1. Introduction
1.1. Theoretical Background

The meaning of sentences containing a universal quantifier like all embedded under negation, such as (1), can be sketched out as follows:

(1) a. The captain didn’t dance with all the mermaids.
    b. literal meaning: \( \neg \forall x [\text{mermaid}(x) \rightarrow \text{danced-with}(\text{captain}, x)] \)

Notice that (1) is compatible with a situation in which the captain did not dance with any mermaid, as shown by the felicity of the following possible continuation of (1): "...in fact he danced with none at all". Yet, these type of sentences usually give rise to pragmatic inferences called indirect scalar implicatures (ISI, cf. Chierchia 2004), which are exemplified in (2):

(2) a. The captain did not dance with all of the mermaids but he danced with some of them
    b. \( \neg \forall x [\text{mermaid}(x) \rightarrow \text{danced-with}(\text{captain}, x)] \land \exists x [\text{mermaid}(x) \land \text{danced-with}(\text{captain}, x)] \)

In (2b), which represent the meaning of (2a), the ISI (underlined) is added to the literal meaning of (1). Similarly to the case of direct scalar implicatures (cf. Levinson 2000 for a review) the pragmatically strengthened interpretation in (2) is argued to arise from the denial of a more informative proposition including a logically stronger scalar item. The stronger alternative to sentence (1) is sentence (3), where all is substituted with any.

(3) The captain did not dance with any of the mermaids
    \( \equiv \neg \exists x [\text{mermaid}(x) \land \text{danced-with}(\text{captain}, x)] \)

The denial of the alternative in (3) results in the implicature in (2). The consequence of the pragmatic enrichment of (1) via ISI is that sentence (2), unlike
(1), is no longer compatible with a situation in which the captain danced with no mermaids.

The current work is aimed to study the interpretation and processing of ISI in children and adults.

1.2. Previous Studies

While the main focal point in the experimental pragmatics literature was on direct scalar inferences, recently ISIs were investigated, specifically regarding their trajectory in language acquisition and their comparability to SIs.

In an offline experiment, Musolino and Lidz (2006) investigated how 5-year-old children respond to ISI violations. In the Truth Value Judgment Task they employed (Crain and Thornton 1998), scenes are acted out by an experimenter using toys and props; later, a puppet, controlled by another experimenter, utters the critical sentence. Participants are asked to judge whether the puppet's description of the visual scene is right or wrong. Musolino and Lidz found that, in contrast to adults, children tolerated violations of strengthened meaning contributed by the ISI; that is, they accepted the puppet’s description in (4) for a scene in which the strong guy did not put any elephant on the table; violating the stronger interference that he at least transferred some of them.

(4) The strong guy didn’t put every elephant on the table.

This is in line with experimental findings for direct SIs, where too, children are found to be tolerant of implicature violations (Katsos and Bishop 2011).

In a more recent study employing a variant of the Covered Box paradigm by Bill et al. (2016), ISIs as in (5a) provided a comprehension increase in 4-to-5-year olds over the results for the SI condition illustrated in (5b).

(5) a. Not all of the rabbits brought balls.
   b. Some of the rabbits brought balls.

Congruent with this finding, Cremers and Chemla (2014) find in their first experiment that ISIs boost comprehension times in adults and that the weak or literal readings were accessed more slowly than the strengthened ones. This contrasts with their results for the SI condition where a reversal was observed: SI strengthening incurred a cost, and was hence slower, than the unenriched semantic meaning of the target utterances. In sum, both studies provide arguments to dissociate SIs from ISIs in both offline and online measurements.

Lohiniva and Panizza (2016) tested scopally ambiguous sentences with a sentence-initial, universally quantified subjects with unbiased prosody (“All the pirates did not go to the ship”). Their results suggest that ISIs facilitate the comprehension of scope inversion in offline tasks but slowed down target identification as indicated by eye-tracking data. The authors conclude that ISIs may result in enhancing accuracy in 4- and 5-year-old children, and thus in providing a pragmatic boost, while at the same time they could have slowed town
online processing when compared to unstrengthened scenarios. In addition, the results seem to suggest a dissociation between online processing on the one hand and offline interpretation on the other.

In conclusion of this brief survey, we are faced with conflicting results. Some studies champion the idea that SIs and ISIs are characterized by comparable results with respect to their comprehension and processing: they both incur a processing cost and the violations thereof are more frequently tolerated by children than adults. Other studies suggest that ISIs seem to behave differently from SIs, in that the derivation of the former appear to be more robust in young learners and processed effortlessly by both adults and children.

The goal of the present work is to shed light on the problems outlined above. More specifically we aim to investigate the following questions related to the comprehension of ISIs:

(6) a. Do adults and children understand sentence like (1) uttered with unbiased intonation?
   b. Are ISIs interpreted by adults and children in a similar way? Does their derivation enhance comprehension and processing of sentences like (1)?
   c. Does tolerance of ISI violations decrease with age, on a par with SI violations?

2. The Current Experiment

The present study is aimed at investigating children’s comprehension and processing of sentences with ISIs, like (1) and to address the questions put forward in (6). In order to accomplish this, we employed the Semantic Choice Task (Lohiniva and Panizza 2016), which combines offline judgments in a Picture Selection Task (during which two different contextual scenarios are displayed simultaneously) with eye-movement recording as an indicator of online processing. The advantage of this methodology is that it allows us to gather information about a) the overt judgments of sentences such as (1) evaluated against scenarios that either support or violate the interpretation enriched by an ISI, and b) the time-course of disambiguation of such scenarios. The combination of this information will tell us whether sentence (1) is enriched by ISI at all, whether there is a preferential interpretation among the possible ones and whether there is any potential cost associated with ISI derivation.

2.1. Procedure and Participants

Three groups of German native speakers were tested in the experiment. The youngest, 4- to 5-year-old children, consisted of 35 participants from a Kindergarten near Göttingen (mean age = 61.2 months), Germany. 48 6-to 10-year-old children (mean age = 104.6 months) recruited from an elementary school constituted the second group. In addition, 48 students from Georg-August-University Göttingen participated as controls.
With the youngest children, the story in the context of which the critical items appeared was acted out by an experimenter using various toys and figurines. Participants were instructed that they were about to witness a story about pirates on the Fantastic Island which was acted out by two different groups: the Red and the Green pirates. Both groups were introduced as performers whose assignment it was to act out a director’s play, namely the story about the pirates’ adventures on the Fantastic Island. Subjects were then tasked with rewarding with a coin that group of pirates which best acted out the story. While the story was narrated by an experimenter, the experimental sentences were pre-recorded and presented via speakers. In addition to the task of rewarding one group of pirates (the Picture Selection Task component), an eye-tracker was placed in the middle of the experimental table, facing the subjects in order to monitor eye movements of participants. The older children as well as the adults saw a computerized version of the experiment, with the story and items displayed via stop-motion videos and pre-recorded audio.

Before the start of the experiment, a 3-point calibration of the eye-tracker was performed. Next, an experimenter introduced the experiment and proceeded with two warm-up trials, which resembled the critical sentences in that they contained the universal quantifier alle (‘all’), though they did not feature negation (“All of the pirates fell off the ship.”). After rewarding the better performing group of pirates by handing them a coin, if the child rewarded the correct group of pirates, the experimenter proceeded with the experiment; if not, children were asked to repeat the sentence, to count the number of pirates, and trained to recognize the correct scenario before progressing.

After the warm-up trials, the participants were presented with 16 experimental sentences with the procedure outlined above. At every trial participants were asked to repeat the sentence they had just heard, in order to verify that they actually heard and recognized every word, including the negative marker. If they were not able to do so, the experimenter triggered again the auditory presentation of the critical sentence and the trial was marked for exclusion. In the computer version, participants were given the additional choice of rewarding neither group of pirates to allow them to judge both scenarios as being infelicitous pairings for the experimental sentence. At the end of the experiment, which lasted approximately 35-45 minutes, children received a book, and adults were paid 7€ for their participation.

2.2. Experimental Design

The experiment featured three critical conditions consisting of German sentences where the universal quantifier (alle) was embedded under negation (nicht), as in (7), and one control condition without negation.

(7) Der Kapitän hat nicht mit allen Meerjungfrauen getanzt.
The captain has not with all mermaids danced
‘The captain did not dance with all the mermaids.’
Conditions 1 and 2 represent the so-called access condition, that is, where the access to the to the literal, ISI violating readings of sentence (7) was tested vs. its interpretation enriched via ISI. Condition 1 presented a scenario in which the captain did not dance with any mermaid (NONE, Fig. 1a) contrasted with one in which the captain was dancing with all the mermaids (FALSE, Fig. 1c). While the NONE scenario is only compatible with the literal reading of (7) (the captain did not dance with all the mermaids and he possibly did not dance with any), the NONE scenario is not compatible with any interpretation of (7). Thus, Condition 1 tests for the access to the non-strengthened reading of (7), that is the one that violates the ISI. A high accuracy in this condition witnesses the ability to access this interpretation, as well as its felicity in adults and older children.

Condition 2 presents a scenario in which the captain danced with only some of the mermaids (NALL, Fig. 1b) contrasted with one in which he did not dance with any (FALSE, Fig. 1c). This condition, thus, employs a scenario that is compatible with both readings of (7): the interpretation without ISI vs. the one enriched by an ISI (the captain did not dance with all the mermaids but he danced with some of them). If participants are able to identify the correct scenario in Condition 2, it means that they were able to access at least one of the two possible readings of (7).

Condition 3 included both possibly true scenarios, NALL vs. NONE, and it was geared towards testing participants’ preference of one scenario over the other.

The sentences were recorded by a German-speaking actor with unbiased prosody toward any of the interpretations. The prosodic contour was generally flat, involving only a mild accent on the two nouns (i.e. Kapitän and Meerjungfrauen) and, crucially, no focal stress on either negation (nicht) or the universal quantifier (alle), contrary to more biased intonational profiles, where both would receive a rather prominent contour. The reason for adopting an unbiased prosody was to allow for a direct comparison with the study by Lohiniva and Panizza (2016), who employed very similar sentences that, however, included the universal quantifier alle in subject position. Adults reported that the sentences sounded quite natural despite the adopted unbiased prosody.

Eye movements were monitored using an Eye-link remote system with a 1000 Hz tracking resolution. Stimuli presentation (in case of the computer version of the experiment), data processing and statistical analysis were performed with Python (www.python.org) and R (R Core Team 2018).
2.3. Predictions

The present experiment is designed to investigate how children and adults comprehend sentences such as (7) in a judgment task, in which they had to evaluate the test sentences in the visual scenarios of Conditions 1-3. We may draw some predictions from the results of the previous studies, which mainly address there questions outlined in (4a-c).

First of all, we expect both children and adults to understand sentences like (5) given that in Lohiniva and Panizza (2016), who employed the same experimental design and similar intonation, also 4- to 5-year-old children display high accuracy (79% of correct choices) in the condition that tested for a pragmatically enriched interpretation via ISI.

Second, if the derivation of an ISI facilitates the comprehension in children (cf. Bill et al. 2016; Lohiniva and Panizza 2016), we predict that accuracy for this group should be higher in Condition 2 than Condition 1. If such a facilitation extends to processing, we expect Condition 2 to be disambiguated more rapidly than Condition 2. If, in contrast, the interpretation of (7) enriched by an ISI is difficult to achieve for children, we expect no difference in accuracy and processing between Condition 1 and Condition 2, which both are compatible with the literal interpretation of (7).

As a general pattern, if the literal interpretation is derived first (cf. Huang and Snedeker 2009; Panizza, Huang, Snedeker and Chierchia 2011; Lohiniva and Panizza 2016), the NONE and NALL contexts in Conditions 1 and 2 should be disambiguated equally rapidly in both adults and children. For both the test sentences in (7) are true in both contexts. If, instead, the pragmatic interpretation enriched via ISI is immediately derived and added to the meaning of the sentence, NALL contexts will display a processing advantage over NONE contexts, as only the former is compatible with the ISI.

Finally, as for the predictions about children and adults' choices in Condition 3, which tests for the preference between the NONE vs. the NALL scenario, we expect two possible scenarios. If children are more pragmatic than adults, as found by Bill et al. (2016) and Lohiniva and Panizza (2016), they will display higher preference for the NALL scenario. If, in contrast, children tolerate more often violations of ISIs, as found with SIs (cf. Katsos and Bishop 2011 among many others), we expect the rate of preference for the NALL scenario in Condition 3 to increase with age, as well as the rate of rejections of the NONE context in Condition 1.

2.4. Results

2.4.1. Offline Results: Semantic Choice

Regarding the question whether all participants groups are able to understand the experimental sentences with unbiased intonation, we have to conclude that 4- to 5-year old children, while correctly repeating them, ignored negation during comprehension. This became apparent in the access conditions: in Condition 1 they mainly (67%) opted for the FALSE scenario, in which sentence (7) is false.
We observed a similar pattern in Condition 2. Here, too, children chose the FALSE scenario (74%) over the ISI supporting scenario (26%). Because of this, we will not report their results from the preference condition.

In contrast, the older children behaved rather differently and interpreted negation correctly: In Condition 2, they chose the NALL scenario 84% of the time, the no-reward option 6% of the time and the FALSE scenario 10% of the time. Looking at Condition 1, 6-to-10-year olds mainly chose the group of pirates acting out the NONE context (76%), while rewarding the FALSE group 13% and rejecting 11% of the time.

For Condition 2, adult controls favored the correct scenario (84%), rejection making up 14% and False totaling 2%. Looking at Condition 1 where a scenario violating the ISI (NONE) was contrasted with one supporting neither the literal nor the enriched interpretation, adults’ rate of rejection doubled (28%) over the NALL case. While wrong choices remained low at 2%, the NONE scenario was only chosen 70% of time.

Let us now turn to Condition 3, where the NALL scenario, supporting the ISI, was presented simultaneously with the NONE case. We found that, over the course of their linguistic maturation, participants developed a stronger preference of the NALL scenario over NONE. So, while 6-to-8-year old children hardly show any preference at all with NALL making up 55% and NONE being chosen 45% of the time, the older subgroup from 9 to 10 years of age only chose the NONE option 32% of the time and thus overwhelmingly preferred the context support the ISI (68%). In line with the trajectory, adult controls favored the NALL case (77%) over the NONE scenario (23%).

2.4.2. Online Results: Eye Movement Data

The aim of the eye movement analysis was to investigate the time course of target identification — the NONE/NALL scenario over the FALSE one, Conditions 1 and 2, respectively — and whether participants display differences between the two conditions. In a first step, we report the target preference data, comprised of the proportion of target fixations (i.e. the correct scenario) in a given time window in relation to the total fixations towards both target and distractor (i.e. the false scenario).

4- to 5-year-old participants were excluded from the analysis because they failed to comprehend the test sentences including negation. We divided the elementary school children into 2 groups by splitting the median (6-8 y/o vs. 9-10 y/o).

From visual inspection of Figures 2, 3 and 4 we observe earlier target disambiguation for the context supporting the pragmatic inference (NALL) compared the violation scenario for all participants. This pattern is also consistent with the measured response times where children and adults were faster in NALL (adults: 5.9 s; children: 5.6 s) scenarios over NONE scenarios (adults: 6 s; children: 6.1 s).

The difference between the solid black line (target preference for NALL scenarios of Condition 2) and the dotted black line (target preference for NONE scenarios of Condition 2)
scenarios of Condition 1) diverge earlier in the younger group of children (between 0.5 s and 1.2 s from the onset of *nicht*) than in the older group (between 1.3 s and 2.2 s) and this difference emerges even at a later point in adults (between 2.3 s and 3 s).

In sum, 6-to-10-year old children were overall faster than the adult controls and even more so in Condition 2 (*NALL*) vs. Condition 1 (*NONE*), which, once more, is parallel to the response time differences reported above. Moreover, looking at the subdivision within the group of children, 6-to-8-year olds were faster than the older group of 9-to-10-year old children.

The statistical analysis was conducted by employing a Linear Mixed Model with *condition* and *group* as fixed factors and *subject* and *item* as random factors. The model was computed on broad time windows composed by parts of the sentence (i.e. Subject: "the captain"; Negation: "has not"; Quantifier: "with all"; Object: "the mermaids"; Verb “danced”; Spillover: 2s after the end of the sentence). The main effect of *condition* was significant in the last three time-windows: Object (p=0.4), Verb (p=.02) and Spillover (p<.01). With the adult group, the only window in which there was a significant effect of *condition*, with *NALL* scenarios receiving more looks than *NONE* scenarios, was the Spillover time-window. In children, instead, all the last three windows showed a significant main effect of *condition* in the same direction.

The factor *group* was significant in two time-windows. Children were overall faster than adults at identifying the correct scenario in both conditions in the Object time-window (p=.02) and in the Spillover one (p<.01). No significant interaction between the two factors was revealed.

![Fig. 2: Prop. of looks to target for 6-8 y/o, time-locked to onset of alle ('all')](image1)

![Fig. 3: Prop. of looks to target for 9-10 y/o, time-locked to onset of alle ('all')](image2)
3. Discussion

Our study sought to investigate the previously conflicting experimental literature on indirect scalar inferences in language acquisition, while focusing in part on the alleged similarity of ISIs with their direct counterparts put forth in earlier studies. To achieve this, we employed both offline and online measures to test comprehension and processing abilities of children and adult controls.

Firstly, we were interested in the question whether children and adults alike succeed in comprehending ISIs without supporting prosodic contours. While the answer is affirmative for the older group of children from 6 to 10 years of age and the adult controls, the youngest group, comprised of children aged 4 to 5, failed to understand the experimental stimuli (contra Lohiniva and Panizza 2016). While it is difficult to pinpoint an exact cause for this, especially since the older age group was not substantially older, we will mention a few possibilities.

One candidate could be the flat intonation used to record the sentences. It might be the case younger children are more reliant on supporting intonation for comprehension than older speakers. There are a few arguments against this explanatory route, however. For one, in a previous study, Lohiniva and Panizza (2016) demonstrated that children are in fact able to understand intonationally unbiased sentences involving triggering environments for ISIs. Secondly, it is unclear why any alleged dependence on prosody should disappear so shortly after 5 years of age – recall that 6-to-8-year old children not only accessed both the literal and the enriched interpretations of the sentences, but our results suggest that they also disambiguated these scenarios faster than 9-to-10 year olds. As far as we know, there is no principled reason to assume any such developments. Another candidate could be the overall complexity and length of the length, that renders it difficult to retain in memory for a few seconds during which the judgment is made. This explanations clashes against the observed behaviour of 4- to 5-year-olds who were perfectly able to repeat the experimental sentences including, crucially, the negative marker in the right sentential position. Yet, they ignored negation at the level of interpretation.

Explaining the systematic disregard of the youngest children for negation in the items used here might have to do with (a combination of) structural factors. In contrast to Lohiniva and Panizza (2016), whose sentences involved a universally quantified subject, the universal quantifier in our items was always embedded in
a Prepositional Phrase (PP) in object position. Bearing this in mind, we find to two structural complexities which could have overloaded the children’s processing abilities. In case of the PP, the deeper embedding of the quantified Noun Phrase might have resulted in a degree of processing load which, coupled with the experimental task, might have been too demanding on the youngest participants in our study. What is more, quantifiers in object position require quantifier raising (May 1978) in order to be interpretable. In our sentences, this meant not only raising from a relatively deep embedding but also, and this could potentially be the more crucial factor, the crossing over negation. In our offline results for the youngest children, it became evident that children did not operate at chance level, as would be expected if they simply did not find an adequate parsing strategy, but they systematically chose the FALSE scenario which was compatible with our experimental items once negation is ignored. To our knowledge, the interplay of quantifier raising over negation and its potential impact on language learners has not yet received experimental or theoretical treatment, so we cannot go into more detail, but we believe this this to be a likely candidate for the patterns observed.

Our next area of interest surrounded the facilitation effect granted to both offline and online measures by ISIs. It has long been observed that SIs incur a cost upon their derivation (Bott, Bailey, and Grodner 2012) and that the literal interpretation is advantaged over the pragmatic one with respect to online disambiguation (Huang and Snedeker, 2009). In the case of ISIs, in contrast, opposite results have been reported in the literature (Bill et al. 2016; Lohniva and Panizza 2016; Cremers and Chemla 2014). In our study, contexts supporting the existential enrichments provided by ISIs were not only judged more accurately by both children and adults, they were also disambiguated and thus processed faster compared to contexts which violate the ISI-strengthened interpretation. Assuming similarity between the two phenomena, this is rather surprising. If ISIs are costly and demanding on the hearer, there should be no comprehension facilitation, which holds especially for younger children in our our study, which represent the age group struggling with direct scalar inferences.

What our results show in particular is the following: chiefly, ISIs are a robust inference that is derived very often and with minimal processing effort/high speed. Also, this pattern extends to young children from 6 to 10 years of age: children are very proficient at deriving and processing ISIs (even more so than adults). Even more so, the pattern that emerges supports a neo-Gricean hypothesis of implicature processing, that is: implicatures are computed by default and immediately added to the first available interpretation of the sentence. A cost is required to withdraw the implicature and go back to the literal interpretation. Future experiments might shed more light on this, especially involving more natural intonation.

Concerning the youngest participant group comprised of 4- and 5-year olds, we are not in a position to draw the same conclusions, but the data obtained in our experiment supports the pragmatic boost hypothesis put forward by Lohniva and Panizza (2016) as well as earlier studies arguing that children perform well with ISIs.
Now, we will attempt a comparison between ISIs and SIs, note however, that these points are tentative because stronger claims would require a direct experimental comparison with a similar design to the present one. Beyond the boost we observed in children and adults, the dissociation between the two kinds of implicature is borne out in further aspects of our results: adults as well as those children who did not ignore negation (though to a lesser degree) were often prepared to reject the experimental sentences in contexts where a ISI violating scenario was paired with one in violation of both the literal and the enriched meaning (in both the rejection rate almost doubled over the ISI supporting condition). What is more, this negative cost associated with ISIs seems to be independent of preference concerns: notably, the younger children freely varied between literal and enriched interpretations despite the processing advantage afforded by the latter. Effectively, children were more tolerant of violating scenarios than the older participants in our study, which is in line with the pragmatic tolerance hypothesis advanced by Katsos and Bishop (2011). That is, only with age did participants form a strong preference of the ISI reading over the literal one, culminating in the adult control group which chose the stronger interpretation in 3 out of 4 cases. Note that, in spite of our remarks to the contrary, the increased preference of enriched interpretations as a function of age is one facet in which predictions for direct scalar implicatures coincided with our results for ISIs.

A last point concerns the delayed overall processing signature as measured by eye gazes to the target over the FALSE scenario of adults when compared to children as well as the slower disambiguation performed by the older (from 9 to 10 years) as opposed to the younger children (6 to 8 years). Here again, one possible avenue lies with the unbiased prosody: potentially, older children and adults rely more heavily on prosodic biasing towards either interpretation due their stronger preference for the enriched reading, which supposedly occurs with a characteristic prosodic profile. In other words, the stronger interpretive preference might correlate with the association of distinct contours. The absence of those conventional forms might necessitate additional processing time to overcome the lack of prosodic encoding, increasing the processing time of the ambiguous sentences. As such the delay can be conceptualized as a negative side effect of conventional prosodic arrangement.

Overall then, prosody might play the principal role in explaining the dissociation of online processing — in which adults were outperformed by children — and offline data, where adults showed a stronger preference than children and were less tolerant towards ISI violations despite slower computation.

To conclude, we demonstrated that, even without intonationally instantiated bias, children from 6 to 10 years of age as well as adults are capable of understanding sentences where a universal quantifier is embedded under negation and which, subsequently, give rise to indirect scalar implicatures. Furthermore, ISI supporting contexts are accessed more accurately in terms of offline choices and processed more rapidly as measured by eye movements when compared to contexts which do not support the strengthening inference – a pattern extending to children and adults alike. Thus, we conclude that
• ISIs provide a pragmatic boost for both comprehension and processing,
• seem to be very rapidly accessible, affecting the earliest interpretation of
  the sentence (immediate disambiguation),
• seem not to pattern with previous results showing costly direct scalar
  implicatures
• the violation of ISIs are yet tolerated more often by adults.

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