

***At least* ignorance inferences come at a processing cost: Support from eye movements**

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We present results from an eye-tracking reading experiment that investigates the time course of ignorance interpretations of sentences with the superlative numeral modifier *at least*. Although superlative numeral modifiers are known to signal ignorance on the speaker's side, we found that processing *at least* in ignorance contexts, as opposed to knowledgeability contexts, is costly. In line with on-line studies testing implicatures associated with other scalar terms by means of a similar paradigm (cf. Breheny, Katsos, & Williams, 2006; Panizza, Chierchia, & Clifton, 2009), this finding is taken to suggest that the processing cost incurred in the ignorance contexts is due to deriving ignorance interpretations as pragmatic inferences. This goes against a semantic account of ignorance effects with *at least*, where ignorance is part of the lexical meaning of *at least* (cf. Geurts & Nouwen, 2007). Rather, it is in favor of a pragmatic account, be it in the neo-Gricean style of Büring (2008), Kennedy (2015), or Schwarz (2013), who derive ignorance inferences with *at least* as a type of scalar implicature, or à la Coppock & Brochhagen (2013), who derive them via another independently motivated pragmatic principle (i.e., the maxim of Interactive Sincerity).

We present results from an eye-tracking reading experiment that investigates the time course of ignorance interpretations of sentences with the superlative numeral modifier *at least*. Although superlative numeral modifiers are known to signal ignorance on the speaker’s side, we found that processing *at least* in ignorance contexts, as opposed to knowledgeability contexts, is costly. In line with studies testing implicatures associated with other scalar terms with a similar paradigm (cf. Breheny, Katsos, & Williams, 2006; Panizza, Chierchia, & Clifton, 2009), this finding is taken to suggest that the processing cost incurred in the ignorance contexts is due to deriving ignorance interpretations as pragmatic inferences.

Background. It is an established fact in the recent semantics/pragmatics literature on numeral modifiers that *at least* and *at most* give rise to so-called ignorance inferences, like the following reading of (1): ‘the speaker is ignorant about the exact number n of movies Sophia watched this year, i.e., whether $n = 20$ or $n > 20$ ’.

(1) Sophia watched at least 20 movies this year.

However, there is an ongoing theoretical debate whether these inferences are part of the semantics of the numeral modifier (e.g., Geurts & Nouwen, 2007) or whether they are derived via a pragmatic mechanism (Büring, 2008; Coppock & Brochhagen, 2013; Schwarz, 2013, *i.a.*). As cancellation data of ignorance effects with superlative numeral modifiers give rise to rather unclear judgements (see (2)), the vast majority of the studies accounting for these effects soon resorted to experimental data.

(2) At least 50 people came to the party yesterday. ??Actually, to be precise, there were 53 people at the party.

According to (2), ignorance effects seem to be hard to cancel, though the continuation sentence is not completely illicit. There has been done quite some experimental research up until now in order to shed light on this dubious status of ignorance inferences with superlative numeral modifiers (e.g., Cummins & Katsos, 2010; Geurts, Katsos, Cummins, Moons, & Noordman, 2010; McNabb & Penka, under revision). Most of these studies, if not all, involved tasks indirectly testing for ignorance inferences. Importantly, Westera & Brasoveanu (2014) set out to directly study the context-sensitivity of ignorance effects with the superlative numeral modifier *at most* (as compared to the comparative *less than*) during self-paced reading in combination with a validity judgement task. They did so by means of two experiments. The reading time data they obtained though in the ignorance-triggering condition in Experiment 1 cannot be taken to purely reflect ignorance interpretations, as the use of perception verbs in their design might have facilitated anti-ignorance interpretations of their test sentences (cf. *I saw at most ten of the coins under the bed*), possibly affecting reading times. Also, Experiment 2 did not replicate the reading time results of Experiment 1.

Current study. We ran an eye-tracking reading experiment in Dutch, aiming to directly measure what happens in real time when interpreting the superlative numeral modifier *minstens* ‘at least’ in ignorance contexts vs. knowledgeability contexts. Doing so would allow us to gain insight into the status of ignorance effects with superlative numeral modifiers.

We set up a context forcing an ignorance reading (Ignorance context) and one that is compatible with the core meaning of *at least* (e.g., $n \geq 20$), but at odds with an ignorance reading (Knowledgeability or else Authority context), see translated example item below. These contexts were preceded by the same introductory text

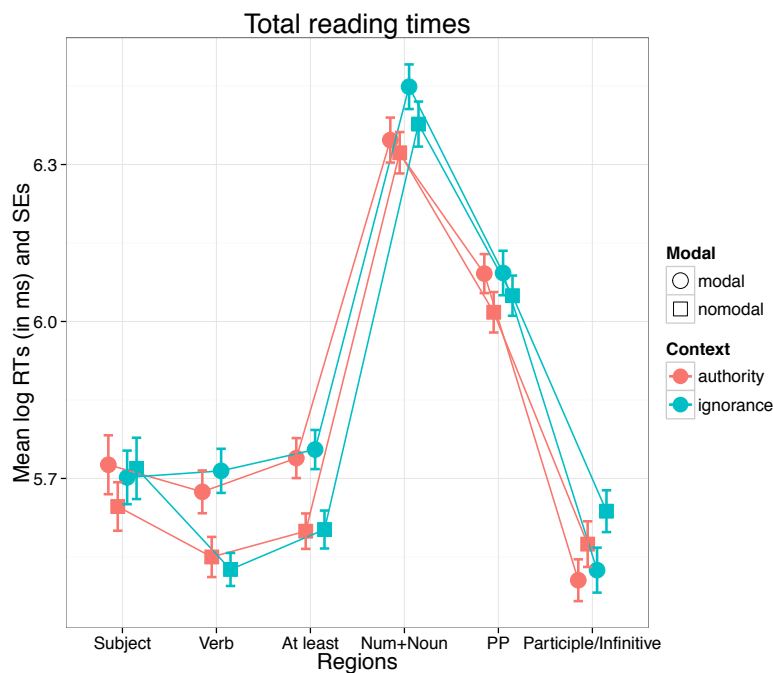
(see intro below) and followed by the target sentence (glossed below):

Intro: Hugo hadn't been to work for one day and his secretary hadn't been able to answer all of his phone calls. As a result, Hugo had to start working hard straight away when he got to work on Tuesday morning.
Ignorance context: I'm not completely sure how it is exactly, but I'll tell you what my impression is.
Authority context: I know exactly how it is because he complained about it to me.
Target sentence: He { had to / has } *at least* twenty phone calls in the morning { deal / dealt } with.

This context manipulation was inspired by Breheny et al. (2006), who in a self-paced reading task measured reading times of a scalar term in a context triggering a scalar implicature, and in a context that did not trigger that implicature. They found a slowdown on the scalar term in the former condition, which they associated with implicature generation. A similar effect was found by Panizza et al. (2009), who tested the interpretation of bare numerals with an eye-tracking reading task with a similar context manipulation. Finally, as is evident from the example item above, we also manipulated the Verb in the target sentence, modal (*had to*) vs. non-modal (*has*), to test a prediction made by many in the literature, viz. that for ignorance to arise with a modal verb, *at least* needs to take wide scope (which is presumably costly, cf. Hackl, Koster-Hale, & Varvoutis, 2012).

In our 2x2 design, the Authority contexts were the reference level for the factor Context, while the reference level for the Verb factor was non-modal. We tested 32 items, interspersed with 92 fillers. All test items were rotated through lists, so that each participant only saw one condition per item. Thirty native speakers of Dutch participated in the experiment.

Results & Discussion. We ran linear mixed-effects regression models with random effects for participants and items. The figure below depicts the mean log-transformed reading times (log RTs) and standard errors (SEs) of the total reading time measure



(i.e., the sum of all fixations in a region, incl. all passes) for each region. The mixed effects regression analyses revealed no significant effect in the CONTEXT region in any measure. There was a positive main effect of Verb in the VERB region up to the last region, where it became negative, in various measures (all $p < .05$), as well as a positive main effect of Verb in the SUBJECT region in re-reading times and re-reading probability (both $p < .05$). All these effects

are of little interest, as they can be due to the fact that different words were used

in the VERB and the last region, differing in, e.g., length, frequency, semantics. In the AT LEAST region there was no effect other than that of Verb. Interestingly, and besides again the effect of Verb, in the NUM+NOUN region there was a positive main effect of Context in right-bounded reading times ($p = .039$), in total reading times ($p = .034$), and in re-reading probability ($p = .050$): Compared to items with Authority contexts, items with Ignorance contexts were read slower in the NUM+NOUN region (note the difference between the blue vs. red points in the NUM+NOUN region in the figure); in addition, the Num+Noun region was also more likely to be re-read in Ignorance contexts as opposed to Authority contexts. These effects of Ignorance contexts are in line with a pragmatic analysis in which ignorance inferences have to be computed online and are costly, parallel to scalar implicatures (cf., e.g., Breheny et al., 2006). Also, they are in conflict with a semantic account (e.g., Geurts & Nouwen, 2007), which has ignorance as part of the lexical meaning of *at least*, predicting that *at least* should be fully compatible with an Ignorance context and no extra processing should be needed. Moreover, there was no effect of Context in the PP (Prepositional Phrase) region. Finally, we found no significant interaction, hence, no evidence indicating that ignorance with *at least* in the presence of a modal operator involves an extra (costly) process, like covert movement.

Alternative explanation. Crucially, it could be the case that the observed Context effects in the NUM+NOUN region are due to not having systematically controlled for the roundness or the preciseness of the number modified by *at least*. *At least* has been found to be more frequently used with round numbers than with non-round numbers (cf. corpus study data by Westera & Brasoveanu, 2014) and one could also expect its use to be incompatible with precise numbers vs. imprecise numbers taking into consideration the granularity level set by the noun (cf. losing *at least* 2.3kg vs. *at least* 2.5kg). Given that, people might have found unnatural the use of a non-round or a precise number with *at least* by an ignorant speaker (with partial knowledge of the number at stake, see example item). This could explain the slowdown found in the NUM+NOUN region in Ignorance contexts. We ran further analyses in order to investigate the possibility that the Context effects we found were confounded by the roundness of the numbers used or by their preciseness. These new analyses (reference levels: round numbers & imprecise numbers, respectively) too showed a positive main effect of Context in multiple measures (both first and subsequent pass, all $p < .05$): Items with Ignorance contexts were costly in round and in imprecise numbers, as contrasted with items with Authority contexts.

Conclusions. We take the slowdown attested in Ignorance contexts in the region following AT LEAST to suggest that it is an effect arising after the interpretation of the whole modified numeral is completed, which, similarly to Breheny et al.'s and Panizza et al.'s studies, is to be attributed to the derivation of a pragmatic inference, that of ignorance here. This would go against a semantic account of ignorance effects with *at least* (cf. Geurts & Nouwen, 2007). Rather, it would be in line with a pragmatic account, be it in the neo-Gricean style of Büring (2008), Kennedy (2015), or Schwarz (2013), who derive ignorance inferences with *at least* as a type of scalar implicature, or à la Coppock & Brochhagen (2013), who derive them via another independently motivated pragmatic principle (i.e., the maxim of Interactive Sincerity).

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