# Evidence of accurate logical reasoning in online sentence comprehension

47th annual meeting of the Society for Philosophy and Psychology

Maksymilian Dąbkowski<sup>1</sup>, Roman Feiman<sup>2</sup> June 30, 2021

<sup>1</sup>University of California, Berkeley, <sup>2</sup>Brown University

slides available at https://ling.auf.net/lingbuzz/005989

# Evidence of accurate logical reasoning in online sentence comprehension

2022-02-19

Evidence of accurate logical reasoning in online sentence comprehension

47th annual meeting of the Society for Philosophy and Psychology

Maksymilian Dąbkowski', Roman Feim. June 30, 2021

\*University of California, Berkeley, \*Brown University

Introduction

comprehension -Introduction

Evidence of accurate logical reasoning in online sentence

Introduction

• what is the status of logic in thought?

Evidence of accurate logical reasoning in online sentence comprehension

Introduction

logic in thought

· what is the status of logic in thought?

What is the status of logic in thought?

- what is the status of logic in thought?
- logic studies relations among propositions

Evidence of accurate logical reasoning in online sentence comprehension

Throduction

Logic in thought



Logic, to characterize it broadly, is the formal study of relations which obtain among propositions.

- what is the status of logic in thought?
- · logic studies relations among propositions

#### Dictum de omni

All rats love to eat.

:. All spotted rats love to eat.

Evidence of accurate logical reasoning in online sentence comprehension

—Introduction

—logic in thought



Logical schemata capture rules which govern correct inference. The example here is the *dictum de omni*, which is the principle that whatever is affirmed of a kind can be affirmed of its subkind.

- what is the status of logic in thought?
- · logic studies relations among propositions

#### Dictum de omni

All rats love to eat.

- :. All spotted rats love to eat.
  - · do such schemata capture the nature of thought?

Evidence of accurate logical reasoning in online sentence comprehension

Introduction

legic in thought

what is the status of logic in thought?

I logic studies inflation almost propositions
(became almost)

All cost to be to each

All options to be seet.

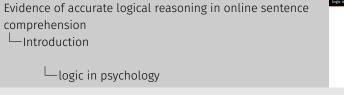
do such schemata capture the values of thought?

└─logic in thought

While such schemata capture normatively accurate inferences, there has been a long standing debate over what their status is in human cognition. This is to say, are such logical schemata the rules of thought?

1

# logic in psychology



The status of logic in thought has been viewed very differently by the disciplines of psychology and linguistics.

# logic in psychology

- psychology has focused on difficulties in logical reasoning
  - · Wason's (1968) selection tasks easier when ecologically valid (Cheng and Holyoak, 1985, 1989; Cheng, Holyoak, et al., 1986)
  - · dual-process theories (Evans and Stanovich, 2013; Kahneman, 2011)

Evidence of accurate logical reasoning in online sentence comprehension

Introduction

-logic in psychology

psychology has focused on difficulties in logical reasoning
 Wason's (1998) selection tasks easier when ecologically valid
 (Cheng and Holyaka, 1987; Stor, Cheng, Holyak, et al., 1998)
 dual-process theories (Evans and Stanovich, 2013, Kahnenan, 2011)

Research in psychology has tended to focus on documenting which logical tasks are more difficult than others and understanding why.

formal semantics presupposes logical ability
 the logical notions are embedded in our deepest nature, in
 the very form of our language and thought
 Chomsky (1988, p. 99)

Evidence of accurate logical reasoning in online sentence comprehension

Introduction

- formal semantics presupposes logical ability
the logical notions are embedded in our despect nature, in
the very form of our language and thought
Chamsky (1988, p. 99)

—logic in linguistics

On on the hand, certain branches of linguistics posit that language has a kind of logical form. Thus, implicitly, linguists credit language-users with a rather high degree of logical sophistication.

- formal semantics presupposes logical ability
   the logical notions are embedded in our deepest nature, in
   the very form of our language and thought
   Chomsky (1988, p. 99)
- · linguists predict some logical thought as effortless as language

Evidence of accurate logical reasoning in online sentence comprehension
Introduction
logic in linguistics

- formal semantics presupposes logical ability the logical notions are embedded in our despect notions in the very form of our language and thought.

Chomsky (1988, p. 99)
- linguists predict some logical thought as effortiess as language.

This view of language predicts that at least some inferences should be as intuitive, automatic, and effortless as thought and language themselves.

formal semantics presupposes logical ability
 the logical notions are embedded in our deepest nature, in
 the very form of our language and thought
 Chomsky (1988, p. 99)

· linguists predict some logical thought as effortless as language

• can we find evidence for spontaneous logical computation?

Evidence of accurate logical reasoning in online sentence comprehension

Introduction

-logic in linguistics

formal semantics presupposes logical ability the logical notions are embedded in our despect notions, in the very form of our longuage and thought choosing (1988, p. 99)
 impaints predict some logical thought as difference as larguage - can we find evidence for spontaneous logical computation?

Thus, the following question arises: Can we find some evidence for fast and automatic reasoning?

 formal semantics presupposes logical ability the logical notions are embedded in our deepest nature, in the very form of our language and thought

Chomsky (1988, p. 99)

- linguists predict some logical thought as effortless as language
- can we find evidence for **spontaneous logical computation**?
- entailment: if p is true, then q is also true

#### Dictum de omni

All rats love to eat.

∴ All spotted rats love to eat.

Evidence of accurate logical reasoning in online sentence comprehension

Introduction

logic in timpostos

- farmal semantics presupposes logical ability
- farmal semantics presupposes logical ability
- farmal semantics presupposes logical ability
- farmal years of the semantic present semantics of the service present of the semantics of the sema

—logic in linguistics

To answer this question, in our study, we focused on the notion of entailment. Entailment is a relation between propositions such that when one proposition is true, another proposition is always also true. Entailment has been argued to be based in the structure of language. Thus, it is a good candidate for a logical notion that is processed fast and automatically.

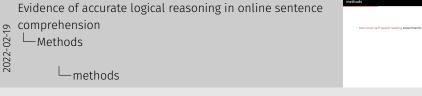
# Methods

Evidence of accurate logical reasoning in online sentence comprehension

Methods

Methods

two novel self-paced reading experiments



We designed two novel self-paced reading experiments.

- two novel self-paced reading experiments
- tested for signatures of accurate inferences between quantified sentences

Evidence of accurate logical reasoning in online sentence comprehension

Methods

∟methods

two novel self-paced reading experiments tested for signatures of accurate inferences between quantified sentences

We tested for signatures of normatively accurate logical inferences between quantified sentences during sentence comprehension.

- two novel self-paced reading experiments
- tested for signatures of accurate inferences between quantified sentences
- experiment 1 involved detecting logical contradictions

Evidence of accurate logical reasoning in online sentence comprehension

Methods

methods

two novel self-paced reading experiments
 seaded for signatures of accurate inferences between quantified entences
 emperiment 1 involved detecting logical contradictions

Experiment 1 tested whether speakers detect logical contradictions.

- two novel self-paced reading experiments
- tested for signatures of accurate inferences between quantified sentences
- experiment 1 involved detecting logical contradictions
- experiment 2 leveraged variable entailments of the first and second arguments of quantifiers to detect incorrect inferences

Evidence of accurate logical reasoning in online sentence comprehension

Methods

two novel self-gazed reading experiments
 seaded for signatures of accurate intersects between quantified sentences
 appointment involved descript logical contradictions
 appointment involved descript logical contradictions
 appointment involved descript logical contradictions
 appointment in a proper description of the first and second algorithms of the first and second algorithms of the description of the first descri

—methods

And Experiment 2 tested detecting something subtler... which is incorrect inferences in the absence of downright contradictions.

- two novel self-paced reading experiments
- tested for signatures of accurate inferences between quantified sentences
- experiment 1 involved detecting logical contradictions
- experiment 2 leveraged variable entailments of the first and second arguments of quantifiers to detect incorrect inferences
- · preregistered design and analyses on OSF

Evidence of accurate logical reasoning in online sentence comprehension

Methods

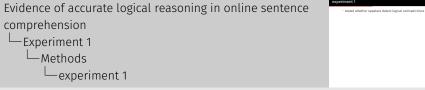
two novel self-paced reading experiments
 tested for signatures of accurate inferences between quantified sentences
 superiment 1 involved detecting logical contradictions
 superiment 2 leveraged unstable entailments of the first and second arunements of quantifiers to detect incorrect inferences.

preregistered design and analyses on OSF

Experiment 1

# Experiment 1

• tested whether speakers detect logical contradictions



But first, experiment 1.

- tested whether speakers detect logical contradictions
- 400 participants on Amazon Mechanical Turk

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 1

Methods

experiment 1

tested whether populars dated logical control
 vide participants on Annate MacChancial link
 vide participants on Annate MacChancial link

We ran 400 participants on Amazon Mechanical Turk.

- tested whether speakers detect logical contradictions
- 400 participants on Amazon Mechanical Turk
- 12 target items displayed line by line

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 1

Methods

experiment 1

experiment 1

- most alwatts operate does layed considerions

- do percipents of Anson Mechanical Turk

- to Legel from diplayed line by line

Participants read 12 target items displayed line-by-line, with line breaks at clausal boundaries.

- tested whether speakers detect logical contradictions
- 400 participants on Amazon Mechanical Turk
- 12 target items displayed line by line
- 6 conditions differing in quantifiers

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 1

Methods

experiment 1

experiment 1

- soud whether speaker disect legical contadictions
- 400 participants on Amazon Mechanical fact
- 5 conditions differing in quantifiers

Across participants, each item appeared in six conditions which differed in what quantifiers were used.

- tested whether speakers detect logical contradictions
- 400 participants on Amazon Mechanical Turk
- 12 target items displayed line by line
- 6 conditions differing in quantifiers

#### Test item

- (1) A group of scientists wanted to know whether spotted rats,
- (2) who are pickier eaters than other rats, liked a new kind of food.
- (3) They tested white, black, and spotted rats of both sexes.
- (4) The scientists discovered that QUANT1 of the rats loved the food.
- (5) Now that they knew that QUANT2 of the rats loved the food,
- (6) they decided to issue a recommendation based on their findings.

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 1

Methods

experiment 1



Each item contained a "premise" in line 4 and a "conclusion" in line 5, which began with *now that they knew that* ..., presupposing that what comes next appeared earlier in the discourse. Otherwise, the two lines differed only in the quantifiers they used.

- tested whether speakers detect logical contradictions
- 400 participants on Amazon Mechanical Turk
- 12 target items displayed line by line
- · 6 conditions differing in quantifiers

#### Test item

- (1) A group of scientists wanted to know whether spotted rats,
- (2) who are pickier eaters than other rats, liked a new kind of food.
- (3) They tested white, black, and spotted rats of both sexes.
- (4) The scientists discovered that QUANT1 of the rats loved the food.
- (5) Now that they knew that QUANT2 of the rats loved the food,
- (6) they decided to issue a recommendation based on their findings.
  - measured variable: RT of the conclusion line (5)
- · participants were asked unrelated comprehension questions
  - The researchers studied rodents.



Evidence of accurate logical reasoning in online sentence comprehension
Experiment 1
Methods

experiment 1



We measured the reading times of the boxed conclusion line as a proxy for processing costs.

#### experiment 1 conditions

	QUANT1	QUANT2
IDENTITY	<b>SOME</b> of the rats loved they knew the	at <b>SOMe</b> of the rats
IDENTITY	<b>not all</b> of the rats loved they knew the	at <b>not all</b> of the rats
ENTAILMENT	<b>all</b> of the rats loved they knew the	at <b>SOME</b> of the rats
ENTAILMENT	<b>none</b> of the rats loved they knew the	at <b>not all</b> of the rats
CONTRADICTION	<b>none</b> of the rats loved they knew the	at <b>SOME</b> of the rats
CONTRADICTION	<b>all</b> of the rats loved they knew the	at <b>not all</b> of the rats

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 1

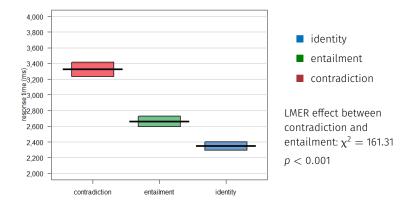
Methods

experiment 1 conditions



There were two conditions where the premise was identical to the conclusion, two conditions where it differed from but entailed the conclusion, and two conditions where it contradicted it.

#### experiment 1 results

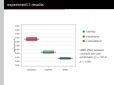


Evidence of accurate logical reasoning in online sentence comprehension

Experiment 1

Results

experiment 1 results

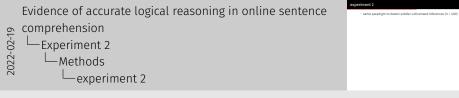


All of the conditions were significantly different from each other. Participants took significantly longer to advance to the conclusion line when it contradicted the premise than when it was entailed by the premise. This is consistent with rapid, normatively accurate sensitivity to the logical relations between these clauses.

Experiment 2

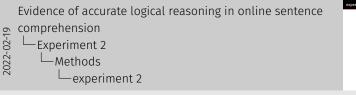
# Experiment 2

• same paradigm to detect subtler unlicensed inferences (n = 400)



Experiment 2 used the same paradigm to test for the capacity to detect subtler unlicensed inferences, even in the absence of strict contradictions.

- same paradigm to detect subtler unlicensed inferences (n = 400)
- $\boldsymbol{\cdot}$  manipulated quantifiers and premise quantifier's  $1^{\text{st}}$  arg





We manipulated the quantifiers in both the premise and the conclusion ... ... as well as the noun phrase in first argument of the quantifier in the premise.

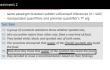
- same paradigm to detect subtler unlicensed inferences (n = 400)
- · manipulated quantifiers and premise quantifier's 1st arg

#### Test item

- (1) A group of scientists wanted to know whether spotted rats,
- (2) who are pickier eaters than other rats, liked a new kind of food.
- (3) They tested white, black, and spotted rats of both sexes.
- (4) The scientists discovered that QUANT of the ((male) spotted) rats loved the food.
- (5) Now that they knew that QUANT of the spotted rats loved the food,
- (6) they decided to issue a recommendation based on their findings.

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2



In the test items, we changed lines four and five to manipulate whether the conclusion was entailed by the premise.

Unlike experiment 1, here, the quantifier was kept constant between the premise and the conclusion. The premise noun phrase appeared with two, one, or zero modifiers. The conclusion noun phrase always appeared with one modifier.

2022-02-

-Methods

-experiment 2

- same paradigm to detect subtler unlicensed inferences (n = 400)
- · manipulated quantifiers and premise quantifier's 1st arg

#### Test item

- (1) A group of scientists wanted to know whether spotted rats,
- (2) who are pickier eaters than other rats, liked a new kind of food.
- (3) They tested white, black, and spotted rats of both sexes.
- (4) The scientists discovered that QUANT of the ((male) spotted) rats loved the food.
- (5) Now that they knew that QUANT of the spotted rats loved the food,
- (6) they decided to issue a recommendation based on their findings.
  - 4 quantifiers × 3 containment relations = 12 conditions

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2

Methods

experiment 2



Thus, the premise noun phrase was a subset of, identical to, or a superset of the conclusion noun phrase. **Four** quantifiers and **three** containment relations yielded twelve experimental conditions in total, which will ultimately reduce to a two-by-two.

Depending on the combination of the quantifier and containment,

- same paradigm to detect subtler unlicensed inferences (n = 400)
- · manipulated quantifiers and premise quantifier's 1st arg

#### Test item

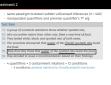
- (1) A group of scientists wanted to know whether spotted rats,
- (2) who are pickier eaters than other rats, liked a new kind of food.
- (3) They tested white, black, and spotted rats of both sexes.
- (4) The scientists discovered that QUANT of the ((male) spotted) rats loved the food.
- (5) Now that they knew that QUANT of the spotted rats loved the food,
- (6) they decided to issue a recommendation based on their findings.
  - 4 quantifiers × 3 containment relations = 12 conditions
    - 4 conditions: premise identical to (trivally entails) conclusion

```
Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2

Methods

experiment 2
```



there were four conditions where the premise was identical to the conclusion, and so it trivially entailed it,

- same paradigm to detect subtler unlicensed inferences (n = 400)
- · manipulated quantifiers and premise quantifier's 1st arg

#### Test item

- (1) A group of scientists wanted to know whether spotted rats,
- (2) who are pickier eaters than other rats, liked a new kind of food.
- (3) They tested white, black, and spotted rats of both sexes.
- (4) The scientists discovered that QUANT of the ((male) spotted) rats loved the food.
- (5) Now that they knew that QUANT of the spotted rats loved the food,
- (6) they decided to issue a recommendation based on their findings.
  - 4 quantifiers × 3 containment relations = 12 conditions
    - · 4 conditions: premise identical to (trivally entails) conclusion
    - 4 conditions: premise identical to (trivally entails) conclusion
    - · 4 conditions: premise entails conclusion

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2

Methods

experiment 2



four conditions where the premise differed from but entailed the conclusion,

- same paradigm to detect subtler unlicensed inferences (n = 400)
- · manipulated quantifiers and premise quantifier's 1st arg

#### Test item

- (1) A group of scientists wanted to know whether spotted rats,
- (2) who are pickier eaters than other rats, liked a new kind of food.
- (3) They tested white, black, and spotted rats of both sexes.
- (4) The scientists discovered that QUANT of the ((male) spotted) rats loved the food.
- (5) Now that they knew that **QUANT** of the spotted rats loved the food,
- (6) they decided to issue a recommendation based on their findings.
  - 4 quantifiers × 3 containment relations = 12 conditions
    - 4 conditions: premise identical to (trivally entails) conclusion
    - 4 conditions: premise entails conclusion
    - 4 conditions: premise does not entail conclusion

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2

Methods

experiment 2



and four conditions where the premise did not entail the conclusion.

- same paradigm to detect subtler unlicensed inferences (n = 400)
- · manipulated quantifiers and premise quantifier's 1st arg

#### Test item

- (1) A group of scientists wanted to know whether spotted rats,
- (2) who are pickier eaters than other rats, liked a new kind of food.
- (3) They tested white, black, and spotted rats of both sexes.
- (4) The scientists discovered that QUANT of the ((male) spotted) rats loved the food.
- (5) Now that they knew that **QUANT** of the spotted rats loved the food,
- (6) they decided to issue a recommendation based on their findings.
  - 4 quantifiers × 3 containment relations = 12 conditions
    - 4 conditions: premise identical to (trivally entails) conclusion
    - · 4 conditions: premise entails conclusion
    - 4 conditions: premise does not entail conclusion
  - within quantifier, critical lines have identical lexical content

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2

Methods

experiment 2



An elegant feature of our design is that within quantifier, we're looking at differences in reading times among lines that have identical lexical content, so whatever the difference is on the critical line, that difference *must be* due to preceding context.

	SOME	NOT ALL	ALL	NONE
$\overline{\text{SUBSET}} \rightarrow$	some of the male spotted rats loved the food. Now that	loved the food. Now that	all of the male spotted rats loved the food. Now that	none of the male spotted rats loved the food. Now that
of spotted rats $\rightarrow$	they knew that SOME of the Spotted rats	they knew that <b>not all</b> of the <b>spotted rats</b>	they knew that <b>all</b> of the <b>spotted rats</b>	they knew that <b>none</b> of the <b>spotted rats</b>
$\stackrel{-}{IDENTICAL} \to$	Some of the spotted rats loved the food. Now that they knew that Some of	not all of the spotted rats loved the food. Now that	all of the spotted rats loved the food. Now that	none of the spotted rats loved the food. Now that they knew that none of
to spotted rats $\rightarrow$	the <b>spotted rats</b>	they knew that <b>not</b> all of the <b>spotted rats</b>	they knew that <b>all</b> of the <b>spotted rats</b>	the <b>spotted rats</b>
$\overline{\text{SUPERSET}}  ightarrow$	<b>SOMe</b> of the rats	not all of the rats	all of the rats loved the food. Now that	none of the rats
of spotted rats $\rightarrow$	they knew that <b>SOME</b> of the <b>Spotted rats</b>	they knew that <b>not all</b> of the <b>spotted rats</b>	they knew that <b>all</b> of the <b>spotted rats</b>	they knew that <b>none</b> of the <b>spotted rats</b>

- trivially entailed
- entailed
- not entailed

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2

Methods

experiment 2 conditions, full

Here, you can see the twelve conditions schematized.

	SOME	NOT ALL	ALL	NONE
$\overline{\text{SUBSET}} \rightarrow$	some of the male spotted rats loved the food. Now that	loved the food. Now that	all of the male spotted rats loved the food. Now that	none of the male spotted rat. loved the food. Now tha
of spotted rats $\rightarrow$	they knew that SOME of the Spotted rats	they knew that <b>not all</b> of the <b>spotted rats</b>	they knew that <b>all</b> of the <b>spotted rats</b>	they knew that <b>none</b> of the <b>spotted rats</b>
$\overline{IDENTICAL}  o$	Some of the spotted rats loved the food. Now that they knew that SOME of	not all of the spotted rats loved the food. Now that they knew that not all of	all of the spotted rats loved the food. Now that they knew that all of the	none of the spotted rats loved the food. Now that they knew that none of
to spotted rats $\rightarrow$	the <b>spotted rats</b>	the <b>spotted rats</b>	spotted rats	the spotted rats
$ ext{SUPERSET}  ightarrow$	<b>some</b> of the <b>rats</b> loved the food. Now that	not all of the rats loved the food. Now that	all of the rats loved the food. Now that	<b>none</b> of the <b>rats</b> loved the food. Now that
of spotted rats $\rightarrow$	they knew that <b>SOME</b> of the <b>Spotted rats</b>	they knew that <b>not all</b> of the <b>spotted rats</b>	they knew that <b>all</b> of the <b>spotted rats</b>	they knew that <b>none</b> of the <b>spotted rats</b>

- trivially entailed
- entailed
- not entailed

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2

Methods

experiment 2 conditions, full



For example, if we look at a quantifier which is upward entailing, such as "some," when the premise noun phrase is a subset of the conclusion noun phrase, the conclusion follows.

entailednot entailed

	SOME	NOT ALL	ALL	NONE
$\overline{\text{SUBSET}} \rightarrow$	some of the male spotted rats loved the food. Now that they knew that SOMe of the Spotted rats	not all of the male spotted rats loved the food. Now that they knew that not all of the spotted rats	all of the male spotted rats loved the food. Now that they knew that all of the spotted rats	none of the male spotted rats loved the food. Now that they knew that none of the spotted rats
of spotted rats $\rightarrow$				
IDENTICAL $\rightarrow$ to spotted rats $\rightarrow$	Some of the spotted rats loved the food. Now that they knew that Some of the Spotted rats	not all of the spotted rats loved the food. Now that they knew that not all of the spotted rats	all of the spotted rats loved the food. Now that they knew that all of the spotted rats	none of the spotted rats loved the food. Now that they knew that none of the spotted rats
$\stackrel{-}{\text{SUPERSET}} \rightarrow$	<b>SOMe</b> of the rats loved the food. Now that	not all of the rats loved the food. Now that	all of the rats	none of the rats
of spotted rats $\rightarrow$	they knew that <b>SOMe</b> of the <b>Spotted rats</b>	they knew that <b>not</b> all of the <b>spotted rats</b>	they knew that <b>all</b> of the <b>spotted rats</b>	they knew that <b>none</b> of the <b>spotted rats</b>
■ trivia	lly entailed			

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2

Methods

experiment 2 conditions, full

	SOME	NOT ALL	ALL	NONE
SUBSET → of sported cats →	male spotted rats that to feet the the try has the BOTH of the spotted rats.	not all you male spotted rats to fine the fine that the second rats of the spotted rats.	male spotted rate in the true in the part the first true in part to spotted rate spotted rate.	male spotted ra
IDENTICAL →	spotted rots tool to feel feel feel took to feel feel feel took source 50 feel of on spotted rats.	spotted rots spotted rots institute for fail to the spotted rots.	aported rots sported rots see the plat the see aported rots	spotted rets
SUPERSET → of sported cars →	- BOTH y/or note had by find the due by how the BOTH y/ or Spotted rots.	not all you rets may be just the for top how the flot all of to spotted rets.	ests in the first fee the ten ten ten ten ten ten ten ten ten spotted rots.	nate limit for the the the try has been the BONE on the Son the Son the special rate.
trivial entail				

When the premise noun phrase is a superset of the conclusion noun phrase we get an unlicensed inference.

	SOME	NOT ALL	ALL	NONE
$\overline{\text{SUBSET}} \rightarrow$	Some of the male spotted rats loved the food. Now that	not all of the male spotted rats loved the food. Now that	all of the male spotted rats loved the food. Now that	none of the male spotted rats loved the food. Now that
of spotted rats $\rightarrow$	they knew that <b>SOMe</b> of the <b>Spotted rats</b>	they knew that <b>not all</b> of the <b>spotted rats</b>	they knew that all of the spotted rats	they knew that none of the spotted rats
IDENTICAL $\rightarrow$ to spotted rats $\rightarrow$	Some of the spotted rats loved the food. Now that they knew that SOME of the Spotted rats	not all of the spotted rats loved the food. Now that they knew that not all of the spotted rats	all of the spotted rats loved the food. Now that they knew that all of the spotted rats	none of the spotted rats loved the food. Now that they knew that none of the spotted rats
${\text{SUPERSET}} \rightarrow$	some of the rats	not all of the rats	all of the rats	none of the rats
of spotted rats $\rightarrow$	they knew that <b>SOMe</b> of the <b>Spotted rats</b>	they knew that <b>not</b> all of the <b>spotted rats</b>	they knew that <b>all</b> of the <b>spotted rats</b>	they knew that none of the spotted rats

- trivially entailed
- entailed
- not entailed

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2

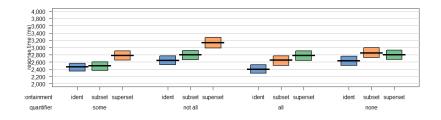
Methods

experiment 2 conditions, full



And when we look at a quantifier that is downward-entailing, such as "none," the pattern reverses.

## experiment 2 results



trivialentailed

not entailed

subset: male spotted rats ≺ spotted rats
ident: spotted rats ≺ spotted rats
superset: rats ≺ spotted rats

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2

Results

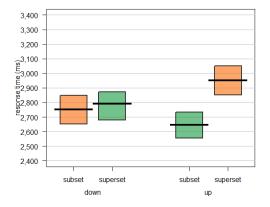
experiment 2 results



In the results of Experiment 2, the twelve conditions are grouped by quantifiers.

We find a main effect of containment, with superset conditions generally slower than subset. What matters, however, is the interaction of entailment and containment, which you can see as the difference between the green bars and the orange bars within each quantifier.

# experiment 2 results, quantifiers grouped by entailment



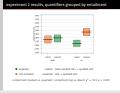
entailed subset: male spotted rats  $\prec$  spotted rats not entailed superset: rats  $\prec$  spotted rats containment (subset vs. superset)  $\times$  entailment (up vs. down):  $\chi^2 = 10.9$ , p < 0.001

Evidence of accurate logical reasoning in online sentence comprehension

Experiment 2

Results

experiment 2 results, quantifiers grouped by



Here, we group the upward- and downward-entailing quantifiers together and drop the "ident" conditions to show the relevant interaction of containment and entailment more clearly. This interaction is significant, showing rapid sensitivity to logical relations between clauses.

# Evidence of accurate logical reasoning in online sentence comprehension Discussion

Discussion

# Discussion

language involves accurate and spontaneous logical computations

Evidence of accurate logical reasoning in online sentence comprehension

Discussion

-discussion

disaussion

- tanguage involves accurate and spontaneous logical computations

In summary, our findings suggest that language processing involves automatic, accurate, and spontaneous logical computations, even in the absence of a task that requires making these inferences to verify text comprehension.

2022-02-19

- language involves accurate and spontaneous logical computations
- differs from dual-process theories of cognition
   it is assumed that people's intuitive logical knowledge
   emerges from a learning process in which key principles have
   been practiced to automaticity

De Neys and Pennycook (2019)

Evidence of accurate logical reasoning in online sentence comprehension

L\_Discussion

-discussion

Language involves accusate and spontaneous logical computations
 diffusion dual-process theories of organizes
 diffusion dual-process theories red organizes
 diffusion dual-process theories red organizes
 diffusion dual-process theories
 been printinged to outcompting
 de Neys and Phrompools (2019)

This view differs from what is assumed by dual-process theories of cognition.

2022-02-19

- language involves accurate and spontaneous logical computations
- differs from dual-process theories of cognition
   it is assumed that people's intuitive logical knowledge
   emerges from a learning process in which key principles have
   been practiced to automaticity

De Neys and Pennycook (2019)

- consistent with some logic being naturally intuitive
  - natural logic in reasoning (e.g. Braine and O'Brien, 1998)
  - · logic (L-analyticity) in grammar (e.g. Gajewski, 2002)

Evidence of accurate logical reasoning in online sentence comprehension

Discussion

Impage involves accurate and opertunenous logical computations of military to affect from adult process theories of registron.

 It is strained that people's function large from the purple for fine and process from the process from the

 $\sqcup_{\mathsf{discussion}}$ 

On the other hand, our findings are anticipated by frameworks which take some logical inferences as naturally intuitive.

- language involves accurate and spontaneous logical computations
- differs from dual-process theories of cognition
   it is assumed that people's intuitive logical knowledge
   emerges from a learning process in which key principles have
   been practiced to automaticity

De Neys and Pennycook (2019)

- · consistent with some logic being naturally intuitive
  - natural logic in reasoning (e.g. Braine and O'Brien, 1998)
  - · logic (L-analyticity) in grammar (e.g. Gajewski, 2002)
- inference derives from compositionality?

Evidence of accurate logical reasoning in online sentence comprehension

L Discussion

-discussion

Language insolvers actuants and spontaneous logical conjugations of differ from dual process thereine of organizon if or casemed that popular insolvers logical the management of the casement of the popular insolvers logical three been practiced on unconnection.

4. On submediate the confunction of the language of the been practiced on unconnection.

5. One language confunction of the language confusion of the l

Thus, we conclude that the compositionality of language and at least *some* inferential thought may both derive from the same cognitive mechanisms.

2022-02-19



.....

slides available at
https://ling.auf.net/lingbuzz/005989

Evidence of accurate logical reasoning in online

### references i

- Braine, Martin D. S. and David P. O'Brien (1998). *Mental logic*. Psychology Press.
- Cheng, Patricia W. and Keith J. Holyoak (1985). "Pragmatic Reasoning Schemas". In: *Cognitive Psychology* 17.4, pp. 391–416.
- Cheng, Patricia W. and Keith J. Holyoak (1989). "On the natural selection of reasoning theories". In: *Cognition*.
  - Cheng, Patricia W., Keith J. Holyoak, Richard E. Nisbett, and Lindsay M. Oliver (1986). "Pragmatic versus syntactic approaches to training deductive reasoning". In: *Cognitive Psychology* 18.3, pp. 293–328.
  - De Neys, Wim and Gordon Pennycook (2019). "Logic, fast and slow: Advances in dual-process theorizing". In: *Current Directions in Psychological Science* 28.5, pp. 503–509.

Evidence of accurate logical reasoning in online sentence comprehension

Discussion

∟references

2022-02-

Braine, Martin D. S. and David P. O'Brien (1998). Mentol logic.

Cheng, Patricia W. and Keith J. Holyoak (1985). "Pragmatic Reasoning Schemas". In: Cognitive Psychology 174, pp. 391–416.

Cheng, Patricia W. and Keith J. Holyoak (1989). "On the natural selection of reasoning theories". In: Cognition.
Cheng Patricia W. Keith J. Holyoak (Pichard F. Nichatt and

Cheng, Patricia W., Keith J. Holycak, Richard E. Nisbett, and Lindsay M. Oliver (1986). "Pragmatic versus syntactic approaches to training deductive reasoning". In: Cognitive Psychology 18.3, no. 293-228.

pp. 293–328.
pp. 293–328.
pp. Wim and Gordon Pennycook (2019). "Logic, fast and slow Advances in dual-process theorizing". In: Current Directions in Psychological Science 28.5, pp. 503–509.

#### references ii

- Evans, Jonathan St. B. T. and Keith E. Stanovich (2013). "Dual-process theories of higher cognition: Advancing the debate". In: Perspectives on Psychological Science 8.3, pp. 223–241.
- Gajewski, Jon (2002). "L-analyticity and natural language". Manuscript. Cambridge, MA: MIT.
  - Kahneman, Daniel (2011). Thinking, Fast and Slow. Farrar, Straus and Giroux.
- Wason, Peter C. (1968). "Reasoning about a rule". In: Quarterly Journal of Experimental Psychology 20.3, pp. 273–281.

Evidence of accurate logical reasoning in online sentence comprehension Discussion

-references

2022-02-19

Evans, Ionathan St. B. T. and Keith E. Stanovich (2013), "Dual-process theories of higher cognition: Advancing the debate". in:

Galewski, Ion (2002), "L-analyticity and natural language", Manuscrip

Kahneman, Daniel (2011). Thinking, Fost and Slow, Farrar, Straus and

Wason, Peter C. (1968). "Reasoning about a rule". In: Quarterly Journal