The Processing of Polar Quantifiers Coupled with Negation

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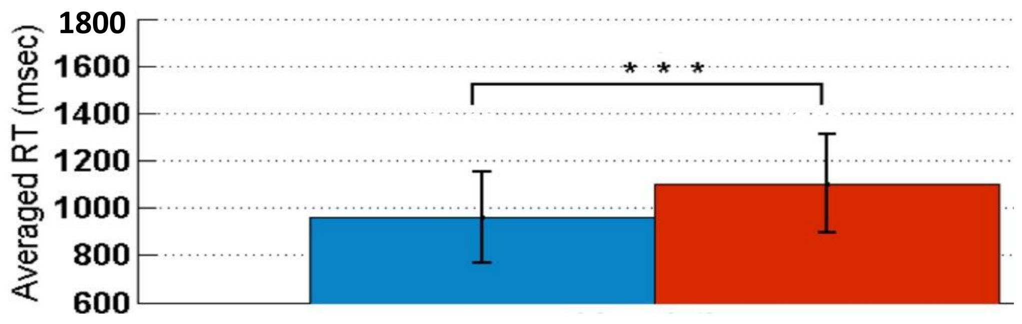
Abstract

We study the contribution of negation to the complexity of sentence processing. Wason (1959) shows that sentences containing the explicit negation *not* take more time to process than their affirmative counterparts. In a recent study, Deschamps et al. (2015) show that the same effect also holds for the processing of implicit negation (e.g. *less than half*, ¬ ≥½, as opposed to *more than half*, >½). There are two ways to explain these findings in a uniform manner: increased processing cost (IPC) arises (i) from performing the negation operation regardless of how it is expressed (explicitly or implicitly), or (ii) from processing downward monotonicity, which assumes that two negations cancel each other (see below). We designed an experiment to adjudicate between (i) and (ii) by studying whether *not less than half* (upward monotone, 2 negations) induces IPC relative to *less than half* (downward monotone, 1 negation). (i) predicts that the IPC induced by explicit negation and the IPC induced by implicit negation accumulate, while (ii) predicts no IPC to arise since the quantifier *not less than half* is upward monotone. To forecast, we found that subjects perform in a manner compatible with hypothesis (ii) but not (i), i.e., IPC follows monotonicity. Our results further show a deviation from the predictions of hypothesis (ii), which we aim to explain with reference to the cost of implicature computation.

Cognitive Background:

In speeded sentence verification tasks:

- Sentences with negation (e.g. *"the book is not on the table"*) take longer to verify than their affirmative counterparts (e.g. *"the book is on the table"*) (Wason 1959).
- Negative quantifiers were shown to contain an implicit negation in linguistic tests. Sentences with negative quantifiers (e.g. "*less than half of the circles are yellow*") take longer to verify than equivalent sentences with positive quantifiers ("*more than half of the circles are blue*") (Deschamps et al. 2015).



Monotonicity:

{x: x is blue and small }⊆{x: x is blue}

Upward Monotone	Downward Monotone
The book is blue ⇑ The book is blue and small	The book is not blue ⇓ The book is not [blue and small]
More than half of the books are blue ⇑ More than half of the books are blue and small	Less than half of the books are blue ⇓ Less than half of the books are [blue and small]

Question:

What complexity metric is correct with respect to the processing of negation?

Hypothesis (i): Negation Model

The main source of difficulty to process a sentence comes from performing individual negation operations regardless of how they are expressed (explicitly or implicitly).

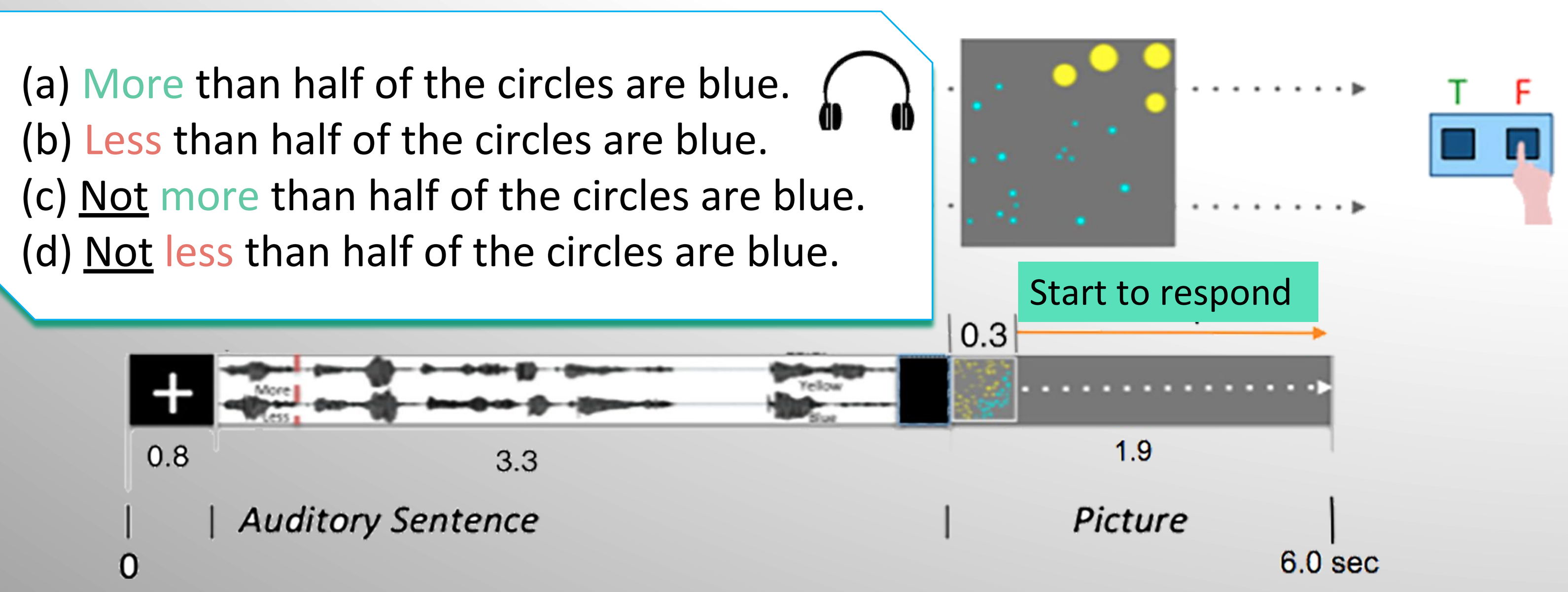
- **Prediction:** More negations – both explicit and implicit – in a sentence, more processing difficulty.

Hypothesis (ii): Monotonicity Model

The main source of difficulty of processing a sentence comes from processing downward monotonicity (DM) regardless of how it is induced.

- **Prediction:** Downward monotone sentences are cognitively more taxing than upward monotone sentences.

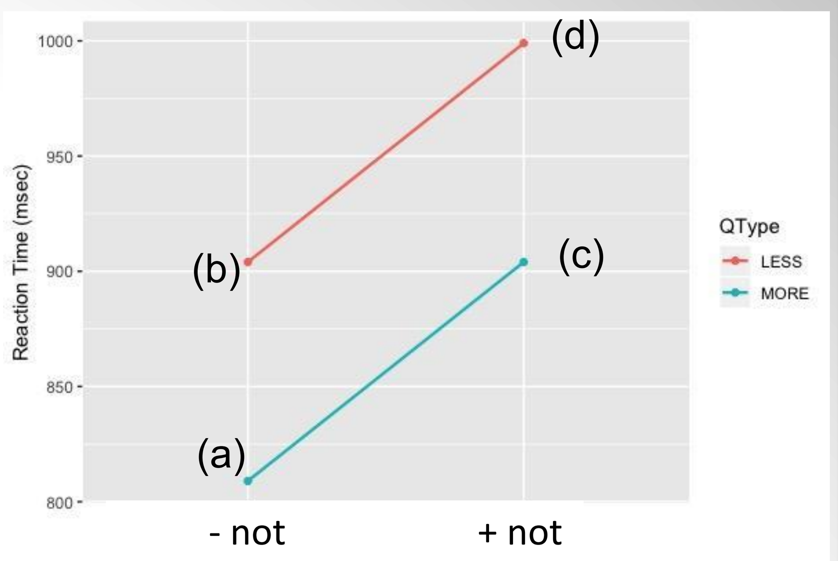
Experiment:



Predictions:

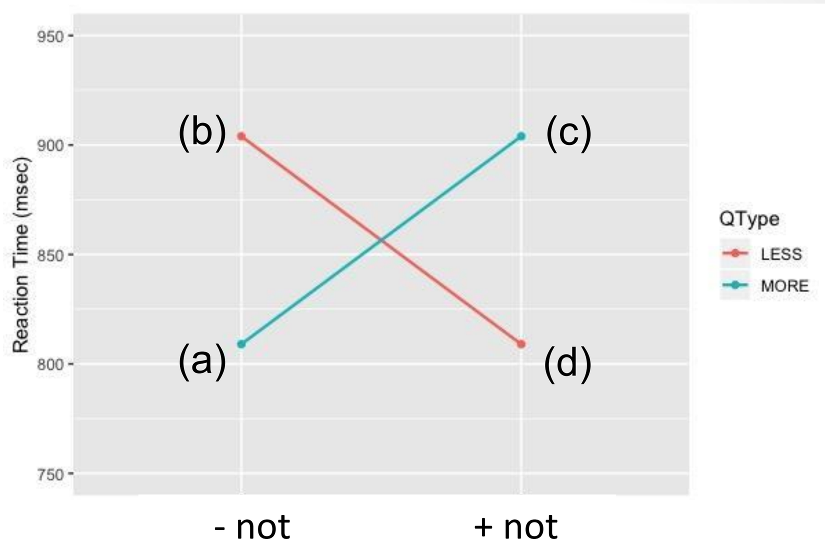
Negation Model (# of negations):

Number of negations	- not	+ not
More	(a) **0**	(c) **1**
Less	(b) **1**	(d) **2**



Monotonicity Model:

Monotonicity	- not	+ not
More	(a) **upward** monotone	(c) **downward** monotone
Less	(b) **downward** monotone	(d) **upward** monotone



Experiment – results and analysis:

We analyzed the data of 25 participants. We ran a 2-way ANOVA on log(RT) (Fig. 1) and found a main effect of negation (p=0.006), but not for the quantifier type factor (p=0.6). A significant quantifier type × negation interaction effect was also found (p=0.024). In the error domain, there is a strong effect of explicit negation (Fig. 2). To test whether learning confounds the aforementioned effects, we plotted the declines of reaction time over trials, which show similar trend across all conditions (Fig. 3).

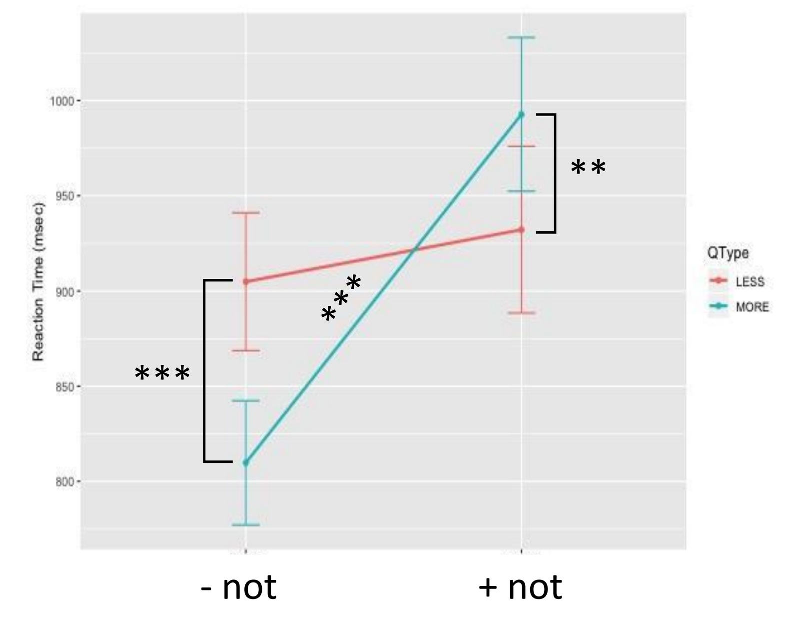


Figure 1: mean RT per condition

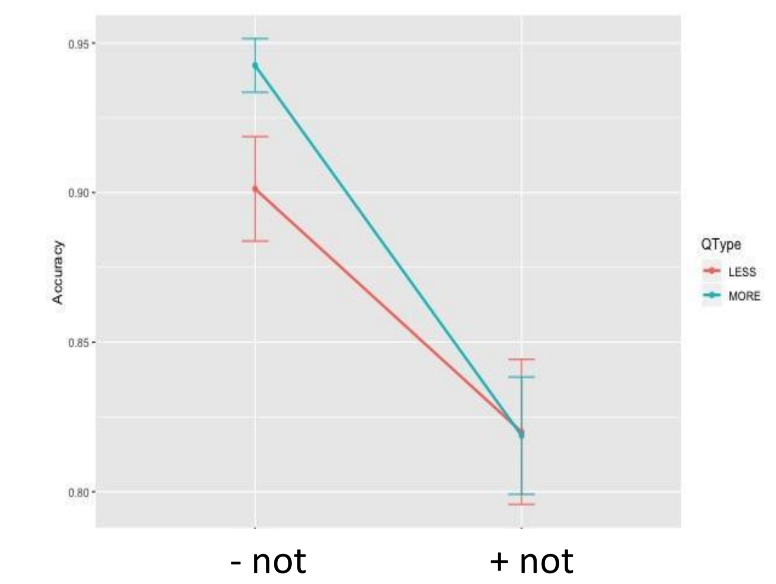


Figure 2: mean accuracy per condition

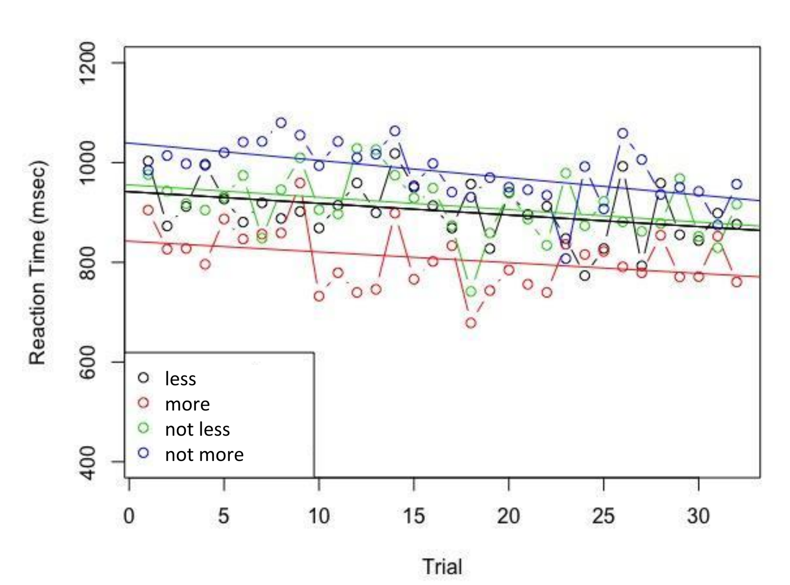


Figure 3: time series of mean RT per trial

Discussion

Based on Wason (1959), Just & Carpenter (1971), and Deschamps et al. (2015), we know that to process a sentence containing negation is costly, regardless of the form of the negation. However, the IPC has more than one possible source: the cost of performing the negation operation, or, the cost of processing downward monotonicity. By combining the two types of negation in our experiment, the contrast between $RT_{(c)}$ and $RT_{(d)}$ shows that the processing cost of downward monotonicity is the dominant factor, rather than the cost of negation itself, suggesting a monotonicity-dependent verification procedure. Next, we already noted that $RT_{(c)}$ and $RT_{(d)}$ are higher than predicted by hypothesis (ii). To account for that, we'll consider the possibility that it is due to an implicature, induced by the negated quantifiers. As demonstrated in (1), (1a) contains a non-negated quantifier, which can be followed by a stronger statement. However, it is not the case in (1b), which contains a negated quantifier.

(1) a. John had *fewer than* 6 cakes. In fact, he had exactly 3 cakes.

b. John had no/*not more than* 5 cakes. #In fact, he had exactly 3 cakes.

Arguably, the incoherence of the follow-up sentence in (1b) is caused by an implicature, either a scalar implicature in the case of *no* or an ignorance implicature in the case of *not.* The implicature computation may explain the deviation from hypothesis (ii) in our results.

References: **Wason C., P. (1959).** The Processing of Positive and Negative Information. *Quarterly Journal of Experimental Psychology*, *11*(2), 92–107. **Deschamps et al. (2015)**. The processing of polar quantifiers, and numerosity perception. *Cognition*, 143, 115-128.