Evidence of accurate logical reasoning in online sentence comprehension

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slides available at  https://ling.auf.net/lingbuzz/005989
Introduction
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?
• 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)
logic in linguistics

- **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

<table>
<thead>
<tr>
<th>Dictum de omni</th>
</tr>
</thead>
<tbody>
<tr>
<td>All rats love to eat.</td>
</tr>
<tr>
<td>$\therefore$ All spotted rats love to eat.</td>
</tr>
</tbody>
</table>
Methods
methods

- 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
Experiment 1
experiment 1

- 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, who are pickier eaters than other rats, liked a new kind of food.
2. They tested white, black, and spotted rats of both sexes.
3. The scientists discovered that QUANT1 of the rats loved the food.
4. Now that they knew that QUANT2 of the rats loved the food, 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. TRUE FALSE

The researchers studied rodents.
### Experiment 1 Conditions

<table>
<thead>
<tr>
<th>QUANT1</th>
<th>QUANT2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Identity</strong></td>
<td><strong>Identity</strong></td>
</tr>
<tr>
<td><em>some</em> of the rats loved</td>
<td><em>not all</em> of the rats loved</td>
</tr>
<tr>
<td><em>they knew that</em> <em>some</em> of the rats knew</td>
<td><em>they knew that</em> <em>not all</em> of the rats knew</td>
</tr>
<tr>
<td><strong>Entailment</strong></td>
<td><strong>Entailment</strong></td>
</tr>
<tr>
<td><em>all</em> of the rats loved</td>
<td><em>none</em> of the rats loved</td>
</tr>
<tr>
<td><em>they knew that</em> <em>some</em> of the rats knew</td>
<td><em>they knew that</em> <em>not all</em> of the rats knew</td>
</tr>
<tr>
<td><strong>Contradiction</strong></td>
<td><strong>Contradiction</strong></td>
</tr>
<tr>
<td><em>none</em> of the rats loved</td>
<td><em>all</em> of the rats loved</td>
</tr>
<tr>
<td><em>they knew that</em> <em>some</em> of the rats knew</td>
<td><em>they knew that</em> <em>not all</em> of the rats knew</td>
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</table>
experiment 1 results

LMER effect between contradiction and entailment: $\chi^2 = 161.31$, $p < 0.001$
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, who are pickier eaters than other rats, liked a new kind of food.
(2) 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
experiment 2 conditions, full

<table>
<thead>
<tr>
<th></th>
<th>SOME</th>
<th>NOT ALL</th>
<th>ALL</th>
<th>NONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBSET →</td>
<td>... <em>some</em> of the male spotted rats loved the food. Now that they knew that <em>some</em> of the spotted rats ...</td>
<td>... <em>not all</em> of the male spotted rats loved the food. Now that they knew that <em>not all</em> of the spotted rats ...</td>
<td>... <em>all</em> of the male spotted rats loved the food. Now that they knew that <em>all</em> of the spotted rats ...</td>
<td>... <em>none</em> of the male spotted rats loved the food. Now that they knew that <em>none</em> of the spotted rats ...</td>
</tr>
<tr>
<td>of spotted rats →</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDENTICAL →</td>
<td>... <em>some</em> of the spotted rats loved the food. Now that they knew that <em>some</em> of the spotted rats ...</td>
<td>... <em>not all</em> of the spotted rats loved the food. Now that they knew that <em>not all</em> of the spotted rats ...</td>
<td>... <em>all</em> of the spotted rats loved the food. Now that they knew that <em>all</em> of the spotted rats ...</td>
<td>... <em>none</em> of the spotted rats loved the food. Now that they knew that <em>none</em> of the spotted rats ...</td>
</tr>
<tr>
<td>to spotted rats →</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUPERSET →</td>
<td>... <em>some</em> of the rats loved the food. Now that they knew that <em>some</em> of the spotted rats ...</td>
<td>... <em>not all</em> of the rats loved the food. Now that they knew that <em>not all</em> of the spotted rats ...</td>
<td>... <em>all</em> of the rats loved the food. Now that they knew that <em>all</em> of the spotted rats ...</td>
<td>... <em>none</em> of the rats loved the food. Now that they knew that <em>none</em> of the spotted rats ...</td>
</tr>
<tr>
<td>of spotted rats →</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- □ trivially entailed
- ■ entailed
- □ not entailed
experiment 2 results

- trivial
- entailed
- not entailed

subset: male spotted rats ≺ spotted rats
ident: spotted rats ≺ spotted rats
superset: rats ≺ spotted rats
Experiment 2 results, quantifiers grouped by entailment

- Entailed
- Not entailed

Subset: male spotted rats ≺ spotted rats
Superset: rats ≺ spotted rats

Containment (subset vs. superset) × entailment (up vs. down): $\chi^2 = 10.9, p < 0.001$
Discussion
• 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?**
thank you!

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