

The processing cost of interpreting superlative modifiers and modals

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Abstract

Superlative modifiers like *at least* and *at most* pose several challenges to formal semantic and pragmatic analyses. A particular challenge is accounting for the ignorance inferences they give rise to, and whether to attribute these inferences to the lexical semantics, the semantic combinatorics, pragmatic implicature, or the interaction thereof. We conducted a self-paced reading study in order to adjudicate between the various analyses proposed for superlative modifiers, taking their interaction with deontic modals as a test case. In the experiment, we aimed to determine which superlative modifier-deontic modal combinations are correlated with which readings as well as the time-course of the interpretation of these expressions in order to better adjudicate between competing analyses. We found that some superlative-modifier combinations have a clear response pattern coupled with faster processing-time and argue that this is an indication that they give rise to an authoritative reading that comprehenders favoured. When such reading wasn't available, participants resorted to a repair mechanism to generate an authoritative reading that is not compositionally available, which came at a processing cost.

Keywords: superlative modifiers; modified numerals; ignorance inferences; experimental pragmatics.

Superlative modifiers and ignorance inferences

Superlative modifiers like *at least* and *at most* have received a lot of attention recently in the semantics and pragmatics literature. A particular challenge for formal analyses comes from the fact that these expressions give rise to ignorance inferences (Geurts & Nouwen, 2007; Nouwen, 2010). For example, *at least 50 minutes* in (1) implies that the speaker is unsure about the baking time and for all she knows, the cake could have baked for exactly 50 minutes or longer.

(1) The cake baked for **at least** 50 minutes.

A number of analyses have been proposed to account for the ignorance inferences of superlative modifiers, ranging from analyses that attribute speaker ignorance to the lexical semantics to accounts deriving speaker ignorance as a pragmatic implicature. A crucial test case for these analyses is provided by the pattern of interactions of superlative modifiers and modals. As first observed by Geurts and Nouwen (2007), ignorance inferences can be suppressed in certain combinations of superlative modifiers and deontic modals. For example, when *at least* co-occurs with a necessity modal, as in (2), the so called authoritative reading is possible where *50 minutes* specifies the lower bound of the range of allowed values, i.e. 50 minutes and longer baking times are allowable, but not baking times shorter than 50 minutes.

(2) The cake **has to** be baked for **at least** 50 minutes.

The existing analyses of superlative modifiers, which will be discussed in more detail in the following section, make different predictions regarding which combinations of superlative modifiers and modals are able to suppress ignorance inferences and what the available readings are in terms of the lower and upper bound of the range of permissible values.

We conducted a self-paced reading study to determine which superlative modifier-deontic modal combinations are correlated with which readings as well as the time-course of the interpretation of these expressions in order to better adjudicate between competing analyses.

Analyses of superlative modifiers

This section provides a brief overview of existing accounts of ignorance inferences arising with superlative modifiers focusing in particular on the predictions these analyses make regarding the interaction of superlative modifiers and deontic modals.

Ignorance inferences as lexical entailments (Geurts & Nouwen, 2007)

In Geurts and Nouwen's analysis, ignorance inferences are hardwired into the lexical meaning of superlative modifiers. According to their analysis, *at least n A are B* means that the speaker is certain that there is a set of *n* As that are B and considers it possible that there is a larger set of As that are B. *At most n A are B* means that the speaker considers it possible that there is a set of *n* As that are B and is certain that there is no larger set of As that are B.

Regarding the interaction with modals, Geurts and Nouwen assume a rule of modal concord, which strips off the layer of epistemic modality just in case the primary epistemic operator in the lexical entry of the superlative modifier (epistemic necessity for *at least*, epistemic possibility for *at most*) matches the modal force of the modal. This predicts that authoritative readings not conveying speaker ignorance are available if *at least* is combined with a necessity modal (cf. 3a) and *at most* with a possibility modal (cf. 6a). As modal concord is assumed to be optional, the speaker insecurity reading is also predicted to be possible in these cases (cf. 3b and 6b). In the other two combinations – *at least* plus possibility and *at most* plus necessity modal – given that the epistemic modal in the superlative modifier and the deontic modal do not correspond in their modal force, modal

concord is not possible and thus only the speaker insecurity reading is available (cf. 5b and 4b).

Nouwen (2010)

Nouwen (2010) derives ignorance inferences from a covert epistemic possibility modal embedded under the superlative modifier. He proposes that superlative modifiers are degree operators indicating minima (for *at least*) or maxima (for *at most*). The proposal builds on two additional assumptions. The first is that numerals and measure phrases are generally ambiguous between a lower- and a double-bounded meaning. Nouwen's second assumption is that linguistic expressions compete: If a certain meaning can be expressed by two or more expressions differing in their complexity, the simpler expression is preferred and more complex expressions are blocked. The components of the analysis, taken together, predict that in many cases superlative modifiers cannot be used because the resulting sentences either express a contradiction or a meaning that is equivalent to the sentence with a bare numeral and thus blocked. To rescue such sentences, Nouwen (2010) argues that a covert epistemic possibility modal can be inserted in the scope of the superlative modifier. If the speaker is unsure about the exact value, i.e. the value varies across the worlds epistemically accessible to the speaker, the superlative modifier applies to a degree property denoting a range of values. This results in non-contradictory truth-conditions, which are not expressed by the bare numeral and thus not blocked.

As a possibility modal rescues a sentence with a superlative modifier, there is no need to insert an additional covert epistemic one in cases with an overt possibility modal. Nouwen's account thus predicts that authoritative readings always arise if *at least* and *at most* take scope over a deontic possibility modal (cf. 4a and 6a). (The narrow scope readings are either contradictory or blocked by the bare numeral.)

When combined with necessity modals, Nouwen's analysis predicts that neither *at least* nor *at most* expresses sensible truth-conditions, because the narrow as well as the wide scope readings are either contradictory or blocked. But we can assume that these combinations too can be rescued by inserting a covert epistemic possibility modal in the scope of the superlative modifier and above the deontic necessity modal, resulting in the speaker insecurity reading (cf. 5b). Nouwen (2010) moreover proposes that a necessity modal is interpreted as a possibility modal when minimality is at stake, such that *at least* plus necessity modal comes out equivalent to *at least* plus possibility modal and thus has the authoritative reading (cf. 5a).

Ignorance inferences as quantity implicatures

Another line of research, pioneered by Büring (2008) and taken up by Schwarz (2011, 2013) and Kennedy (2013), derives ignorance implications of superlative modifiers as pragmatic inferences, more precisely as quantity implicatures in a neo-Gricean fashion. While the different proposals differ in the details, the key idea is that utterances with superlative modifiers are obligatorily considered against alternative,

more informative utterances. In case of unembedded occurrences of superlative modifiers, the scalar alternatives are symmetric, i.e. they cannot simultaneously be false while the assertion is true. In this case ignorance implications rather than scalar implicatures are generated, similarly to the pragmatic mechanism that gives rise to ignorance inferences in disjunction (see Sauerland, 2004).

These pragmatic accounts also predict that ignorance inferences can be obviated when superlative modifiers are combined with necessity modals. When *at least* and *at most* are interpreted in the scope of a necessity modal, the scalar alternatives are not symmetric, and consequently scalar implicatures rather than ignorance implications are generated, giving rise authoritative readings (cf. 3a, 5a). In addition, speaker insecurity readings (cf. 3b, 5b) are available from an LF where if *at least* or *at most* takes wide scope over a necessity modal. In these cases the scalar alternatives are symmetric leading to ignorance implications (cf. 3b and 5b).

For combinations with possibility modals, the neo-Gricean approach predicts obligatory ignorance inferences for both *at least* and *at most* (cf. 4b and 6b), because the narrow as well as the wide scope readings lead to symmetric scalar alternatives and thus to ignorance implications.¹

Coppock and Brochhagen (2013)

Coppock and Brochhagen (2013) also take a pragmatic approach to the ignorance inferences arising with superlative modifiers, but cast their analysis in a different framework, namely Inquisitive Semantics. They analyze superlative modifiers as expressions denoting sets of alternatives ("possibilities" in Inquisitive Semantics parlance) that are ranked at least as high (for *at least*) or at most as high (for *at most*) according to some pragmatic ranking. Speaker ignorance is attributed to a Maxim of Interactive Sincerity, according to which a speaker should only utter a sentence denoting a set of alternatives if her information state is consistent with those alternatives.

Regarding the interaction with modals, we again have to consider the wide and narrow scope configurations. The configuration where a superlative modifier takes wide scope over a modal denotes a set of alternatives, just as unembedded cases of superlative modifiers, and thus gives rise to ignorance implicatures (cf. 3b, 5b, 4b and 6b).

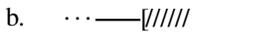
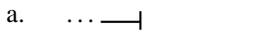
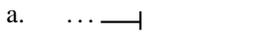
If superlative modifiers take narrow scope under a modal, no ignorance inferences arise due to Existential Closure, which applies in the scope of modals and whose function is to gather all the alternatives into a single proposition corre-

¹ An obvious way to extend the pragmatic account would be to build on the fact that disjunction in combination with possibility modals leads to free choice inferences, which would go beyond the neo-Gricean approach (see Fox (2007) among others). If we assume that the Büring-Schwarz-Kennedy-account can be extended along the line of free choice, we would expect that both *at least* and *at most* give rise to authoritative readings under possibility modals. The predictions of this extended version of the analysis would then be equivalent to the ones discussed for the account of Coppock and Brochhagen (2013).

sponding to the disjunction of all these alternatives. Coppock and Brochhagen (2013) therefore predict that for each superlative modifier-modal combination, both a reading with and without speaker ignorance is possible. In the scope of a necessity modal, *at least* and *at most* specify the lower and upper bound of the deontic range, respectively (cf. 3a and 5a). For *at most n* in the scope of a possibility modal, Coppock and Brochhagen (2013) argue that the resulting reading, which says that values up to *n* are permissible, is strengthened by an exhaustivity implicature, according to which values higher than *n* are not permissible (cf. 6a). The same reasoning should apply to *at least n* in the scope of a possibility modal: The truth conditions derived from this structure specify that *n* and higher numbers are permissible and are subsequently strengthened by an implicature to the effect that lower numbers are not permissible (cf. 6b). Note that this strengthening by implicature effectively makes *at least* + \diamond equivalent to *at least* + \square , and *at most* + \diamond equivalent to *at most* + \square .

Summary of predictions

For the following discussion, it will be useful to summarize and graphically illustrate the readings predicted to be available by the different analyses. The straight line signifies the range of permissible paper lengths, which we will also call the deontic range, the shaded area (marked with forward slashes) signifies the epistemic range, i.e. the range of values that for all the speaker knows might or might not be permissible.

- (3) \square + *at least n*:
 - a.  G&N, N, B/S/K, C&B
 - b.  G&N, B/S/K, C&B
- (4) \diamond + *at least n*:
 - a.  N, C&B
 - b.  G&N, B/S/K, C&B
- (5) \square + *at most n*:
 - a.  B/S/K, C&B
 - b.  G&N, N, B/S/K, C&B
- (6) \diamond + *at most n*:
 - a.  G&N, N, C&B
 - b.  G&N, B/S/K, C&B

Experimental study

Research question

We see that all the analyses discussed here make clear predictions regarding (i) which combinations of superlative modifiers and modals can suppress ignorance inferences and give rise to the authoritative reading and which only have a speaker insecurity reading, and (ii) whether the respective reading is in terms of upper or lower bound of permissible values. As the discussion in the previous section made clear, the different analyses vary considerably regarding their predictions. The aim of the experiment we report on here is to determine which

readings predicted by the various analyses are in fact borne out and whether the time-course of the detected interpretations could shed light on the semantic and pragmatic complexity of the inferences required to arrive at the attested interpretations.

Methods

We conducted an incremental self-paced reading experiment, in which 40 German speakers (27 Female, Mean Age: 24.5) read scenarios like the following. The CONTEXT (7) introduced two interlocutors, where Speaker A asked Speaker B for information. The context left open whether Speaker B had the relevant knowledge and was presented sentence for sentence.² Speaker B then provided the requested information in the form of an UTTERANCE (8), which included a necessity (\square , e.g., *muss* ‘must’) or possibility (\diamond , e.g., *darf* ‘can’) deontic modal and a superlative modifier (*mindestens* ‘at least’ or *höchstens* ‘at most’). The utterance was then followed by a DESCRIPTION sentence (9), in which the number was either lower (UNDER CONDITION) or higher (OVER CONDITION) than the one used in B’s utterance. The utterance and description sentences were introduced on the screen incrementally as with the context, but unlike the context, they were introduced region by region (and not sentence by sentence), where each region was a constituent (see 8-9 for illustration.) Then, participants were asked whether the description was in accordance with the utterance.

- (7) CONTEXT: (German)

John möchte einen Kuchen backen. | Deshalb fragt er seine Mutter nach dem Rezept für seinen Lieblingsskuchen. | Nachdem er alle Schritte befolgt hat, schiebt er den Kuchen in den Ofen. | Da er nicht möchte, dass der Kuchen verbrennt oder roh ist, fragt er seine jüngere Schwester Lisa, wie lange er den Kuchen backen soll. | Sie sagt ihm: |

CONTEXT: (English translation)

John wants to bake a cake. | So he asks his mother for the recipe of his favourite cake. | After he follows all the instructions, he puts the cake in the oven. | As he doesn’t want the cake to be under- or over-baked, he asks his younger sister Lisa how long he should bake the cake for. | She tells him: |

- (8) UTTERANCE:

²The vertical lines represent breaks in the text, and participants were required to press the space bar to view the subsequent text chunk.

Region 1	Modal	Superlative Modifier	Region 4	Region 5
„Der Kuchen	{ darf muss }	{ mindestens höchstens 50 Minuten }	im Ofen	backen.”
“The cake	{ can has to }	{ at least at most 50 minutes }	for the oven	bake.”

“The cake {can / has to} bake in the oven for {at least / at most} 50 minutes.”

(9) DESCRIPTION:

			Evaluation region	
John	bäckt	den Kuchen	{ 47 53 }	Minuten lang.
John	baked	the cake	{ 47 53 }	minutes long.

“John baked the cake for {47 / 53} minutes.”

The task presented here is adapted from an off-line study of superlative modifiers and deontic modals in English (McNabb & Penka, 2014).

The purpose of the online task was two-fold: First, we wanted to see whether some of the superlative modifier-modal combinations are more difficult to interpret and thus lead to processing difficulty. We expect such an effect to manifest itself in two main regions: the first one being the superlative modifier region in the utterance (8) and any spill-over effects in the following regions, and the second one being the EVALUATION REGION, in which a precise value is specified in the description sentence ({47 / 53} minutes in (9)) and where we hypothesize participants arrived at a decision.

Second, we aimed to determine what the preferred readings were for the various superlative modifier-modal combinations in terms of upper and lower bound of permissible values. To see how our task allows us to determine the preferred readings, consider the two readings predicted by the various analyses for □ + *at least* illustrated in (3). Under the authoritative reading in (3a) only higher values than *n* would be allowable when *at least n* is combined with a necessity modal. Therefore, we expect to get No responses in the Under condition and Yes responses in the Over condition. Under the speaker insecurity reading in (3b), the speaker is unsure about the minimally-required number and thinks that the lower bound of the deontic range might be *n* or more. Therefore, again, we expect to get No responses in the Under condition. But since the speaker only considers it possible, but is not certain, that *n* or higher numbers are permissible, both Yes and No responses in the Over condition are compatible with this reading.

Results

In presenting the results of our study, we start with the preferred readings in terms of lower and upper of permissible values. We found that three of the superlative modifier-modal

combinations led to clear interpretations, namely *at most* with either □ or ◇ and □ + *at least*. As shown in Table 1, in the □ + *at least* combination, the vast majority of participants accepted the description in the Over Condition and rejected it in the Under Condition. This means that the number was interpreted as denoting the lower bound. The number in the □ + *at most* combination was interpreted as specifying the upper bound, shown by the lower Yes rates in the Over Condition. In the ◇ + *at most* combination, the number is interpreted as the upper bound, shown by the fact that most participants rejected the description of in the Over Condition and accepted it in the Under Condition.

The pattern we found for ◇ + *at least* is less clear cut. Participants tended to choose the lower-bound reading, as shown by the fact that participants said Yes in 85.89% of the cases in the Over condition. But in the under condition, in a reliable minority (23.36%) of the cases, values lower than the ones specified by the modified numeral (e.g. 47 minutes in (9)) were accepted ($W = 16297, p < 0.01$), which is incompatible with the lower-bound reading.

Table 1: Means of “Yes” Responses

Discrepancy Condition	□ + <i>at least</i>	◇ + <i>at least</i>	□ + <i>at most</i>	◇ + <i>at most</i>
Over	94.56%	85.89%	5.13%	1.67%
Under	2.87%	23.36%	89.83%	93.57%

As shown in Figure 1, the reading times in the utterance were significantly longer for *at least* following ◇ and *at most* following □ both for the superlative modifier region and region 4. There was no main effect of superlative modifier or modal but there was an interaction between the two (Superlative modifier region: $F_{Within}(1,1548) = 5.36, p < 0.05$; Region 4: $F_{Between}(1,36) = 7.14, p < 0.05$; $F_{Within}(1,1503) = 25.21, p < 0.01$).

We have found a few significant differences in the reading times of the evaluation region of the description sentence. An ANOVA of the evaluation region shows no main effect of superlative modifier but a significant interaction between superlative modifier and modal ($F(1,1472)_{Within} = 6.68, p < 0.01$). Comparing specific conditions with a sufficient number of observations, we have found the arriving at a No answer in the under condition—that is, ruling out values lower than the numeral modified by *at least*, thereby interpreting it as specifying the lower bound—in the ◇ + *at least* condition took significantly longer than arriving at the same answer in the □ + *at least* condition ($W = 14968, p < 0.05$). In addition, arriving at a Yes answer in the under condition—that is, not interpreting the modified numeral as specifying the lower bound—in the □ + *at most* condition took significantly longer than arriving at the same response in the ◇ + *at most* ($W = 15350.5, p < 0.01$). This difference suggests that suggesting that □ + *at most* is more difficult to interpret than ◇ + *at most* despite the clear response pattern shown in Table 1. No other comparisons reached significance.

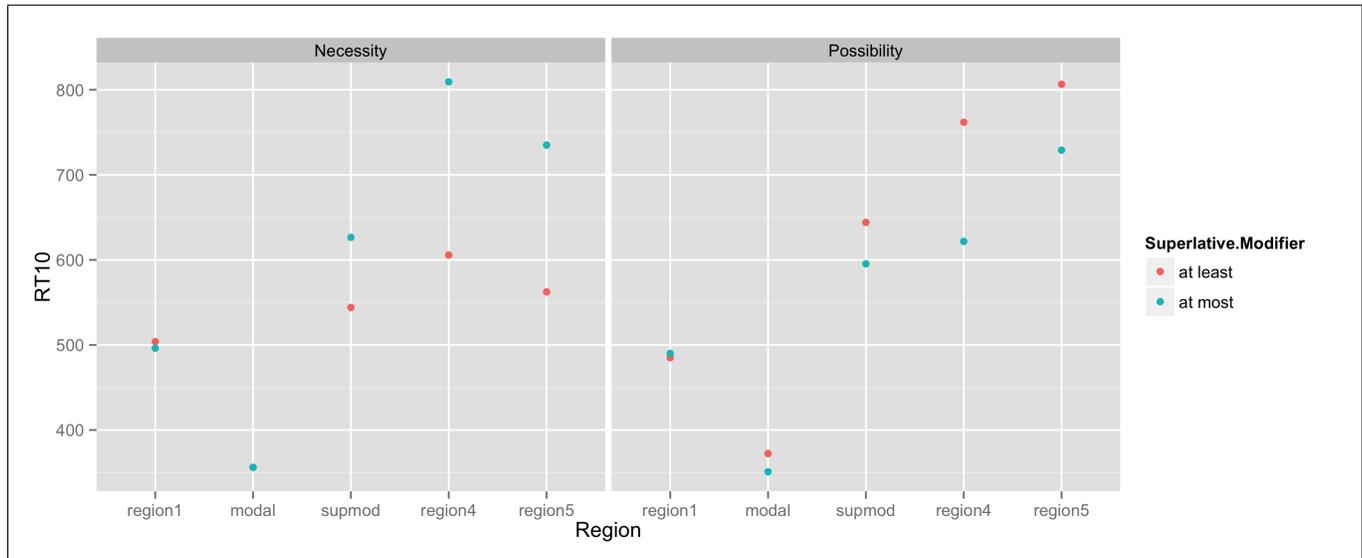


Figure 1: Reading Times per Region in the Utterance

Table 2: Means reading times of the evaluation region in the description sentence

Condition	Reply	\square + at	\diamond + at	\square + at	\diamond + at
		least	least	most	most
Over	Yes	930.64	1135.21	784.87	725.23
	No	584.20	987.10	950.99	1008.57
Under	Yes	685.54	1239.54	1207.14	1095.43
	No	938.37	1204.68	814.01	781.88

Discussion

Before we considered the results in light of the predictions the various analyses make regarding the interpretation of superlative modifiers embedded under modals, a few remarks regarding what the results teach us about the inferences comprehenders make regarding the speaker’s epistemic state and the preference for pragmatic strength and informativity.

Recall that the contexts presented in the target items left open whether Speaker B had the relevant knowledge that would enable her to make a precise statement about the value in question. It is nevertheless likely that participants assumed that the speaker was informed about the topic the utterance pertained to. For instance, in the example stimulus in (7), that John’s sister should know how long the cake should be baked for may be inferred from the fact that he asked her for such information. Comprehenders’ likely assumption that the speaker is in the position to provide the information in the utterance is related to the concept of epistemic authority in psychology and sociology, whereby individuals attribute high confidence to information provided by a source they identify as epistemic authority, consequently often assimilating it to the common ground as uncontested truth (Kruglanski, 1989). What is relevant to this study is that even in contexts in which

the knowledge of the speaker was underdetermined, it could be that participants inferred that the speaker did in fact have sufficient information and thus participants would favour the authoritative reading.

The observation that our task might have biased participants towards authoritative readings is important for the interpretation of our results in two respects. We assume that authoritative readings are faster and easier to compute as well as preferred when a competing, speaker-uncertainty reading is also available. We therefore expect that in those cases where a modal-superlative modifier combination gives rise to both the authoritative and uncertainty reading, participants would prefer the authoritative reading and ignore the speaker uncertainty reading (for the purpose of the task used in this experiment), although the uncertainty reading is a theoretically possible and coherent reading. Moreover, we interpret significantly prolonged reading times of a certain type of superlative modifiers following a certain type of modal in comparison with the reading times of the same type of superlative modifiers following a different type of modal as an indication that the authoritative reading is unavailable for this combination.

As we turn to comparing the results of our study with the predictions of the different analyses, let us start with the processing costs, namely the reading times of the superlative modifier in the utterance, depending on which modal it followed. Recall that we found that two combinations, \diamond + at least and \square + at most, show significantly longer reading times in the utterance than the other two combinations. This is in line with Geurts and Nouwen’s (2007) analysis, who argue that \square + at least and \diamond + at most go together naturally in the sense that they are able to express an authoritative reading, while for \diamond + at least and \square + at most only the speaker insecurity reading is available. Under the analysis of Nouwen (2010), under which superlative modifiers go well together

with possibility modals, it is unexpected that $\diamond + at\ least$ is harder to process. Under Neo-Gricean accounts of ignorance inferences of superlative modifiers (Büring, 2008; Schwarz, 2011, 2013; Kennedy, 2013), in contrast, we would expect that superlative modifiers preferably combine with necessity modals to yield an authoritative reading. This is at odds with our finding that *at most* is harder to process when it combines with \square than when it combines with \diamond . Finally, Coppock and Brochhagen (2013) predict that for all of the combinations, both the authoritative and the speaker insecurity reading are available, which should make all combinations equally natural and comparable in processing, contrary to our results.

In order to compare the readings in terms of upper and lower bound of permissible values predicted by the various analyses with our findings, it is helpful to measure the results against the predicted readings summarized in (3)-(6) against our results in Table 1.³

- (10) $\square + at\ least\ n$:
 - a. $\text{—————} \dots$ G&N, N, B/S/K, C&B
 - b. $\text{//////—} \dots$ G&N, B/S/K, C&B
 - c. 2.87% < 94.56%
- (11) $\diamond + at\ least\ n$:
 - a. $\text{————} \dots$ N, C&B
 - b. $\dots\text{——}//////$ G&N, B/S/K, C&B
 - c. 23.36% < 85.89%
- (12) $\square + at\ most\ n$:
 - a. $\dots\text{——}$ B/S/K, C&B
 - b. $//////\text{——} \dots$ G&N, N, B/S/K, C&B
 - c. 89.83% < 5.13%
- (13) $\diamond + at\ most\ n$:
 - a. $\dots\text{——}$ G&N, N, C&B
 - b. $\dots\text{——}//////$ G&N, B/S/K, C&B
 - c. 93.57% < 1.67%

Starting with the combination $\square + at\ least$, for which we found a clear response pattern, it turns out that the predictions of all four analyses are compatible with our results. For $\square + at\ least$, greater values than *n* were accepted in 94.56% of the cases, while lower values were rejected in 97.13 % of the cases cf. (10c), as expected under the authoritative reading (10a), which according to all of the analyses is predict to be available. The additional, weaker, reading in (10b) may be available as well, but as discussed above, we hypothesize that when participants are faced with a choice between a strong and a weak reading, they will tend to choose the strong one.

³The response patterns in the current study in German replicated for the most part the response patterns in the English study in (McNabb & Penka, 2014), except for the rates for $\square + at\ most$ in German, which were different for those for $\diamond + at\ most$ in English but not in German. Accounting for this difference between German and English goes beyond the scope of this paper.

Turning next to $\diamond + at\ most$ in (13), we found that only smaller values than *n* were accepted. This result too is compatible with the predictions of all of the analyses. Although the Neo-Gricean approach (Büring, 2008; Schwarz, 2011, 2013; Kennedy, 2013) only predicts the speaker insecurity reading (13b) to be available for this combination, participants accepting lower values in the vast majority of the cases is compatible with this reading. As explained before, under this reading, the speaker is not sure whether values in the epistemic range are permissible or not. Since participants were forced to decide whether the number in the description sentence was in accordance with the utterance or not and didn't have the option to hedge their response, we take the high rate for Yes responses to indicate that values in the epistemic range were interpreted as permitted values in spite of the possibility that the speaker may not be entirely certain whether these values are permitted.

The remaining two combinations, $\diamond + at\ least$ and $\square + at\ most$ are more interesting, as here the different analyses make contrasting predictions.

For $\diamond + at\ least$ we found that greater values than *n* were accepted in 85.89% of the cases, but smaller values were still accepted in about a quarter of the cases. This pattern is not compatible with the predictions of any of the analyses. If the authoritative reading (11a) had been consistently available, as predicted by Nouwen (2010) and Coppock and Brochhagen (2013), this should have been the dominant reading and lower values should have been rejected. But if only the speaker insecurity reading (11b) had been available, lower values should have been consistently accepted. So this mixed pattern suggests that in about a quarter of the cases, participants got the speaker insecurity reading, while in the majority of cases they got the authoritative reading.

For $\square + at\ most$, our results are compatible with the predictions of the pragmatic accounts, the Neo-Gricean approaches (Büring, 2008; Schwarz, 2011, 2013; Kennedy, 2013) on the one hand and Coppock and Brochhagen (2013) on the other. These analyses predict an authoritative reading where the modified numeral specifies the upper bound if the deontic range (12a). This is the reading participants preferred, as shown by the fact that lower values were accepted in about 90% of the cases, higher values were rejected in the majority of the cases. If only the speaker insecurity reading (12b) were available, as predicted by Geurts and Nouwen (2007) and Nouwen (2010), lower values should have been consistently accepted.

So how can our data best be explained in light of the available theoretical analyses? Since there are two groups of superlative modifier-modal combinations differing in the processing costs they incur, the first conclusion is that two combinations, namely $\square + at\ least$ and $\diamond + at\ most$, go together more naturally than the other two combinations ($\diamond + at\ least$ and $\square + at\ most$). If we take into account that our task may have bias participants towards authoritative readings, the lower processing costs we observed for $\square + at\ least$ and $\diamond +$

at most can be interpreted as indicating that the authoritative reading is available for these combinations, but not for the other two. This is in line with the analysis of Geurts and Nouwen (2007), but not any of the others.

We further hypothesize that the higher processing costs we observed for $\diamond + \textit{at least}$ and $\square + \textit{at most}$ might be due to some kind of repair strategy, to which participants resorted in order to derive authoritative readings for combinations for which these readings are not compositionally available. Since the authoritative reading wasn't available for these superlative modifier-modal combinations, participants may have re-analyzed the modal in order to derive a reading, namely an authoritative reading, which would assist in making a clear-cut decision. In the case of $\diamond + \textit{at least}$ and $\square + \textit{at most}$, the only possible compositional reading is one in which all values are potentially allowed, some within the deontic range and some within the epistemic range (that is, the speaker cannot rule out any values, modulo pragmatic restrictions involving relevance). This unrestricted reading may have been felt to be at odds with the speaker's utterance, which included two expressions that normally communicate restriction, namely deontic modals and superlative modifiers. Participants might have therefore decided that the reading conveying speaker ignorance was not felicitous and opted to reanalyze the modal to arrive at an authoritative reading. This could also explain why we got mixed results for $\diamond + \textit{at least}$: It seems that in the majority of cases, participants opted for the strong reading that necessitated modal reanalysis, but in the minority of cases, participants nevertheless opted for the compositional reading conveying speaker ignorance. This does not seem to carry over to the combination $\square + \textit{at most}$, for which we also found higher processing costs but a more clear-cut pattern of preferred readings.

Acknowledgments

We thank audiences at the universities of Konstanz, Tübingen, and Chicago, ZAS Berlin, and at *CUNY 2014*. We have especially benefited from conversations with Oliver Bott, Irene Heim, Itamar Francez, Chris Kennedy, Manfred Krifka, Rick Nouwen, Fabian Schlotterbeck, and Maribel Romero. Ali Eglimez, Vasiliki Erotokritou, and Bianca Vesper were very helpful with creating, editing and translating stimuli and running experiments. We also gratefully acknowledge funding from the DFG and the Zukunftskolleg at the University of Konstanz.

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