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Scope Assignments and Scalar Implicatures in Child English: The Role of Working Memory

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Abstract

Acquisition delays have been found for scope assignments and scalar implicatures (cf. Musolino 1998; Lidz 2016; Chierchia et al. 2001; Noveck 2001; Katsos & Bishop 2011). Both acquisition delays have separately been attributed to childrenís immature processing capacities, like their limited working memory. Yet, no study has ever directly looked at the role of processing limits in the acquisition of scope assignments or in the acquisition of scalar implicatures. Moreover, no one has looked at the two fields in combination. Therefore, this paper aims to investigate English-speaking childrenís mastery of scope assignments as well as their command of scalar implicatures. Most importantly, I also tested each childís digit span which is generally used to measure working memory. The results showed that although inverse-scope readings are allowed in English, adults hesitated to accept them but children were more permissive. Moreover, a significant correlation was found between participantsí acceptance of inverse-scope readings and their digit span. Regarding scalar implicatures, children did not compute the scalar implicatures while adults did, and a significant correlation was observed between a childís computation of scalar implicatures and their digit span. These findings provide new support for the processing approaches to the observed delays in scope assignments and scalar implicatures.

Scope Assignments and Scalar Implicatures in Child English: The Role of Working Memory

Shuyan Wang*

1 Introduction

Sentences with two quantifiers (a universal quantifier and an existential quantifier) in English are ambiguous: they have both a surface-scope interpretation and an inverse-scope interpretation, as shown in (1). The scope ambiguity potentially complicates the learning process of children who have to generalize the principles from the notoriously poor input. How could a child decide whether a language allows scope ambiguity or not? This inspires many a linguist to investigate the developmental pattern of children's command of quantification. Children's command of scope assignments is influenced by many factors, including syntax, pragmatics, and processing capacity (e.g. Lidz 2016, Musolino 1998, Reinhart 1999, Reinhart 2004, Szendrői et al. 2017, Wang 2018, Wang 2019). However, few studies have looked into the role of processing limits. This paper aims to uncover the relation between children's processing capacities and their scope assignments.

(1) There is a dog chasing every cat. ($\exists > \forall / \forall > \exists$)

Another difficult task faced by children is that speakers' intended meanings can go beyond the literal meaning of their utterances. For example, upon hearing the utterance in (2), an adult is very likely to infer that Mary did not eat all of the cookies. Although the statement would be literally true if Mary ate all the cookies, it implies that she did not. This inference is referred to as a scalar implicature (e.g. Grice 1978, Grice 1989, Horn 1972).

(2) Mary ate some of the cookies.
~> Mary did not eat all of the cookies.

Many acquisition studies show that young children know the basic semantics of scalar items (like *some*) but have difficulties in computing scalar implicatures (e.g. Barner et al. 2011, Chierchia et al. 2001, Noveck 2001, Papafragou and Musolino 2003, Syrett et al. 2017, Wang 2019, among many others). Some studies attribute children's problems with scalar implicatures to their processing limits (e.g. Chierchia et al. 2001, Reinhart, 2004, Pouscoulous et al. 2007, Wang submitted).

As discussed above, acquisition delays in both scope assignments and scalar implicatures have been proposed to follow from children's immature processing capacities. Yet no one has examined the two phenomena within the same group of children. This paper will provide within-subject data from English-speaking children on processing capacity, scope assignments for structures like (1) and scalar implicatures like (2).

Section 2 will focus on the theoretical background, including theories for scope assignments and scalar implicatures. Section 3 will discuss the existing acquisition studies of scope assignments and scalar implicatures. A new experiment will be introduced in Section 4. The general discussion of the new results and conclusion will be presented in Section 5.

2 Theoretical Background

2.1 Scope Ambiguity

Quantifier Raising (QR) has long been believed to be responsible for the non-isomorphic scope reading of quantifiers. As May (1977) suggests, QR is essentially a covert movement of quantified

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DPs to a higher position in the syntactic tree. For instance, in (3), there are two distinct logical forms corresponding to the two different interpretations. Sentence (3) is ambiguous between two readings: one is that there is only one bear chasing every cat; the other says that for each cat, there is a distinct bear chasing it.

(3) A bear is chasing every cat.
  a. [$_S$ [A bear]$_1$ [$_S$ [every cat]$_2$ [$_S$ t_1 is chasing t_2]]]
  b. [$_S$ [every cat]$_2$ [$_S$ [A bear]$_1$ [$_S$ t_1 is chasing t_2]]].

According to Reinhart (1999, 2004), QR, although it is available in the Computational System (CS), is a marked and costly operation. This idea originated mainly from the intuition that the inverse-scope reading resulting from QR is hard to access. Much cross-linguistic data collected by Gil (1982) offers evidence for this. Gil (1982) noticed that even though the inverse-scope reading is permitted, the surface scope is overwhelmingly preferred. Assuming that QR is not free, Reinhart (1999, 2004) argues that the scope shift, although available in the Computational System (CS), violates some condition of the CS. Reinhart suggests that QR violates a broader economy principle. Essentially, the economy principle, which requires minimizing interpretative options, inhibits covertly expanding the set of interpretations of one PF derivation. According to Reinhart, only when the inverse scope of a quantifier is different from its surface scope can it undergo the covert movement. In this case, such a covert movement still violates the economy principle. So far, regardless of what condition violated, QR is assumed to be a costly and constrained operation.

Even though QR is an 'illicit' operation, Reinhart (1999, 2004) proposes that the operation is still a part of the CS and can be used to meet the interface needs. She argues that applying QR entails a global comparison of all potential alternatives. In other words, in order to undergo the scope-shifting QR, a given derivation needs to be checked for whether the resulting interpretation is unique or not, compared with interpretations derived by derivations without QR. If there is such an alternative, the scope shift will be blocked, because derivations without any covert movement are always favored by the economy principle. Reinhart (1999, 2004) refers to this set of alternative derivations as a reference set. The involved computation is believed to be computationally costly. It involves retrieving alternative derivations, holding them in working memory, and comparing them. The computation may exceed the processing ability of children, in particular their working memory, which has not fully developed.

Szendrői et al. (2017) propose that children have access to QR as adults do. The difference between adults and children lies in their ability to perform the involved reference set computation. Szendrői et al. (2017) further suggest that young children with limited processing capacities may simply skip the computation and then directly access inverse-scope readings, and thus that children should be more permissive than adults with regard to inverse-scope readings. Therefore, according to Szendrői et al. (2017), an inverse correlation is expected between a child's working memory and their acceptance of inverse-scope readings: worse working memory predicts a higher acceptance rate of inverse-scope readings

Finally, the proposal of reference set computation is also compatible with the 'soft constraint' proposed by Bobaljik and Wurmbrand (2012). They propose that *Scope Transparency* prevents scope reversal at LF by QR, as in (4). It is, however, a soft constraint which can be overridden by economy considerations (Bobalijk and Wurmbrand 2012).

(4) *Scope Transparency:*
  If the order of A and B is A > B at LF, then A > B at PF.

According to this constraint, utterances with the surface-scope reading are favored over those with the inverse-scope reading. They argue that German, unlike English, allows objects to scramble over subjects. The structure with scrambling expresses the inverse-scope reading of the structure without scrambling. It also shares the same numeration as the structure without scrambling. Therefore, the availability of scrambling in German blocks the application of QR. Bobaljik and Wurmbrand (2012) further argue that topic structures and passive counterparts in English cannot function as a blocker for inverse-scope readings, because they do not share the same numerations. In particular, according to Bobaljik and Wurmbrand (2012), there may be various distinct competing derivations to express a given interpretation. This analysis is essentially compatible with Reinhart's reference set computation.

2.2 Scalar Implicatures

It is commonly assumed that speakers' intended meanings can go beyond the literal meaning of their utterances. For example, upon hearing the sentence in (5), a listener is very likely to infer that Mary did not eat all of the cookies. The statement is logically true if Mary actually ate all the cookies, but it implies that Mary did not eat all of them. This is a typical example of scalar implicatures (e.g. Grice 1978, Grice 1989, Horn 1972).

(5) Mary ate some of the cookies.
  ~> Mary did not eat all of the cookies.

Horn (1972, 1989) suggests that the quantifier *some* is a "scalar item". It is part of a scale, whose members are ordered according to their informativeness. For *some*, the relevant scale members include *a, many, most, all*. The ordering of the scale members is shown in (6), with the leftmost being the least informative.

(6) *<a, some, many, most, all>*

Grice (1969, 1975) proposes that communication between speakers and listeners is based on a principle of cooperativity, which can be broken down into four conversational maxims. Following Grice (1975), during a conversation, a speaker's contribution is assumed to be true (quality maxim), clear (maxim of manner), relevant (maxim of relevance), and adequately but not overly informative (quantity maxim). Based on the Grice's quantity maxim, a speaker is expected to be as informative as possible. Thus, if the speaker chooses to use a weaker term like *some* in (5) rather than the more informative term *all*, the listener would infer that the speaker does not have enough evidence to believe that the stronger term is true. If the listener takes the speaker to be knowledgeable, he will further infer that the stronger term is false: it is false that Mary ate all of the cookies.

It is generally assumed that the computation of scalar implicatures requires access to alternative sentences, *ALT*. In particular, the listener first computes the literal meaning of the sentence containing a scalar term, and then generates a set of alternative expressions that might have been used. Alternative sentences can be generated by replacing the scalar term with its scalar alternatives. After that, the listener restricts these alternatives by focusing on the more informative ones. Finally, they strengthen the interpretation of the sentence by negating the more informative alternatives. The computation process is roughly summarized as in (7).

(7) Suppose *A* and *B* form a scale such that *B* is more informative (stronger) than *A*. Then if one says *S(A)*, the statement is interpreted as *S(A) and not S(B).*
(Adopted from Barner et al. 2011)

Reinhart (1999, 2004) suggests that the computation of scalar implicatures also involves the reference set computation. In particular, in order to derive a scalar implicature of a sentence, a listener needs to retrieve the alternative expressions that are relevant in the context, compare their informativeness, and then negate those stronger propositions (e.g. Chierchia et al. 2001, Reinhart 1999, Reinhart 2004). Therefore, children's processing capacities should also predict their computation of scalar implicatures.

Note that the reference set computation associated with scalar implicatures is not necessarily identical with the reference set computation associated with inverse-scope readings. For example, the reference sets involved are different. Regarding the computation of inverse-scope readings, the reference set should contain the derivations semantically equivalent to the sentence with the inverse-scope, like scrambling structures (e.g. Szendrői et al. 2017, Bobaljik and Wurmbrand 2012). The reference set associated with scalar implicatures, however, contains alternative expressions on the same scale, or those alternatives relevant in the same context. The key point is that although the reference set computations related to inverse-scope readings and scalar implicatures are not identical, they both require the comparison between the target sentence and alternative expressions.

Therefore, following the idea of the reference set computation, it is expected that we will find a correlation between children's processing capacity and their computation of inverse-scope readings/scalar implicatures. In particular, better processing capacities indicate more adult-like performance on scope assignments and scalar implicatures.

3 Acquisition Studies

3.1 Scope Assignments in Child Language

Children's knowledge of quantification has been intensively studied over recent decades. Initially, the so-called isomorphism tendency was proposed: while adults could access the non-isomorphic scope interpretation (i.e. the inverse-scope reading), children entertained only the isomorphic scope reading (i.e. the surface-scope reading). This is what Musolino (1998) called 'the observation of isomorphism' (see also Lidz and Musolino 2002).

As for the underlying reason of this systematic discrepancy, Lidz and Musolino (2002) discussed two possibilities. One is that children's grammar lacks the covert syntactic operation (i.e. Quantifier Raising) which is responsible for the non-isomorphic scope reading. The other possible explanation focuses on the limitation of children's computational capacity. Lidz and Musolino (2002) propose that English-speaking children may have access to both isomorphic and non-isomorphic scope readings. However, during the real-time comprehension, the computation involved for deriving the non-isomorphic scope is too demanding for children to accomplish.

However, many acquisition studies later found an opposite and more flexible pattern: children actually can access non-isomorphic scope interpretations (inverse-scope readings), while adults feel reluctant to permit these interpretations (e.g. Goro 2007, Szendrői et al. 2017, Wang 2018, Wang 2019). For example, Goro (2007) tested English-speaking and Japanese-speaking children with sentences like *'Someone ate every food'*. These sentences are scope-ambiguous in English, while they only allow a surface-scope reading in Japanese. He found that both English-speaking adults and English-speaking preschoolers allowed about 40% of inverse-scope readings. However, Japanese-speaking adults and Japanese-speaking children showed significant differences: adults never accessed inverse-scope interpretations, but children accepted inverse-scope readings about 40% of the time. Zhou and Crain (2009) also found that, regarding sentences with a universal quantifier and negation (e.g. 'Every horse did not jump over the fence'), Mandarin-speaking adults only permitted surface-scope readings, while Mandarin-speaking children accepted both surface-scope readings and inverse-scope readings (see also Wang 2018).

3.2 Scalar Implicatures in Child Language

The acquisition of scalar implicatures has also been widely studied. Many studies suggest that children younger than 7 years of age cannot derive these implicatures at an adult-like level (e.g. Barner et al. 2011, Guasti et al. 2005, Noveck 2001, Wang submitted). For example, Noveck (2001) found that 8-year-old and 10-year-old children accepted underinformative sentences like (8) far more often than adults did. The sentence in (8) implies that not all giraffes have long necks. If children could get the scalar implicature, they should reject it. However, the results show that children rejected it far less often than adults did.

(8) Some giraffes have long necks.
~> Not all giraffes have long necks.

Barner et al. (2011) found that, in a context where all three animals are reading, 4-year-old children did not reject the underinformative statement in (9). This suggests that preschoolers failed to derive the relevant scalar implicature: not all of the animals are reading. Furthermore, 4-year-olds also failed to access the strengthened interpretation with the exhaustive operator *only*, as in (10).

(9) Some of the animals are reading.
~> Not all of the animals are reading.

(10) Only some of the animals are reading.

However, Barner et al. (2011) found that children could derive strengthened propositions for sentences with the exhaustive operator *only*, when alternatives were provided contextually. In an example trial, they presented 4-year-old children with a picture where three animals (a cat, a cow, and a dog) were sleeping. Then children were asked the question in (11). If participates derived the strengthened interpretation, they would provide a negative answer. Barner et al. (2011) found that children provided a negative answer 86% of the time.

(11) Are only the cat and the cow sleeping?
~> Only some, not all, of the animals are sleeping.

According to Barner et al. (2011), those child participants did not know that the relevant alternative of *some* was *all*. Thus, children failed to derive scalar implicatures with context-independent scales, or to get the strengthened interpretation with the operator *only*. On the other hand, the alternatives associated with context-dependent scales were provided by the context. In this case, children could directly access them in the context (Gotzner et al. 2020, Skordos and Papafragou 2016).

Another group of accounts attribute children's failure with scalar implicatures to their limited processing capacities (e.g. Chierchia et al. 2001, Tieu et al. 2016, Wang submitted). For example, Chierchia et al. (2001) report that English-speaking children know that *A and B* is more informative than *A or B* in positive contexts where both statements are true, when both structures are presented overtly to children. Chierchia et al. (2001) suggest that children's adult-like performance might result from the reduced processing load of the task. When the alternative sentence (i.e. *A and B*) was presented overtly, the processing load of computing scalar implicatures was reduced.

Some studies attribute children's non-adult-like performance on scalar implicatures to their immature pragmatic knowledge. For example, Katsos and Bishop (2011) employed a ternary judgment task and found that child participants showed sensitivity to underinformativeness. It means that children could access scalar implicatures. Katsos and Bishop attributed children's previous failure to compute scalar implicatures to their tolerance to underinformativeness. In particular, children are actually sensitive to informativeness but just reluctant to reject those underinformative statements that are otherwise logically true (see also Veenstra et al. 2017).

In summary, scalar implicatures are assumed to be acquired late. Although some studies found that children are sensitive to scalar implicatures, it usually requires certain manipulations of the context or the experimental techniques. Some works attribute children's failure with scalar implicatures to difficulties with alternatives. Regarding the difficulties with alternatives there are at least two different proposals: one is related to children's immature knowledge of lexical scales (e.g. Barner et al. 2011), while the other focuses on the processing load (e.g. Chierchia et al. 2001, Reinhart 1999, Reinhart 2004, Tieu et al. 2016, Wang submitted).

4 Experiment

4.1 Motivation

As discussed above, the role of processing capacity in the acquisition of scope assignments and scalar implicatures is unclear. An experiment was designed to fill these gaps. In particular, a covered-box task was used to uncover both the command of scope assignments and the computation of scalar implicatures by English-speaking children. The same group of children also took a digit span test which was used to measure their working memory. These tasks enabled me to explore the correlation between processing capacity and the command of scope assignments/scalar implicatures.

Following the processing account for the delayed acquisition of scope assignments, I assume that inverse-scope readings requires the reference set computation, which is beyond the processing capacities of young children. It is likely that children just skip the reference set computation, and then cannot find blockers for inverse-scope readings. Therefore, children may directly accept inverse-scope readings. In particular, children's working memory should be able to predict their acceptances of inverse-scope readings: worse working memory predicts a higher acceptance rate of inverse-scope readings (i.e. less adult-like performance).

Similarly, following the processing account for the delayed mastery of scalar implicatures (e.g. Chierchia et al. 2001, Tieu et al. 2016, Wang submitted), I assume that the computation of scalar implicatures is too taxing for young children to accomplish. Thus, it is possible that children may fail to negate the stronger propositions. Again, children's working memory should be able to predict their computation of scalar implicatures: worse working memory predicts a lower computation rate of scalar implicatures (i.e. less adult-like performance).

In addition, if both the access to inverse-scope readings and the computation of scalar implicatures involve a reference set computation, a correlation is expected to be found for the acquisitions of these two. To be specific, if a child is non-adult-like at scope assignments, it is very likely that he/she will fail to derive scalar implicatures.

4.2 Method

Regarding the acquisition of scope assignments and scalar implicatures, I chose to use the covered-box task. The covered-box task is a variant of the picture matching task, in which children are asked to choose one picture from a set of pictures. One of the options is hidden in an opaque box, so that children cannot see it. However, children can choose the hidden picture if they think all the other visible choices are incorrect. This makes a big difference because it allows participants to deny all the visible pictures. For example, the covered-box task allows us to present three pictures: one tested reading (e.g. the inverse-scope reading), one distractor, and one hidden picture. In this case, if children do not allow this interpretation, they can go for the hidden picture, which in their view, should express the correct interpretation. In addition, with the covered-box task, a participant needs to first assess the two visible pictures before he decides to choose the covered picture. Therefore, even if a reading is strongly dispreferred, a participant needs to consider it once it is represented in a visible picture.

A digit-span test was used to study working memory. The digit-span test is commonly used to test memory span, partially because the performance on a digit-span task cannot be affected by factors such as semantics, frequency, and complexity (Jones and Macken 2015).

4.3 Participants

This experiment involved 19 English-speaking children and 14 English-speaking adults. They participated in all the three tasks. Another 6 children only took the scalar-implicature study and the digit-span test. All the participants were monolingual. They did not have any training in linguistics. All the child participants were recruited from local preschools in Connecticut, USA. The adult participants were all undergraduates at the University of Connecticut.

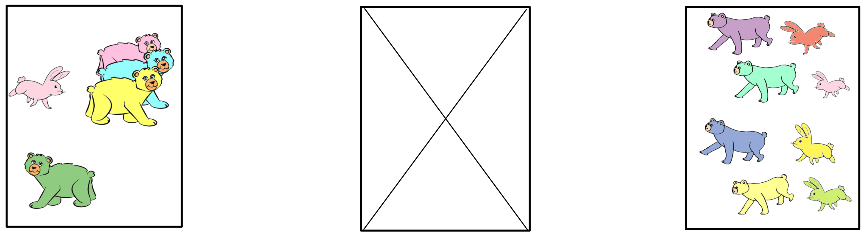
4.4 Materials

Regarding the scope assignment study, test sentences contain an existential quantifier and a universal quantifier, as shown in (12). Such sentences in English allow both a surface-scope interpretation and an inverse-scope reading. Three actional verbs were used, such as *touch*, *push*, and *chase*. Nine different animal names were involved.

(12) There is a dog chasing every cat. $(\exists > \forall / \forall > \exists)$

In the covered-box task, each trial consisted of a set of three pictures. Two pictures were visible while a third picture was covered. In the test condition, one of the two visible pictures depicted the inverse-scope reading, as in (13). If participants allowed the target reading, they would choose the visible picture. Otherwise, they would choose the covered picture, which in their view, should represent the correct reading. There were 9 items for the test condition, with 3 items for each verb.

(13) *Sentence:* There is a rabbit chasing every bear.

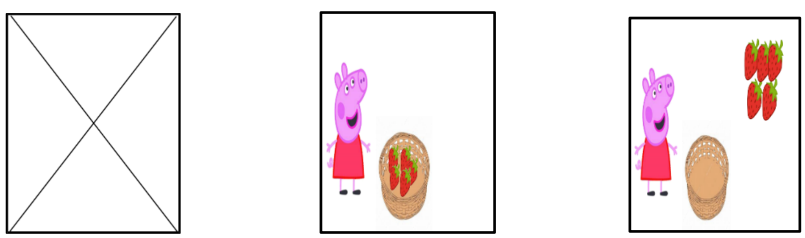


Distractor Hidden Picture Target (Inverse-scope)

In the control condition, the target picture depicted a surface-scope reading. There were 9 control items, with 3 items for each verb. There were also 9 filler items. The filler sentences were unambiguous. The target picture was either visible or hidden. The key function of the fillers was to remind subjects that the correct choice could be the hidden picture.

Regarding the test of scalar implicatures, I focused on the scale <*some*, *all*>. Scalar implicatures were also tested with the covered-box task. Three different types of items were created: test condition, control condition, and fillers. For the test condition, the test sentences contain *some* and the target picture depicted a stronger proposition. Here I refer to these trials as 'logically true and pragmatically underinformative' (LU), because against the target picture, the test sentence was logically true but pragmatically underinformative. For example, in (14), the test sentence states that Peppa Pig took some strawberries. One visible picture shows that Peppa Pig took all the strawberries, while the other visible picture shows that Peppa Pig took none of the strawberries. If participants computed the scalar implicature, they should select the hidden picture. There were 6 items for the test condition.

(14) *Test sentence:* Peppa Pig took some strawberries.



Hidden Picture Target (LU condition) Distractor

There were 6 control items. The target picture depicted a logically true and pragmatically informative scenario (LI). In addition, 6 filler items were created. The test sentences did not contain any scalar items. The target pictures were either visible or hidden.

The digit-span test consisted of two parts: forward recalling and backward recalling. The forward recalling test started from 3 digits, while the backward recalling test started from 2 digits. Given that the backward recalling is much more challenging than the forward recalling, the longest sequence for the backward recalling consisted of 8 digits, while the longest sequence for the forward recalling had 9 digits. 2 items were given for each digit span.

4.5 Results

For the scope assignment task, in order to be included, a participant had to be correct on at least 7 of the 9 control items, and on at least 7 of the 9 filler items: p(at least 7 out of 9 correct|H0) = .008. All the adults and 16 children (age range: 4;00-8;07, mean age: 4;11) passed the screening.

The results showed that both adults and children accepted the surface-scope readings (88.89% and 87.62%). There was no significant difference between the two groups. Regarding the inverse-scope readings, the adults hesitated to accept the inverse-scope readings (59.52%), while the children were more permissive to inverse-scope readings (86.11%). Regarding the digit span test, the average forward-recalling digit span for adults was 7.21, while the children's average digit span was shorter, 5. In the backward-recalling test, the average digit span for the adults was 5.36, while the average digit span for the children was much worse, 1.19.

For adults, a significant inverse correlation was found between their backward recalling spans and their acceptance rates of inverse-scope readings ($r= -0.561$, $r^2= 0.3148$, two-tailed $p= 0.0367$). In particular, if an English-speaking adult showed a longer backward-recalling span, it was more likely for him/her to accept inverse-scope readings. No other significant correlation was found.

For children, their acceptances of surface-scope readings were not found significantly correlated with their digit spans (either forward-recalling or backward-recalling). Furthermore, no significant correlation was found between a child's acceptance rate of inverse-scope readings and his digit span (either forward-recalling or backward-recalling). In fact, this was not surprising, given that almost all the English-speaking children allowed the inverse-scope interpretations. There was little variation among English-speaking children's attitude towards the inverse-scope interpretations.

For the scalar implicature study, in order to be included, a participant had to be correct on at least 5 of the 6 control items, and on at least 5 of the 6 filler items: p(at least 5 out of 6 correct|H0) = .017. All the adults and 23 children (age range: 3;11-9;11, mean age: 5;08) passed the screening.

The results showed that both the adults and the children selected the target picture in the LI conditions (100% and 97.10%). It suggests adults and children knew that 'some but not all' scenarios were compatible with the scalar item *some*. However, children and adults differed in LU conditions. The adults hesitated to select the target 'all'-scenarios (29.76%). It suggests that the adults computed the scalar implicatures. On the contrast, the English-speaking children frequently selected the target picture (83.33%). It indicates that these children failed to compute the scalar implicatures.

There was no significant correlation found between adults' digit spans and their computation of scalar implicatures. This was expected, given that almost all the adults computed scalar implicatures and adults' digit spans were similar. The focus is the correlation between children's computation of scalar implicatures and their digit spans. First, there was no significant correlation found between children's acceptance rate of LI conditions and their digit spans (either forward-recalling or backward-recalling). This was also not surprising, since almost all the children selected the target picture in the LI conditions (97.10%). Second, children's selection of the target picture in LU conditions was found inversely correlated with their digit spans (forward-recalling test: $r= -0.6142$, $r^2= 0.3772$, two-tailed $p= 0.0018$; backward-recalling test: $r= -0.7551$, $r^2= 0.5702$, two-tailed $p< 0.0001$). When a child had a shorter digit span, it was more likely for the child to select the 'all'-scenarios in LU conditions (non-adult-like performance).

Finally, 14 children (age range: 4;00-8;07, mean age: 4;11) passed the screening of both the test of scope assignments and the test of scalar implicatures, and thus their data was analyzed together. First, children's digit spans (both forward-recalling and backward-recalling) were found to be significantly correlated with their acceptance rates of the target pictures in LU conditions. When a child displayed a longer forward-recalling digit span or a longer backward-recalling digit span, the child is less likely to select the 'all'-scenarios in LU conditions (i.e. more computation of scalar implicatures). No significant correlation was found between children' scope assignments and their computation scalar implicatures. This was not unexpected. Although children's acceptance of LU conditions was inversely correlated with their digit spans, their acceptance of the inverse-scope interpretations was not significantly correlated with their digit spans. Almost all the children accepted the inverse-scope interpretations, there was little variation among their behavior. Thus, it is not surprising to find no correlation between their scope assignments and their digit spans.

5 General Discussion

The results of the covered-box task showed that English-speaking adults hesitated to accept the inverse-scope readings, but English-speaking children were more permissive towards the inverse-scope readings. The results were not compatible with the 'observation of isomorphism' proposed by Musolino (1998). Children's permissive behavior could be explained by the current processing account. According to the processing account, when faced with an inverse-scope interpretation, one needs to retrieve alternative structures, to check whether there are any structures deriving the same interpretation without the costly operation QR (e.g. Bobaljik and Wurmbrand 2012, Reinhart 1999, Reinhart 2004). Although English allows scope ambiguity and does not have any blockers for inverse scope, speakers still need to perform the reference set computation. This reference set computation is assumed to be too taxing for young children to accomplish. It is possible that the children fail to perform the relevant computation and then directly accept the inverse-scope interpretations.

No significant correlation was found between children's scope assignments and their digit spans. As discussed above, this should not be very surprising, given that almost all the children accepted both the surface-scope interpretations and the inverse-scope interpretations (i.e. little variation among their behavior).

One remaining question is why English-speaking adults hesitated to accept the inverse-scope interpretations (59.52%). This finding is compatible with the results in Goro (2007): English-speaking adults accepted inverse-scope readings only 40% of the time. There are several potential explanations. First, some English-speaking adults might find wrong blockers for the inverse scope. Since English allows scope ambiguity, the target grammar should not contain any blockers. Then this explanation implies that some adults have a different grammar. The second explanation is more convincing. Adults may employ some task-specific strategies. For instance, adults may try to guess which choice should be the correct answer in the experimenter's view. Inverse-scope interpretations are usually dispreferred. Some English-speaking adults might be more conservative, which led to a lower acceptance rate of the inverse-scope readings.

The results of the scalar implicature study showed that the adults always computed the scalar implicatures associated with *some*, but children failed to do it. Importantly, a significant correlation was found between a child's digit span (both forward-recalling and backward-recalling) and their computation of scalar implicatures. The results have provided support for the processing account.

Finally, there were 14 children passing the screening of both scope assignments and scalar implicatures. Their data from all the three tasks (scope assignments, scalar implicatures, and digit span) was analyzed together. Since almost all the children accepted the surface-scope interpretations and the inverse-scope interpretations, there was little variation among their behavior. It is then not surprising that no significant correlation was found between children' scope assignments and their computation scalar implicatures.

However, one question does arise: why did the same group of English-speaking children perform differently on inverse scope and scalar implicatures, if both involve a reference set computation? It may be related to the fact that inverse scope is actually allowed in English, while *some* is logically true but pragmatically infelicitous against the 'all'-scenarios. Following the current proposal, those children with limited working memory may skip the reference set computation and then directly accept the inverse-scope readings. On the other hand, those children with relatively better processing capacities should also accept the inverse-scope readings, because English allows scope ambiguity. In other words, even if these children were able to accomplish the referent set computation, they should not be able to find blockers for inverse scope. Therefore, it is not surprising that almost all the children accepted the inverse scope, and that no significant correlation was found between a child's digit span and their acceptance of the inverse scope.

In summary, this paper has studied scope assignments and scalar implicatures in child English. Importantly, the study has also investigated the role of processing capacities in the development of scope assignments and scalar implicatures, by directly measuring children's digit spans. The results showed that the development of the three parts, scope assignments, scalar implicatures, and digit spans, were closely related.

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