When Pragmatics Helps Syntax: An Eye Tracking Study on Scope Ambiguity Resolution in 4- to 5-Year-Old Children

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1. Introduction
1.1. Theoretical Background

Sentences with multiple scope-taking operators often lead to interpretational ambiguity. Consider the sentence in (1).

(1) All pirates did not return to the ship

The sentence in (1) contains a subject-position universal quantifier *all* and negation, and it can be assigned two interpretations. The *surface scope* interpretation is exemplified in (2a), and corresponds to a reading where the operators are interpreted in the order in which they appear in the sentence. Under the *inverse scope* interpretation, the operators are interpreted in an inverse order with respect to the sentence, as exemplified in (2b).

(2) a.   surface scope: All pirates are such that they did not return to the ship
$\forall$x [pirate(x) $\rightarrow$ ¬ return_to_the_ship(x)]
     b.   inverse scope: It is not the case that all pirates are such that they returned to the ship
¬$\forall$x [pirate(x) $\rightarrow$ return_to_the_ship(x)]

While (2a) is only true in a context where none of the pirates returned to the ship, (2b) is true when no pirates or some but not all of the pirates returned. Notice that (2a) asymmetrically entails (2b): in each context in which (2a) is true, (2b) will be true as well, but not vice versa. The surface scope interpretation is thus logically stronger than the inverse scope interpretation.

The sentence in (1) may also receive a third interpretation that is semantically distinct from (2a) and (2b), and comes about through pragmatic strengthening. As the interpretation in (2b) enters in a scalar relationship with the logically stronger alternative (3a) in which the quantifier *no* is substituted for *not all*, given the negative scale <*not all*, *no*> (cf. Horn 1989, Levinson 2000),

the scalar algorithm can generate the strengthened interpretation in (3b) via an indirect scalar implicature (Chierchia 2004).

(3) a. stronger alternative of (2b):
        No pirate returned to the ship
        $\neg \exists x$ pirate(x) $\rightarrow \neg$ return_to_the_ship(x)
   b. strengthened interpretation of (2b):
        It is not the case that all pirates are such that they returned to the ship, but some of them did.
        $\neg \forall x$ [pirate(x) $\rightarrow$ return_to_the_ship(x)] &
        $\exists x$ [pirate(x) & return_to_the_ship(x)]

Critically, the strengthened interpretation in (3b) is only true in a scenario in which some but not all of the pirates returned to the ship. It is logically stronger than (2b), but semantically distinct from the surface scope reading in (2a): the truth of the strengthened (3b) entails the falsity of (2a).

1.2. Previous developmental studies

Children's interpretation of scopally ambiguous sentences has been the topic of extensive research in the last two decades, and the questions concerning children's capacity to access both scopal interpretations of (1) and their possible preferences for one or another interpretation have received different answers. Early studies (Musolino 1998, Musolino, Crain and Thornton 2000) found that English-speaking children almost uniquely adopt surface scope interpretations of sentences including subject-*every* and negation. Musolino et al. (2000) investigated 5-year-old children's interpretation of sentences such as (1) using the Truth-Value Judgment Task (TVJT, Crain and Thornton 1998). In the TVJT, an experimenter-controlled puppet describes a scene acted out with props and toys. Participants must judge whether the puppet's description of the visual scene is right or wrong. Musolino et. al found that when the experimental sentence was used as a description of a story in which the surface scope interpretation was false and the inverse scope interpretation was true, adults accepted the sentence uttered by the puppet, while children consistently rejected it. For example, in a story where three horses had debated jumping over a fence, and only two of them consequently jumped, the subjects had to decide whether the sentence 'Every horse didn't jump over the fence' was true or not. Children uniformly rejected the puppet's statement as a true description of what happened in the story, which Musolino et al. took as evidence for them not being able to access the inverse scope interpretation. The reasoning behind this conclusion was based on the Principle of Charity (Grice 1975, Davidson 1984): if both scopal interpretations are available and one of them makes the sentence false, the interpreter will tend to select the one making the sentence true. Therefore, as

children rejected the sentence, they could not access the interpretation that would have made the sentence true.

Further experimental work revealed that under certain contextual manipulations, children fare better at accessing inverse scope interpretations. Gualmini et al. (2008) and Musolino and Lidz (2006) first showed that while children are in fact capable of assigning an inverse scope interpretation to sentences like (1) and (3), their doing so depends on the experimental context. Gualmini et al. argued that the previous results were due to the infelicity of the negative sentences used in these experiments, as they did not entail an answer to the Question Under Discussion (QUD). They ran an experiment using the TVJT where both surface and inverse scope interpretations were made salient and constituted good answers to the QUD, while using a prosodic contour that is naturally associated with inverse scope interpretations. They found that children accepted the inverse scope scenario in 80% of the trials. Musolino and Lidz (2006) also obtained a boost in the inverse scope acceptance rate from 15% to 55% by presenting affirmative statements involving a universal quantifier before the test sentences, and Viau, Lidz and Musolino (2010) saw a rise from 20-40% to 80% of inverse scope interpretations by semantically priming inverse scope. Finally, Conroy, Lidz and Musolino (2009) reported a split pattern of results between 4- and 5-year-old children with the rate of inverse scope interpretations being 81% in the younger group vs. 44% in the older, and suggested that while both groups struggle with revising the initial parse, only 5-year-old children show an early preference for surface scope. For this reason, younger children displayed adult-like behaviour and the developmental trajectory of scope assignment was argued to follow a developmental U-curve.

1.3. Four factors that can influence scope ambiguity resolution

If children are able to derive an inverse scope interpretation, why do they fail at deriving it in certain contexts? Which factors affect their comprehension of scopally ambiguous sentences? Several answers to these questions have been put forward in the literature. Gualmini et al. (2008) maintain that such failure is due to children's pragmatic limitations, which can be overcome by designing experiments so that the QUD is sufficiently salient. Musolino and Lidz (2006) and Viau, Lidz and Musolino (2010), on the other hand, propose that neither grammatical competence nor pragmatic competence on their own can be the source of the observed behaviour. Limited processing sources may prevent children from accessing an inverse scope interpretation, and contextual facilitation may help in overcoming this limit. Given these considerations, we aim to test the following hypothesis through the current study:

(4) The Processing Limitations Hypothesis:
    The cognitive capacities (e.g. working memory) required for structural

revision are limited in children. Since inverse scope interpretations require a revision of the initial parse, children can only access an inverse scope interpretation if they are provided with some kind of facilitation.

The hypothesis above relies on two assumptions. First, it is assumed that the surface scope interpretation is derived first, and the inverse scope interpretation is derived through a re-analysis of the initial parse. Second, it is assumed that children struggle at performing structural revisions, as was found in other developmental studies (cf. Trueswell et al. 1999). This is why they only derive inverse scope interpretations when provided with pragmatic or semantic facilitation.

A second factor that has been argued to influence children and adults' scope choices is prosody. Büring (1998) provides a description of the intonation assigned to the readings in (2a) and (2b) where the former is associated with falling intonation and a single main stress, and the latter presents a falling-raising contour with two stresses. Syrett, Simon and Nisula (2014) found that prosody affects adults' interpretation of scopally ambiguous sentences, while children have been shown to be insensitive to contrastive stress (McDaniel and Maxfield, 1992; Gualmini, Maciukaite and Crain, 2003) .

Finally, a third factor that could influence children's performance in interpreting sentences like (1) is the relationship between accessing vs. preferring a given reading. Take, for instance, Musolino's (1998) original findings. If we assumed that children can in fact access both scopal configurations but they have a strong surface scope preference for some reason (e.g. it is easier to process, more frequent in the linguistic input, etc.), the expected behaviour in the critical trials where two out of three horses jump over the fence would be identical to that reported in the study: a consistent rejection of the puppet's statement. Therefore, disentangling access vs. preference of each possible reading is critical in order to rule out this alternative interpretation.

Summing up, we identify four possible factors influencing children's interpretation of scopally ambiguous sentences such as (1): i) possible processing limitations and available parsing strategies, ii) the saliency of the QUD, iii) prosody, and iv) the influence of an interpretation preference on the final response. In the next section, we illustrate the present experiment, designed to take these factors into account.

2. The current experiment

The goal of the present study is to explore 4- to 5-year-old German children's interpretation of (1) through an experimental design that allows controlling for the factors discussed in the previous section. To achieve this goal, we employed a modification of the TVJT that we called the Semantic Choice Task (SCT). The main difference consists in the simultaneous

presentation of two contextual scenarios (SCT) instead of one (TVJT). The felicity of the negative sentence is controlled for, as more than one good answer to the QUD is visually prominent in the setup and corresponds to an actual choice option. The development of a sharp experimental design with the SCT permitted investigating separately the issues of access vs. preference of a given interpretation, and the presentation of previously recorded test sentences allowed controlling for prosody. By recording the participants' eye movements using eye-tracking, we could observe whether they display an initial preference and whether one interpretation requires more cognitive effort to be derived.

2.1. Procedure and participants

The participants were 45 4- to 5-year-old German speaking children (mean age = 61.6 months) and 50 adult controls, who took part in a computer version of the experiment. At the beginning of each session, which lasted about 45 minutes, a German-speaking experimenter introduced the children to the experimental setup. A second experimenter was responsible for acting out the story using toys. The participants were told that they were about to hear a story about some pirates and their adventures on the Fantastic Island. They were then informed that the pirates were actually actors at a theatre, belonging to two different groups: the Red pirates and the Green pirates. The task of the subject was to help the theatre director, a character that communicated with the experimenter and the subject via the telephone, in rewarding the group of actors whose acting matched more closely with the instructions of the director. The pre-recorded experimental sentences were uttered by the director during his calls and played to the participants through speakers.

The experiment was conducted on an experimental table, divided into two "theatre scenes" on which the actors played. The eye-tracker was positioned in the middle, in front of the subject sitting by the table with the experimenter. Before the start of the session, a 3-points calibration of the eye-tracking system was performed. After calibration, the experiment started with the director calling the experimenter to present himself to the subject and the experimenter. Two warm-up trials were then presented to the participants. The first warm-up trial followed the Red and Green pirates' ships being suddenly caught in a strong storm. The shaking of the ships caused all of the Green pirates to fall into the sea, while only three out of five of the Red pirates fell. The director called and uttered a warm-up sentence with a subject-position universal quantifier *alle* but no negation ("All of the pirates fell from the ship"). The experimenter then asked the participant to give a coin reward to the group of pirates whose acting corresponded better to the sentence the director uttered. Regardless of whether the child correctly rewarded the Green pirates or incorrectly rewarded the Red pirates, the experimenter then asked the subject how many pirates in each group fell into the sea, repeated the warm-up sentence, and asked again which team

performed better. When the subject rewarded the correct team, acknowledging that all of them fell, the experimenter moved on to the second warm-up trial.

After the warm-up trials, the subjects saw 16 experimental trials where the same procedure was used, except that the experimental sentence was only repeated if the child refrained from providing an answer (which happened very rarely). The computer version of the experiment also included a no-reward option, so as to verify whether the matching between sentences and scenarios was judged felicitous by adult controls. At the end of the experiment, the subject identified the winning group of pirate actors by counting the teams' coins. Children received a book for participating, and adults received 5€.

2.2. Experimental Design

The experimental design consists of three test conditions involving sentences with negation (*nicht*) and a subject-position universal quantifier (*alle*), as in (5), and one control condition involving sentences with an existential quantifier *einige* 'some' but no negation.

(5) **Alle** Piraten sind **nicht** auf das Schiff zurückgekehrt.
   '**All** of the pirates did **not** return to the ship.'

Two conditions investigate access to the surface, inverse and strengthened inverse scope interpretations of (1) (described in (2a), (2b) and (3b), respectively). The NONE-FALSE condition includes a NONE scenario (Fig. 1a), in which no pirate returned to the ship, and a FALSE scenario (Fig. 1b), in which all pirates did. The NONE scenario is compatible with surface and non-strengthened inverse scope interpretations, and a correct reward response means that either of those interpretations was adopted. The SOME-FALSE condition, in contrast, includes the same FALSE scenario vs. a SOME scenario (Fig. 1c), in which some but not all of the pirates returned. The SOME scenario is compatible with an inverse scope interpretation with or without a scalar implicature, but not with a surface scope interpretation. Thus, correctly choosing

Figure 1a (NONE)   Figure 1b (FALSE)   Figure 1c (SOME)

the SOME scenario means an inverse scope interpretation was adopted. Finally, the NONE-SOME condition investigates the participants' preference for one of the two possibly true scenarios. If children only access the surface scope interpretation of (1), they should consistently prefer the NONE scenario over the SOME scenario. If they prefer the SOME scenario or display no preference, however, we have evidence that they were able to access an inverse scope interpretation.

The experimental sentences were recorded by a German-speaking actor with a prosody that is not biased towards any of the scopal interpretations. This intonation was generally flat, involving a mild accent on the two nouns (i.e. *Piraten* and *Schiff*) and, critically, no focal stress on either negation (*nicht*) or the universal quantifier (*alle*). Adults reported that the sentences sounded quite natural despite the adopted unbiased prosody.

Eye movements were monitored through an Eye-link remote system with a 1000 Hz tracking resolution. Stimuli presentation, data processing and statistical analysis were performed with Python (www.python.org) and R (www.R-project.org).

2.3. Predictions

First of all, the experiment was designed to test whether German 4- and 5-year-old children can access inverse scope interpretations of sentences like (5) in the absence of contextual, semantic or prosodic bias. If children perform above chance in the SOME-FALSE access condition, the results provide further empirical evidence that inverse scope is accessible to young learners.

Second, if German children prefer surface scope over inverse scope, as found for English children in many previous studies, a preference for the NONE scenario over the SOME scenario is expected in the preference condition. Moreover, we expect to find an overall facilitation for surface scope responses throughout the conditions. That is, we predict to obtain higher accuracy in the NONE-FALSE access condition compared to the SOME-FALSE condition, for the former is compatible with both surface and inverse scope interpretations.

Third, we expect to find faster on-line target disambiguation for NONE scenarios vs. SOME scenarios either because surface scope is derived first (cf. the Processing Limitations Hypothesis) or because whichever interpretation is accessed first, the NONE scenarios but not the SOME scenarios are compatible with both interpretations.

In general, the Processing Limitations Hypothesis predicts higher off-line accuracy and faster on-line disambiguation in the NONE-FALSE condition compared to the SOME-FALSE condition, as well as a preference for the NONE scenario in the NONE-SOME condition.

Finally, although our experiment was not designed to contrast 4- to 5-year-old children, the children's performance might be found to vary across age with

respect to access to inverse scope interpretations. If younger children perform better than older children, the hypothesis advanced by Conroy et al. 2009 will find empirical support.

3. Results
3.1. Off-line results: Semantic choice

Adults' semantic choice results show an overall preference for the NONE scenario, compatible with both surface and inverse scope. In the NONE-FALSE condition, adults selected the NONE scenario in 80% of the trials, the no-reward option in 12% of the trials and the wrong FALSE scenario in 8% of the trials. In the SOME-FALSE condition, they selected the SOME scenario in 70% of the trials, the no-reward option in the 25% of the trials and the FALSE scenario in 5% of the trials. The difference between the two access conditions was tested in a Generalized Linear Mixed Model (GLMM) and resulted in a significant main effect of *condition* (p=.035). In the preference condition, adults showed a slight preference for the NONE scenario (48% vs. 37% of choices) and selected the no-reward option in 15% of the trials. In sum, the controls display a generally high accuracy and found the test sentences more felicitous when evaluated in a NONE scenario compared to a SOME scenario.

Strikingly, children display a rather different pattern of results. Contrary to our expectations and in contrast with what was found in the control group, they show an overall facilitation and preference for the SOME scenario, which is only compatible with an inverse scope interpretation. As children were forced to make a choice, we only report accuracy for the access conditions. Children's reward responses were correct in 65% of the trials in the NONE-FALSE condition, and 79% of the trials in the SOME-FALSE condition (GLMM main effect of *condition*: p=.000). Thus the rate of FALSE answers amounts to 35% and 21 % in the NONE-FALSE and SOME-FALSE access conditions respectively. Furthermore, in the preference condition, they showed a slight preference for the SOME scenario (56% of SOME answers).

To investigate whether the profile of decision choices varied across age, we performed a median split into two groups of children (younger than 62 months (n=22) and older than 62 months (n=23)). Both groups showed higher accuracy for the SOME vs. NONE scenario in the access conditions (young: NONE = 57% vs. SOME = 72%; old: NONE = 73% vs. SOME = 84%). In the preference condition, the younger group selected the SOME scenario in 60% of the trials, while the older group did so in 54% of the trials.

Finally, to determine whether these results were uniformly determined by all participants regardless of their comprehension rate, we conducted a further analysis by setting up a criterion of at least 3/4 correct answers in both access conditions, excluding children who did not fully understand the experimental sentences (17 out of 45). After exclusion, accuracy rose to 92% in the NONE-

FALSE access condition and to 93% in the SOME-FALSE access condition, whereas the preference condition results showed no preference at all for either scenario (49% of NONE answers). The facilitation effect for the SOME scenario was thus due to the poor comprehenders. In contrast, the 28 children with good comprehension did not show any facilitation or preference for either scenario.

3.2. On-line results: eye movement data

The aim of the eye movement analysis was to investigate how quickly participants identify the correct scenario (i.e. the NONE/SOME scenario over the FALSE one) and whether they display any difference in the two access conditions. We will first report the *target preference* analysis, which considers the proportion of fixations to the target (i.e. the correct scenario) in a given time window divided by the total fixations towards both target and distractor (i.e. the false scenario). This analysis was performed only on correct answers. In Figure 2 and 3, the target preference for the young (<62 months) and old (>62 months) children is plotted over the relevant time windows. When the target preference departs from the 0.5 line, representing the chance level, the participants developed a preference for the target in their on-line gaze.
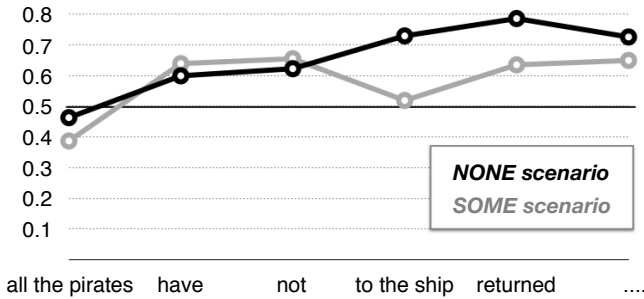
Figure 2. Target preference in children older than 62 months
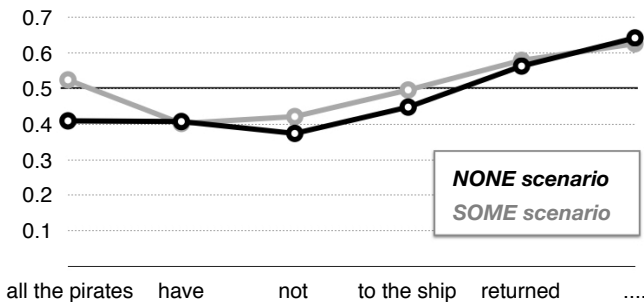
Figure 3. Target preference in children younger than 62 months

As shown by the graphs above, from the time region that includes the prepositional phrase (PP, i.e. 'to the ship'), which immediately follows negation (*nicht*), the older children display a steady preference for the target only in the NONE-FALSE condition. The same group in the SOME-FALSE condition, as well as the younger children in both conditions, display a consistent preference for the target only from the following region that includes the past participle (*zurückgekehrt* 'returned'). This difference results in a significant interaction between *age* and *condition* (p=.34) as well as a main effect of *condition* (p=.43) in the PP region. These data suggest that the on-line disambiguation of the NONE scenario, compatible with both surface and inverse scope interpretations, took place more quickly than that of the SOME scenario.

The second analysis that we present is the *shift latency* analysis, which computes the delay in making a shift from the FALSE to the NONE/SOME scenario after hearing the critical word *nicht*. Older children took on average 1218 ms to shift their looks towards the target in the NONE-FALSE condition vs. 1777 ms in the SOME-FALSE condition. Younger children took 1714 ms to shift their looks towards the target in the NONE-FALSE condition vs. 1895 ms in the SOME-FALSE condition. The statistical analysis yields significant main effects of *age* (p=.37) and *condition* (p=.42), but no significant interaction. The shift latency analysis confirms what was found in the target preference analysis, and brings further support to the idea that a) there is an on-line facilitation for the NONE scenario over the SOME scenario, and b) this effect is brought by both subgroups of children, although it is more prominent in the older children.

4. Discussion

We illustrated an experimental study investigating the off-line interpretation and on-line processing of structurally ambiguous German sentences including a subject-position universal quantifier and negation in 4- to 5-year-old children and adults. This experiment attempts to overcome the limits of previous studies in the following respects: a) it controls for prosody by pre-recording test sentences with unbiased intonation, b) it presents two visual scenarios simultaneously and allows for separate investigation of accessing vs. preferring different scope interpretations, and c) it provides simultaneously collected off-line and on-line data, crucial for addressing processing-related questions.

The first aim of this study was to investigate whether German children access inverse scope interpretations of sentences like (5) in the absence of contextual, semantic or prosodic bias. The answer to this question is affirmative. In the SOME-FALSE access condition, children displayed a very high accuracy rate, comparable to the adult rate, in rewarding the scenario that was only compatible with an inverse scope interpretation. The possibility that this outcome be due the prosody that we used, which could have favoured an inverse scope interpretation, can be ruled out: as the adult rate of no-reward answers

was higher in the SOME-FALSE condition compared to the NONE-FALSE condition, which means that the sentence was judged less felicitous in the former condition, the adults' responses attest that the adopted prosody did not bias towards an inverse scope interpretation. These results provide empirical evidence in favour of the claim put forward by Gualmini et al. (2008), who stated that children can access an inverse scope interpretation if the QUD is made salient by the experimental context. Indeed, we demonstrated the validity of this claim even in the absence of biased prosody towards inverse scope.

The second main finding is that, contrary to our expectations, the scenario that is only compatible with an inverse scope interpretation had a higher overall accuracy rate than the one compatible with both surface and inverse scope. Remarkably, the higher accuracy for SOME-FALSE vs. NONE-FALSE access conditions was significantly present in both age groups. This result cannot be explained in terms of higher visual prominency or easier processing of the SOME scenario: as witnessed by the eye movement analyses, the NONE scenario was disambiguated faster than the SOME scenario by both groups of participants. Why is it, then, that the SOME scenario was more difficult to identify, but at the same time it's selection was less error-prone in poor comprehenders?

The answer to this question is by no means a simple one if we consider that the NONE scenario is always compatible with a non-strengthened inverse scope interpretation. The only reading of (5) that is true in the SOME scenario but false in the NONE scenario is the inverse scope interpretation enriched by an indirect scalar implicature, namely, 'not all the pirates returned to the ship but some of them did'. The hypothesis that we advance to explain this finding is that the scalar implicature provided a pragmatic boost, facilitating comprehension and identification of the correct scenario in poor comprehenders. While we know from a large experimental literature that children are generally poor at calculating scalar implicatures (cf. Noveck 2001), some findings suggest that children are indeed able to derive scalar implicatures if the alternatives are made salient in the context (Papafragou and Tantalou 2004). Furthermore, recent findings by Bill et al. (2014) suggest that children's comprehension of indirect implicatures (e.g. 'not all' implicates 'not all but some') is better than that of direct scalar implicatures (e.g. 'some' implicates 'some but not all'). Thus, a pragmatic boost might well be the source of this finding.

The plausibility of this explanation can be further investigated by examining what happens on-line. Eye movement results show that the SOME scenario is disambiguated generally later than the NONE scenario. The target preference analysis shows this effect only for older children, whereas the shift delay analysis suggests that both age groups manifest this behaviour although it is more prominent in older children. If we assume that pragmatic strengthening requires the derivation of an inverse scope interpretation, and that this derivation results from the revision of a surface scope interpretation, we find that the on-

line results support this explanation. If so, the facilitating effect of pragmatic strengthening must take place late, when the difference between the SOME vs. NONE scenarios is revealed in the participants. Under an alternative explanation, surface and inverse scope interpretations are both immediately available, and the delay displayed by the SOME scenario reflects the cognitive cost of deriving a scalar implicature. In this case, the hypothesis that pragmatic strengthening facilitates the comprehension process is supported as well.

A second goal of this study was to seek evidence in favour or contra the Processing Limitations Hypothesis which assumes that surface scope is derived first and inverse scope requires a structural revision of the parse. This assumption first seems to find support in our results, given that the NONE scenario is disambiguated more rapidly than the SOME scenario. However, greater ease of disambiguation with the NONE scenario does not lead to higher accuracy in semantic choice. Instead, we find the opposite pattern, with access to the SOME scenario resulting in a facilitation for poor comprehenders, while the good comprehenders display neither facilitation nor preference for any of the two scenarios. Thus, not only does the Processing Limitations Hypothesis not find full support in our results, but we might also end up questioning the assumption that surface scope is derived first. As mentioned above, there could be another factor slowing down the target identification in the SOME scenario vs. the NONE scenario, which is the derivation of a scalar implicature.

Finally, our results do not align with those reported by Conroy et al. 2009, who found 4-year-old children to perform better than 5-year-old children at deriving inverse scope. While our younger subjects show a high accuracy rate for the scenario that is only compatible with inverse scope (the SOME scenario) in the off-line choices, the older subjects' accuracy rate was even higher.

To conclude, we demonstrated that 4- and 5-year-old German-speaking children access both surface and inverse scope interpretations of (5) in the absence of contextual, semantic or prosodic bias. Furthermore, we found that inverse scope interpretations boost the accuracy of poor comprehenders, whereas scenarios compatible with both surface and non-strengthened inverse scope are faster to disambiguate, especially in older children. We propose that these effects can be explained in terms of a pragmatic boost carried over by the derivation of an indirect scalar implicature. Further research is needed to provide more evidence for this hypothesis and to determine whether the results reported in this study are replicable in other languages, as would be expected.

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