N400 modulated by truth-value

- ▶ All ... Red ($F > T$)
- ▶ Some ... Red ($F > T$)
- ▶ Most ... Red ($F > T$)
- ▶ None ... Blue ($F > T$)

N400 modulated by visual prime

- ▶ All ... Red ($UP > P$)
- ▶ Some ... Red ($UP > P$)
- ▶ Most ... Red ($UP > P$)
- ▶ None ... Red ($UP > P$)

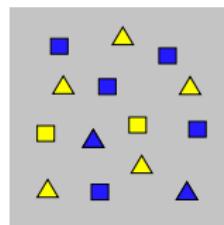
Hypothesis Table

**ALL**

All of the squares are blues
All of the squares are reds

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None of the squares are blues
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**MOST**

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

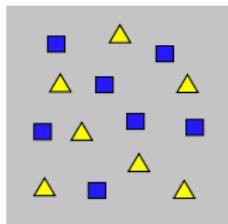
N400 modulated by truth-value

- ▶ All ... Red ($F > T$)
- ▶ Some ... Red ($F > T$)
- ▶ Most ... Red ($F > T$)
- ▶ None ... Blue ($F > T$)

N400 modulated by visual prime

- ▶ All ... Red ($UP > P$)
- ▶ Some ... Red ($UP > P$)
- ▶ Most ... Red ($UP > P$)
- ▶ None ... Red ($UP > P$)

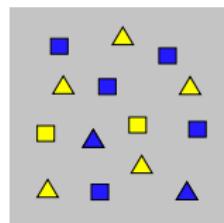
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All of the squares are blues
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**MOST**

Most of the squares are blues
Most of the squares are reds

SOME

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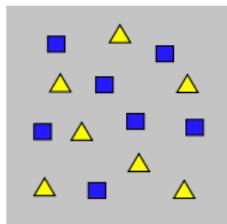
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- ▶ All ... Red (F>T)
- ▶ Some ... Red (F>T)
- ▶ Most ... Red (F>T)
- ▶ None ... Blue(F>T)

N400 modulated by visual prime

- ▶ All ... Red (UP>P)
- ▶ Some... Red (UP>P)
- ▶ Most ... Red (UP>P)
- ▶ None... Red (UP>P)

Hypothesis Table

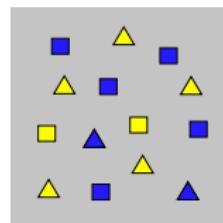


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

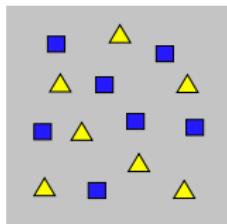
N400 modulated by truth-value

- ▶ All ... Red ($F > T$)
- ▶ Some ... Red ($F > T$)
- ▶ Most ... Red ($F > T$)
- ▶ None ... Blue ($F > T$)

N400 modulated by visual prime

- ▶ All ... Red ($UP > P$)
- ▶ Some ... Red ($UP > P$)
- ▶ Most ... Red ($UP > P$)
- ▶ None ... Red ($UP > P$)

Hypothesis Table

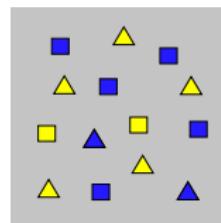


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

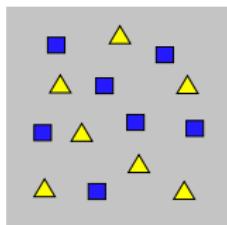
N400 modulated by truth-value

- ▶ All ... Red ($F > T$)
- ▶ Some ... Red ($F > T$)
- ▶ Most ... Red ($F > T$)
- ▶ None ... Blue ($F > T$)

N400 modulated by visual prime

- ▶ All ... Red ($UP > P$)
- ▶ Some ... Red ($UP > P$)
- ▶ Most ... Red ($UP > P$)
- ▶ None ... Red ($UP > P$)

Hypothesis Table

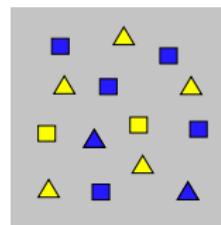


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

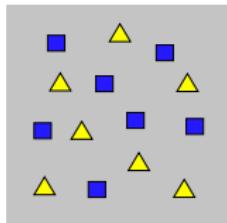
N400 modulated by truth-value

- ▶ All ... Red ($F > T$)
- ▶ Some ... Red ($F > T$)
- ▶ Most ... Red ($F > T$)
- ▶ None ... Blue ($F > T$)

N400 modulated by visual prime

- ▶ All ... Red ($UP > P$)
- ▶ Some ... Red ($UP > P$)
- ▶ Most ... Red ($UP > P$)
- ▶ None ... Red ($UP > P$)

Hypothesis Table

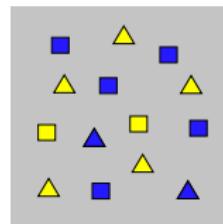


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

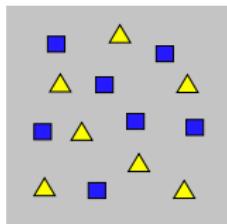
N400 modulated by truth-value

- ▶ All ... Red ($F > T$)
- ▶ Some ... Red ($F > T$)
- ▶ Most ... Red ($F > T$)
- ▶ None ... Blue ($F > T$)

N400 modulated by visual prime

- ▶ All ... Red ($UP > P$)
- ▶ Some ... Red ($UP > P$)
- ▶ Most ... Red ($UP > P$)
- ▶ None ... Red ($UP > P$)

Hypothesis Table

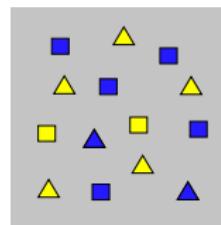


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

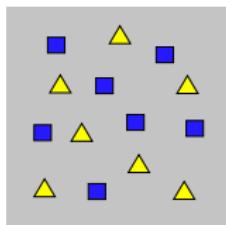
N400 modulated by truth-value

- ▶ All ... Red ($F > T$)
- ▶ Some ... Red ($F > T$)
- ▶ Most ... Red ($F > T$)
- ▶ None ... Blue ($F > T$)

N400 modulated by visual prime

- ▶ All ... Red ($UP > P$)
- ▶ Some ... Red ($UP > P$)
- ▶ Most ... Red ($UP > P$)
- ▶ None ... Red ($UP > P$)

Hypothesis Table

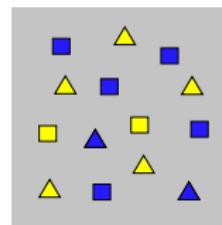


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

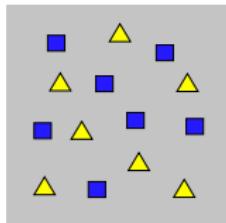
N400 modulated by truth-value

- ▶ All ... Red (F>T)
- ▶ Some ... Red (F>T)
- ▶ Most ... Red (F>T)
- ▶ None ... Blue(F>T)

N400 modulated by visual prime

- ▶ All ... Red (UP>P /F>T)
- ▶ Some... Red (UP>P /F>T)
- ▶ Most ... Red (UP>P /F>T)
- ▶ None... Red (UP>P /T>F)

Hypothesis Table

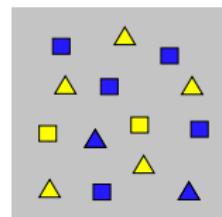


ALL

All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds



MOST

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

N400 modulated by truth-value

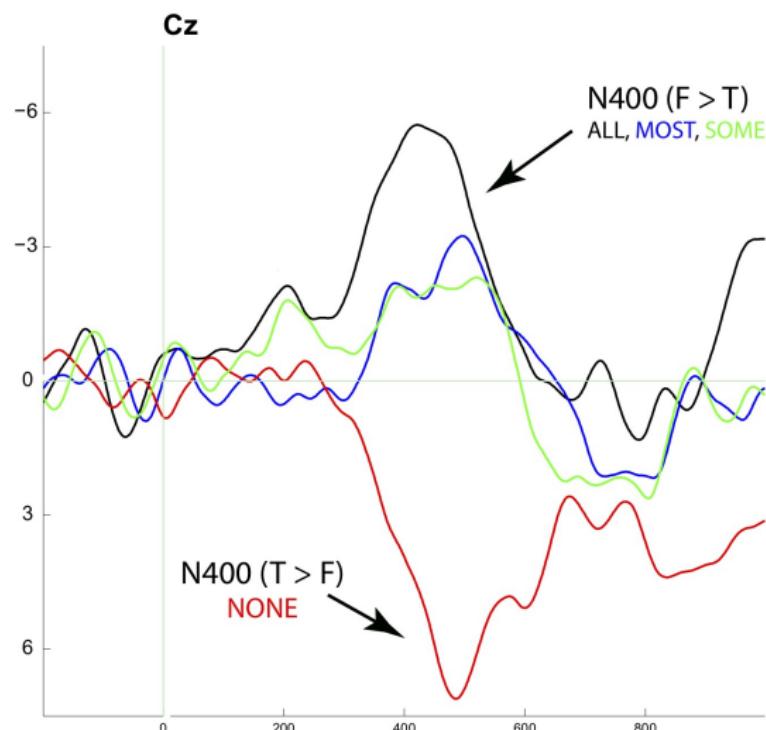
- ▶ All ... Red ($F > T$)
- ▶ Some ... Red ($F > T$)
- ▶ Most ... Red ($F > T$)
- ▶ None ... Blue ($F > T$)

N400 modulated by visual prime

- ▶ All ... Red ($UP > P / F > T$)
- ▶ Some... Red ($UP > P / F > T$)
- ▶ Most ... Red ($UP > P / F > T$)
- ▶ None... Red ($UP > P / T > F$)

N400 Effects of Truth-Value and Priming

- ▶ ERPs (F-T) time-locked to predicate onset



Interim Summary: Priming and Truth-Value

N400 modulated by truth-value

- ▶ All ... Red ($F > T$)
- ▶ Some ... Red ($F > T$)
- ▶ Most ... Red ($F > T$)
- ▶ None ... Blue ($F > T$)

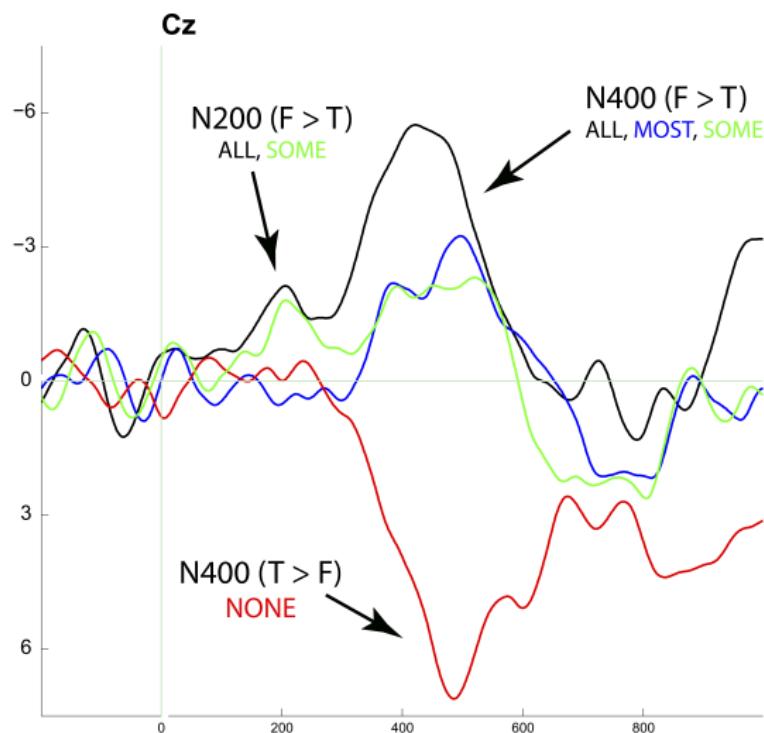
N400 modulated by visual prime

- ▶ All ... Red ($UP > P/F > T$)
- ▶ Some... Red ($UP > P/F > T$)
- ▶ Most ... Red ($UP > P/F > T$)
- ▶ None... Red ($UP > P/T > F$)

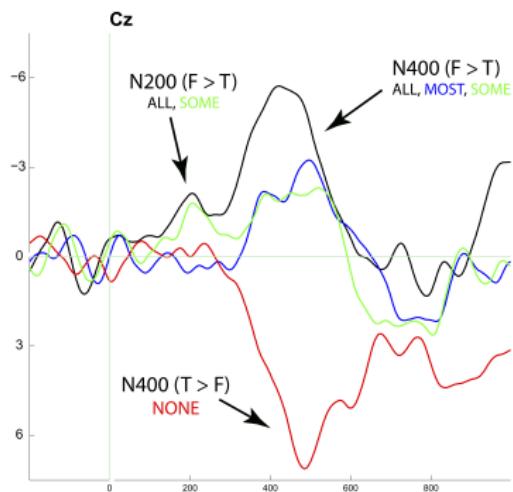
- ▶ Truth-value does not modulate N400 amplitude.
- ▶ N400 is driven by priming the expected continuation;

A Closer Look: N200 Effects

- ▶ ERPs (F-T) time-locked to predicate onset



Prediction Effects on the N200

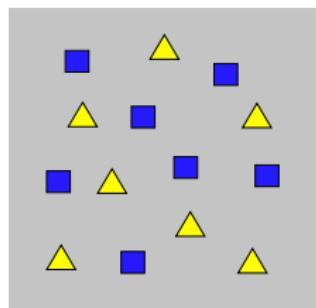


Hypothesis

Prediction Effects on N200:

- ▶ Phonological Mismatch Negativities (Connolly&Phillips,1994).

Quantifiers and Early Prediction Effects (1/4)



ALL

All of the squares are blues

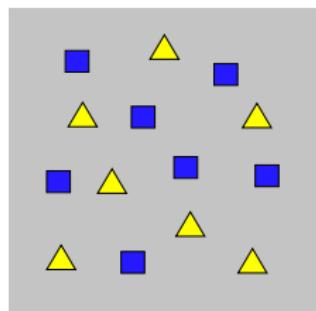
All of the squares are reds

NONE

None of the squares are blues

None of the squares are reds

Quantifiers and Early Prediction Effects (1/4)



ALL

All of the squares are blues

All of the squares are reds

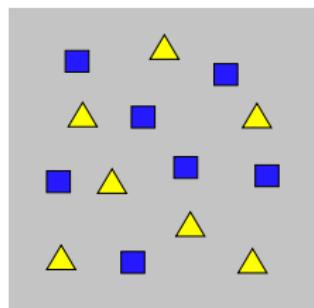
NONE

None of the squares are blues

None of the squares are reds

All of the squares are reds

Quantifiers and Early Prediction Effects (1/4)



ALL

All of the squares are blues

All of the squares are reds

NONE

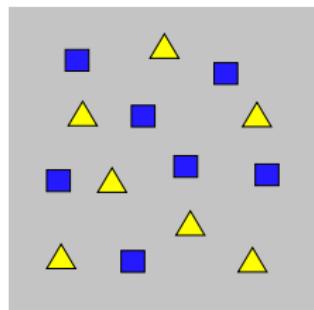
None of the squares are blues

None of the squares are reds

blue

All of the squares are reds

Quantifiers and Early Prediction Effects (1/4)



ALL

All of the squares are blues

All of the squares are reds

NONE

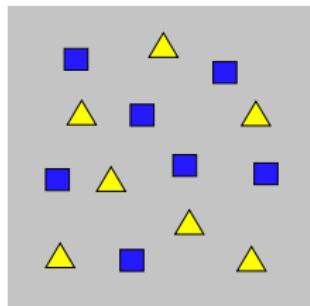
None of the squares are blues

None of the squares are reds

blue

All of the squares are reds

Quantifiers and Early Prediction Effects (1/4)



ALL

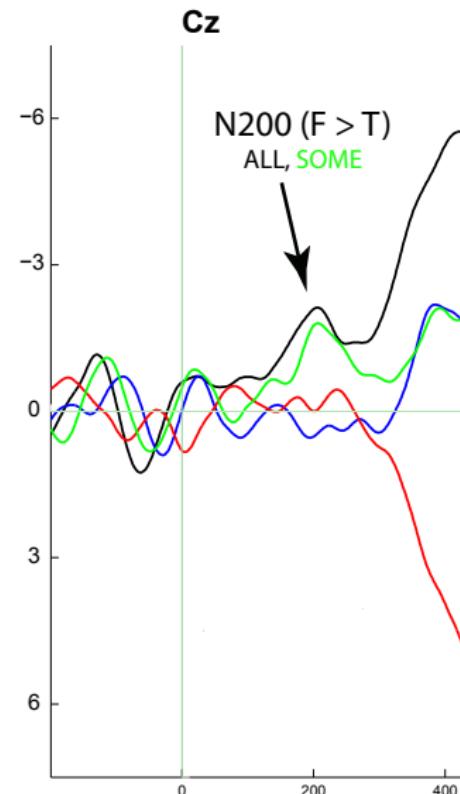
All of the squares are blues
All of the squares are reds

NONE

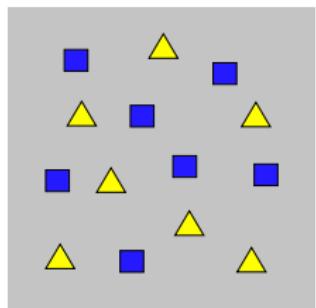
None of the squares are blues
None of the squares are reds

blue

All of the squares are reds



Quantifiers and Early Prediction Effects (2/4)



ALL

All of the squares are blues

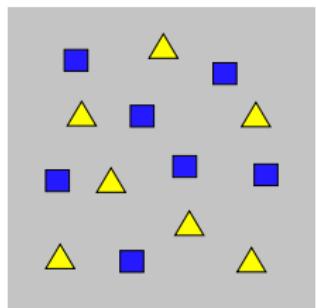
All of the squares are reds

NONE

None of the squares are blues

None of the squares are reds

Quantifiers and Early Prediction Effects (2/4)



ALL

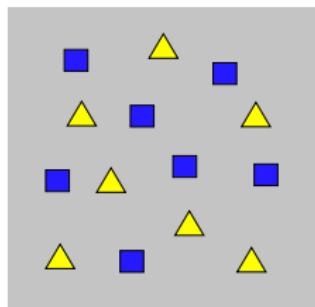
All of the squares are blues
All of the squares are reds

NONE

None of the squares are blues
None of the squares are reds

None of the squares are reds

Quantifiers and Early Prediction Effects (2/4)



ALL

All of the squares are blues

All of the squares are reds

NONE

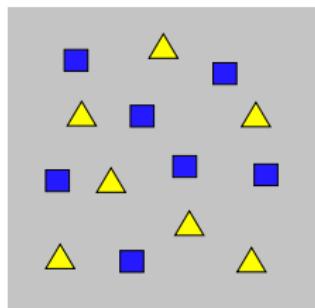
None of the squares are blues

None of the squares are reds

¬ blue

None of the squares are reds

Quantifiers and Early Prediction Effects (2/4)



ALL

All of the squares are blues
All of the squares are reds

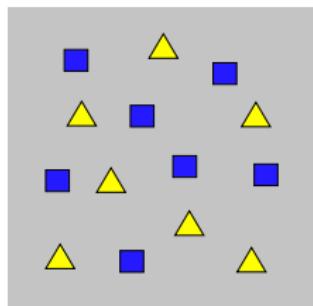
NONE

None of the squares are blues
None of the squares are reds

¬ blue

None of the squares are reds

Quantifiers and Early Prediction Effects (2/4)



ALL

All of the squares are blues
All of the squares are reds

NONE

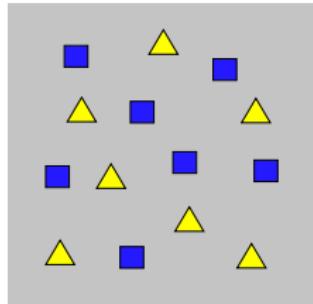
None of the squares are blues
None of the squares are reds

{yellow, red, green,...}

¬ blue

None of the squares are reds

Quantifiers and Early Prediction Effects (2/4)



ALL

All of the squares are blues
All of the squares are reds

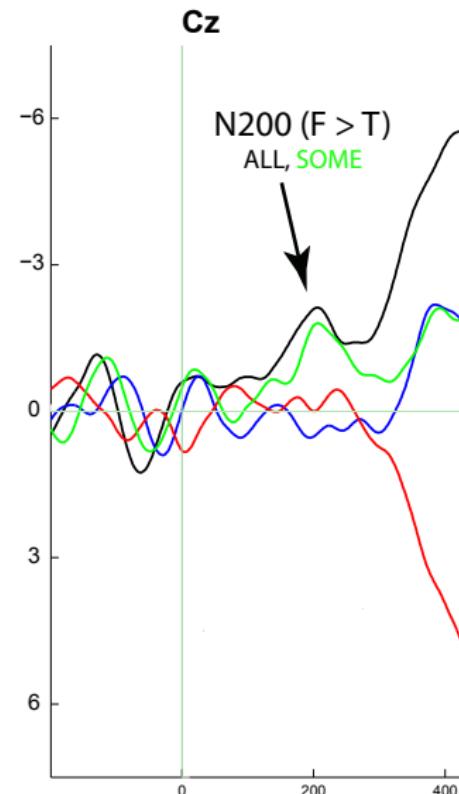
NONE

None of the squares are blues
None of the squares are reds

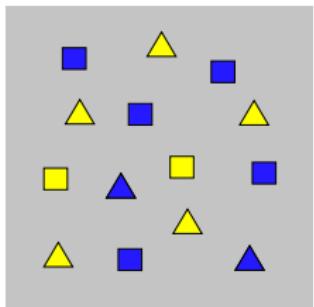
{yellow, red, green,...}

¬ blue

None of the squares are reds



Quantifiers and Early Prediction Effects (3/4)



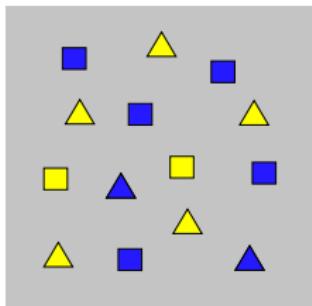
MOST

Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

Quantifiers and Early Prediction Effects (3/4)



MOST

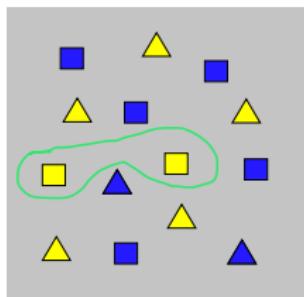
Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

Some of the squares are reds

Quantifiers and Early Prediction Effects (3/4)



MOST

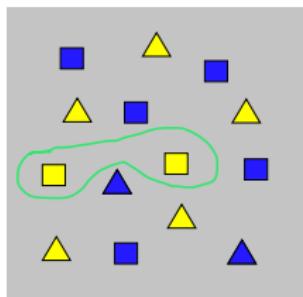
Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

Some of the squares are reds

Quantifiers and Early Prediction Effects (3/4)



MOST

Most of the squares are blues
Most of the squares are reds

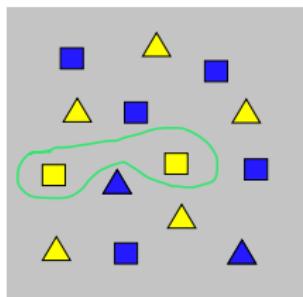
SOME

Some of the squares are yellows
Some of the squares are reds

yellow

Some of the squares are reds

Quantifiers and Early Prediction Effects (3/4)



MOST

Most of the squares are blues
Most of the squares are reds

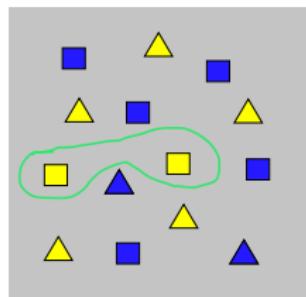
SOME

Some of the squares are yellows
Some of the squares are reds

yellow

Some of the squares are reds

Quantifiers and Early Prediction Effects (3/4)



MOST

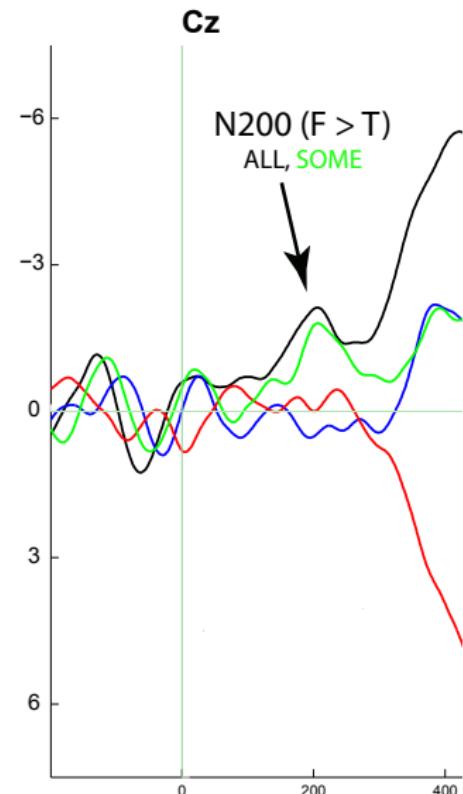
Most of the squares are blues
Most of the squares are reds

SOME

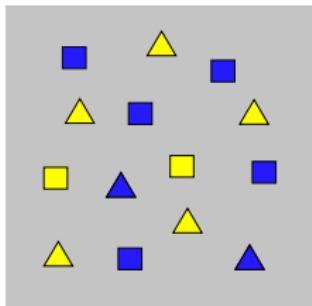
Some of the squares are yellows
Some of the squares are reds

yellow

Some of the squares are reds



Quantifiers and Early Prediction Effects (4/4)



MOST

Most of the squares are blues

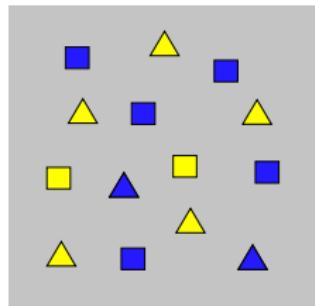
Most of the squares are reds

SOME

Some of the squares are yellows

Some of the squares are reds

Quantifiers and Early Prediction Effects (4/4)



MOST

Most of the squares are blues

Most of the squares are reds

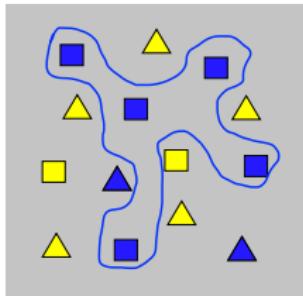
SOME

Some of the squares are yellows

Some of the squares are reds

Most of the squares are reds

Quantifiers and Early Prediction Effects (4/4)



MOST

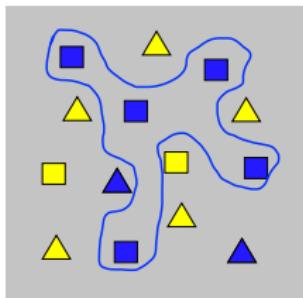
Most of the squares are blues
Most of the squares are reds

SOME

Some of the squares are yellows
Some of the squares are reds

Most of the squares are reds

Quantifiers and Early Prediction Effects (4/4)



MOST

Most of the squares are blues
Most of the squares are reds

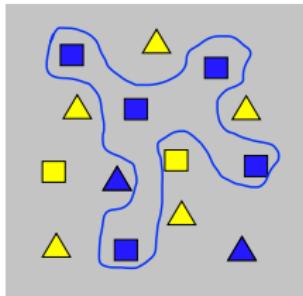
SOME

Some of the squares are yellows
Some of the squares are reds

blue

Most of the squares are reds

Quantifiers and Early Prediction Effects (4/4)



MOST

Most of the squares are blues
Most of the squares are reds

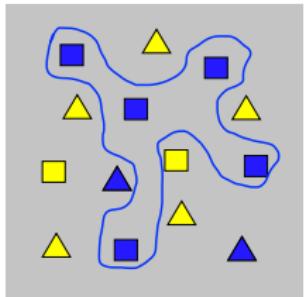
SOME

Some of the squares are yellows
Some of the squares are reds

blue

Most of the squares are reds

Quantifiers and Early Prediction Effects (4/4)



MOST

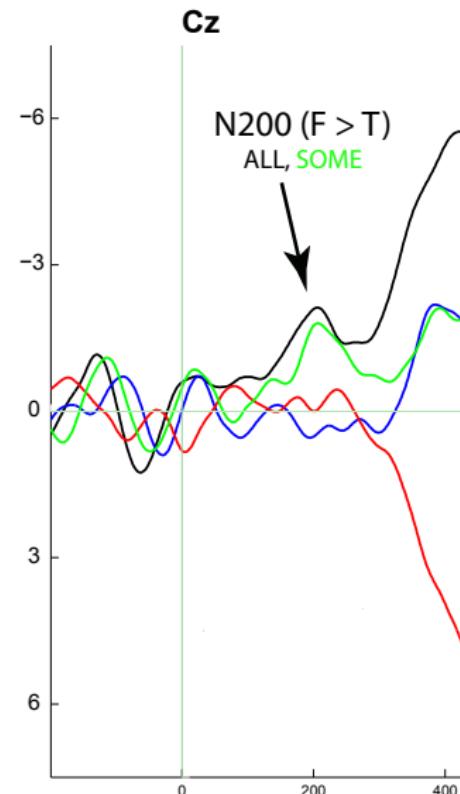
Most of the squares are blues
Most of the squares are reds

SOME

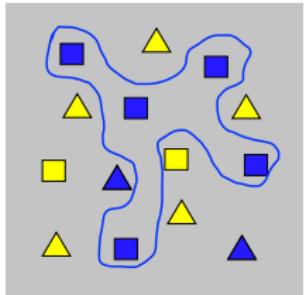
Some of the squares are yellows
Some of the squares are reds

blue

Most of the squares are reds



Quantifiers and Early Prediction Effects (4/4)



MOST

Most of the squares are blues
Most of the squares are reds

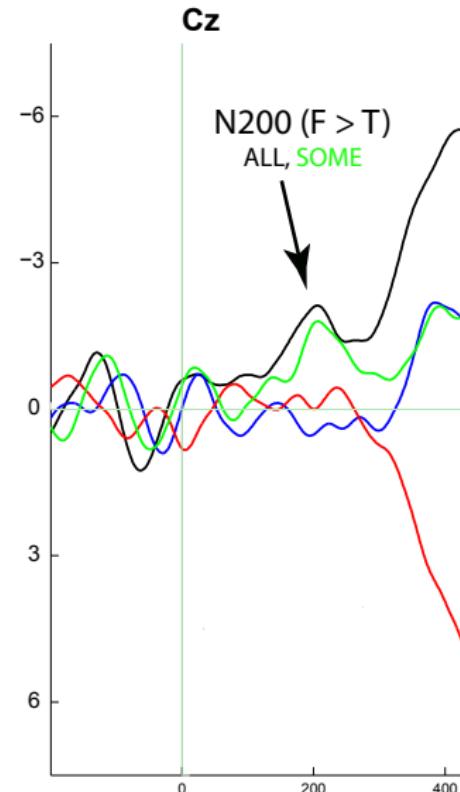
SOME

Some of the squares are yellows
Some of the squares are reds

blue

???

Most of the squares are reds



Complexity Effects for MOST

- ▶ Complexity effects for higher-order quantifiers (McMillan et al. 2005; Szymanik, 2016)
 - ▶ Time-locking signals (F-T) to the onset of the quantifiers...

Complexity Effects for MOST

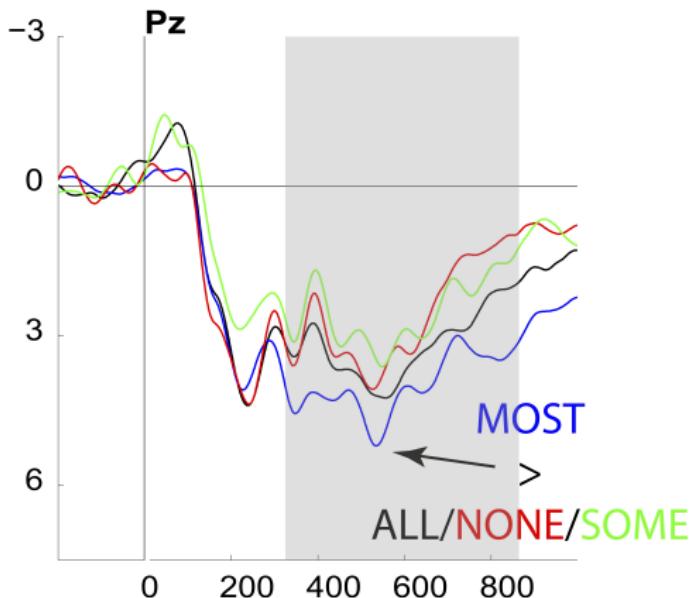
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Hypothesis: MOST doesn't cue early prediction effects ...

... due to additional working memory resources recruited in the processing of proportional quantifiers.

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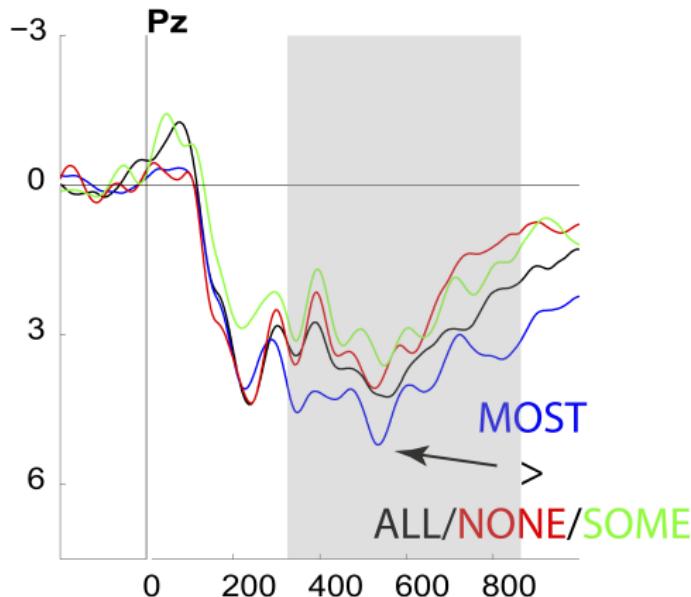


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Tracing Back Our Steps

Priming and Truth-Value

- ▶ N400 for ALL/SOME/MOST ($F > T$) relative to NONE ($T > F$)
- ▶ N400 is driven by priming the expected continuation

Prediction Effects on N200?

- ▶ early negativity for ALL/SOME vs. NONE/MOST
(False $>$ True, peaking ~ 200 ms)
- ▶ PMMNs \rightarrow anticipatory effects + truth-conditional properties of quantifiers

Markers of Quantifier Complexity?

- ▶ positivity for MOST $>$ ALL/NONE/SOME ($\sim 350\text{-}450$ ms)
- ▶ complexity effects associated with **initial encoding** of quantifiers

A plethora of future research directions...

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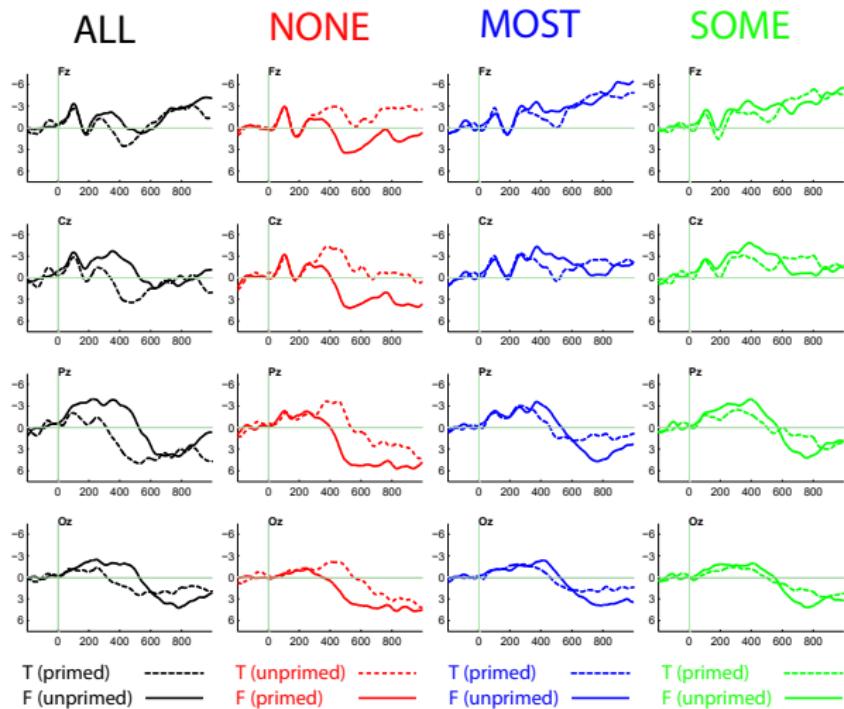
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Selected References I

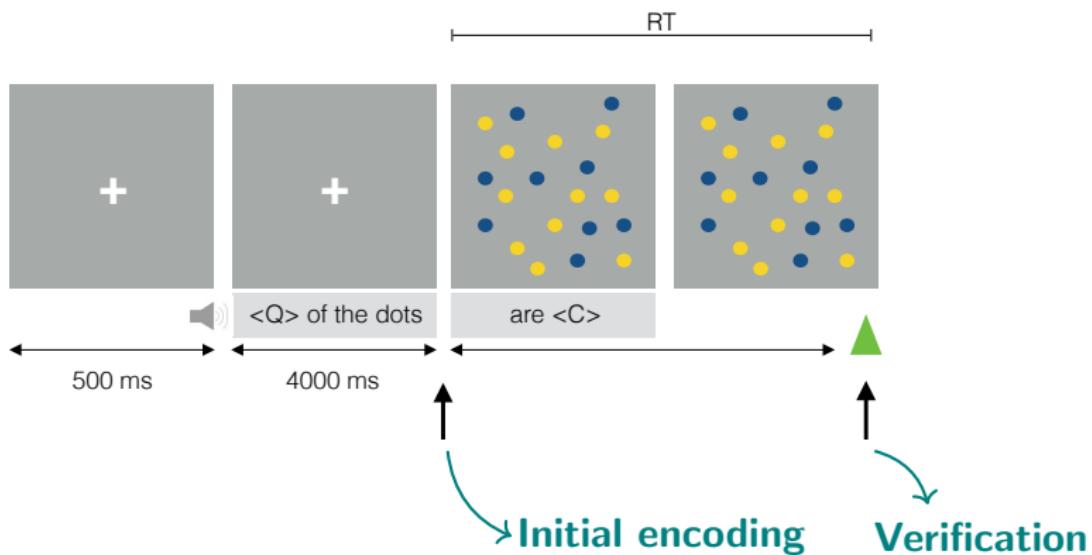
- 1 Connolly, J. F., Phillips, N. A.** (1994). Event-related potential components reflect phonological and semantic processing of the terminal word of spoken sentences. *J. of Cognitive Neuroscience*.
- 2 Fischler I., Bloom P., Childers D., Roucos S., Perry N.** (1983) Brain potentials related to stages of sentence verification. *Psychophysiology*.
- 3 Kounios J, Holcomb P.** (1992) Structure and process in semantic memory - evidence from event-related brain potentials and reaction-times. *J. of Experimental Psychology: General*.
- 4 Lüdtke, J., Friedrich, C., Filippis, M., Kaup, B.** (2008). Event-related Potential Correlates of Negation in a Sentence—Picture Verification Paradigm. *Journal of Cognitive Neuroscience*, 1355-1370.
- 5 McMillan, C. T., R. Clark, P. Moore, C. Devita, and M. Grossman** (2005). Neural basis for generalized quantifier comprehension. *Neuropsychologia*.
- 6 Nieuwland MS, Kuperberg GR.** (2008) When the truth isn't too hard to handle: An event-related potential study on the pragmatics of negation. *Psychological science*.
- 7 Szymanik, J.** (2016). *Quantifiers and Cognition: Logical and Computational Perspectives*. Springer International Publishing.

Appendix

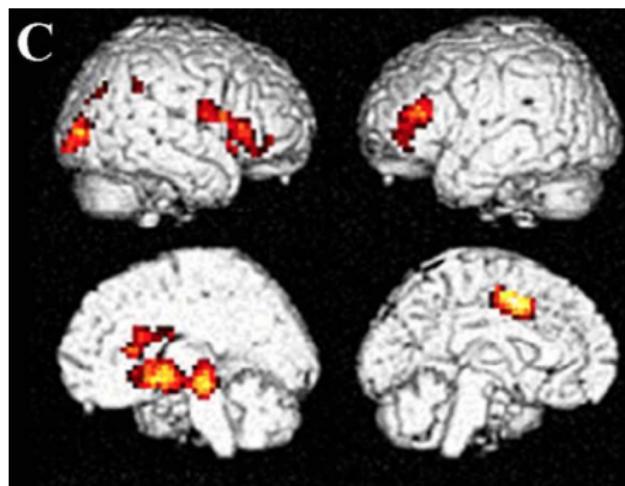


All conditions, time-locked to the predicate onset, midline electrode

Encoding vs. Verification



Neurobehavioral studies (McMillan et al. 2005)



Differences in brain activity.

- ▶ All quantifiers are associated with numerosity:
→ recruit right inferior parietal cortex.
- ▶ Only higher-order activate working-memory capacity:
→ recruit right dorsolateral prefrontal cortex.

Semantic Automata (Szymanik & Zajenkowsky 2009)

FSA

PDA

$\{All, Some\} < \{Even, Odd\} < \{At\ least\ n, At\ most\ n\} < \{Less\ than\ half, More\ than\ half, Most\}$

