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When Children Are as Logical as Adults: the Interpretation of Numerals in Child Language

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1. Introduction

During their first few years of life, children develop the ability to communicate with other people through a complex and highly structured system of linguistic principles and parameters. One striking fact about this process is that the linguistic competence achieved by children as young as three years old is, in many respects, equivalent to that of adult speakers. At a young age, children are able to understand a wide range of linguistic constructs, including nouns, verbs, adverbial modifiers, logical connectives and determiners, and they are able to perform linguistic operations involving these constructs such as agreement, predication, tense and aspectual modification, adverbial modification and logical operations like variable binding and assigning scope relations. These are all examples of linguistic phenomena where there is continuity between the linguistic systems of children and adults, and where children's performance is comparable to that of adults from the very first time they manifest knowledge of the specific constructs that pertain to the relevant phenomena, and children make no substantive changes in performance during the remainder of their lives.

In contrast, there are other aspects of language that take more time for young learners to acquire, and some of these aspects of language present developmental discontinuities, such that children's linguistic behavior differs, sometimes radically, from the linguistic behavior manifested by adults. One example of this is central to the present study. This is children's capacity to compute the kinds of pragmatic inferences (implicatures) that fix the meanings of quantifiers and numerals in adult languages. Generally speaking, delays in language development can either be due to limitations in competence or in performance. If children lack competence with a given linguistic construct, that construct has yet to be incorporated into children's grammars. If the problem resides in the performance system, the source of the difficulty is not children's grammar, but limitations in some other cognitive ability (e.g. reasoning, attention, verbal working memory), perhaps because the resources required to perform the computations involved in using the construct have not yet fully

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matured at the stage where difficulties are observed.

In language acquisition research, the absence of behavioral differences in the language abilities of adults and children leads to the inference that children's linguistic skills have reached the requisite levels of maturity in both competence and performance, and will not change thereafter. By contrast, the finding that some specific linguistic behaviors are associated with discontinuities can also be quite revealing. If the linguistic behavior of children and adults differs, experimental investigations are needed to identify the source of these differences. These investigations are informative in two ways. First, they may shed light on the underlying source of the difficulties children are experiencing, competence or performance. And depending on which system (competence or performance) is the source of the observed differences, this can shed further light, by providing evidence that confirms or disconfirms specific theoretical models of adult linguistic competence or models of adult performance. This is the aim of the present study.

The goal of the present study is to investigate whether or not 3-5-year-old children's interpretation of numerals is affected by the entailment patterns of the sentences in which they occur, just as it is for adult speakers. If so, then we can infer that the linguistic system of children, at least in this respect, closely matches that of adults - both use the same core representations and operations to interpret numerals. On the other hand, if we uncover a substantial discontinuity in children's interpretation of numerals, as compared to adults, then we will be invited to conclude that children employ different representations or different interpretative strategies. Not only will this inform us about changes in the cognitive systems of 3-5-year-old children with respect to the interpretation of numerals, but it will also help us refine and evaluate theories of the interpretation of numerals by adults.

2. The acquisition of numerals and their properties as quantifiers

Before introducing the relevant concepts for the present study (e.g., entailment patterns, the different interpretations of numerals), it will be useful to comment briefly on how children acquire the meaning of numerals. Children acquire the meaning in several stages (Wynn, 1990). First, they master the meaning of the numeral *one* (and no other numerals), so children at the initial stage are called *one-knowers*. If asked to hand over exactly one object, one-knowers are able to comply with the request, but if asked to hand over more than one object (say *two*), one-knowers may give three or more objects. Children become *two-knowers* next. At this stage, children respond correctly when asked for *one* object or *two* objects, but they fail to consistently provide the appropriate number of objects for higher cardinal numbers. The developmental path proceeds in this fashion for *three* and for *four*. Following the stage at which children are *four-knowers*, children become *CP-knowers*, because at this final stage they have learned the Cardinality Principle. The principle states that the last numeral produced in a counting procedure represents the cardinality of the set of objects under consideration (Gelman and Gallistel, 1978). CP-knowers, then, are virtually capable of assigning the appropriate numeral expression to sets of any cardinality, just like adults are.

Not only can CP-knowers use numerals appropriately to name sets of objects, but CP-knowers are competent language users in other respects. Importantly, CP-knowers have mastered the use of natural language quantifiers. It is worth noting in this regard that numerals share important properties with natural language quantifiers. First, like natural language quantifiers, numerals take modifiers (e.g. "more than *two/a few*", "not *two/many*", "almost *two/all*"). Second, both numerals and quantifiers are subject to scope interactions; for example, the sentence ***Every*** *child loves* ***two/some*** *toys* has two interpretations, depending on whether the universal quantifier *every* takes scopes over *two/some* or the reverse. Third, both the interpretation of numerals and the interpretation of quantifiers are governed by the entailment properties of other linguistic expressions. This last property is critical for the present study.

To see how numerals pattern with natural language quantifiers in this last respect, consider the simple sentences in (1), where (1a) contains the numeral *two*, and (1b) contains the quantifier *some*.

(1) a. John caught *two* of the butterflies.
b. John caught *some* of the butterflies.

Sentences containing either numerals or quantifiers, as in (1a) and (1b), are logically entailed by sentences that are identical except for the substitution of a logically stronger numeral or quantifier. This is illustrated in (2), where the weaker terms *two* and *some* in the sentences in (1) have been replaced by the stronger terms *three* and *all*.

(2) a. John caught *three* butterflies
b. John caught *all* of the butterflies

The notions of logical entailment and logical strength are critical for the present study. Logical entailment can be defined using conditional statements (i.e., by material implication); it can be shown, for example, that (2a) and (2b) logically entail (1a) and (1b) respectively, by pointing out the validity of the following conditional statements: *If John caught three/all of the butterflies, then he also caught two/some of them*. This relationship is a matter of 'logic' and holds independently of variations in the conversational context, e.g., the number of butterflies in the vicinity, whether John uses his hands or a net to catch the butterflies, and so on. In short, the entailment is entirely due to the semantic properties of the terms involved.

Using the concept of logical entailment, we can proceed to define logical strength, along the following lines. The numeral *three* and the quantifier *all* are logically stronger than *two* and *some,* because sentences containing the terms *three* and *all* asymmetrically logically entail sentences in which these terms have been replaced by *two* and *some*. That is why examples (2a) and (2b) logically entail examples (1a) and (1b). In the remainder of the paper, we use the abbreviations *entails* and *stronger/weaker* instead of *logically entails* and *logically stronger/weaker*. The next section discusses another interesting property of numerals, the fact that they can be used to express more than one meaning.

3. The meaning of numerals

Simple sentences with a numeral, such as *John caught two butterflies,* can be assigned two interpretations. On one reading, the numeral *two* has an 'exact' reading ('John caught exactly *two* butterflies'). On the other, the numeral *two* has an 'at least' reading ('John caught at least *two* butterflies'). Only the latter interpretation is entailed by a sentence containing a stronger numeral such as *three*, because if John caught three (or more) butterflies, then he could not have caught exactly two. The 'at least' reading of *two* becomes apparent when a numeral is embedded in the antecedent of a conditional statement, such as *If John caught two butterflies, his father will be proud*. No one would quarrel with the inference that John's father would be proud if it turned out John actually caught three butterflies, or more. The different readings of numeral expressions have been analyzed in different ways in the theoretical literature. According to one set of accounts, the 'exact' reading is derived from the 'at least' reading; according to another set of accounts, the 'at least' reading is derived from the 'exact' reading.

Consider the neo-Gricean account first (cf., among others: Horn, 1972; Levinson, 2000). The basic semantic meaning of a numeral is the 'at least' interpretation, and the 'exact' interpretation is derived through a pragmatic inference, namely a scalar implicature. A scalar implicature is triggered when a term (e.g. *some*) activates an asymmetrical entailing scale (e.g. < *some, many, most, all* >) that contains both the triggering term and one or more stronger alternatives to this term. The application of the scalar implicature yields the denial of the sentences that contain the stronger scalar terms. For example, the sentence *John caught all of the butterflies* contains the stronger alternative *all*, as compared to the sentence that contains the weaker term *some*. The use of the weaker term, *some*, in the sentence *John caught some of the butterflies* activates the scale < *some, many, most, all* > and yields the negation of the sentence with the stronger term, *all*, so the pragmatic inference is that John did not catch all of the butterflies. On the neo-Gricean account, numerals are subject to the same kind of scalar implicature, where a sentence with *two* implies the denial of the corresponding sentence with the stronger alternative *three*, with respect to the numeral scale < *two, three, four, five*, ... >.

An alternative proposal by Breheny (2008) maintains, like the neo-Gricean account, that the interplay between the meanings of numerals undergoes an 'enrichment' of meaning, but the alternative proposal is that the enrichment goes in the opposite direction. The basic meaning of a numeral is the 'exact' reading, on this account, and the 'at least' interpretation arises via a pragmatic inference. A third set of proposals contends that numerals are lexically ambiguous (Horn, 2004) or underspecified in meaning (Carston, 1998). The selection of the intended interpretation, on this account, is influenced by additional factors, such as discourse context and the speaker's intentions. When taken together with the findings of previous experimental studies of the acquisition of numerals, the present study is designed to provide evidence for adjudicating among these different accounts. The next section reviews the relevant previous literature.

4. Experimental data on the interpretation of numerals in adults and children

Experimental studies investigating children's interpretation of numerals and scalar quantifiers like *some* seem to have led to different conclusions. Studies of children's understanding of numerals have by-and-large reached the conclusion that children as young as three generate the stronger ('exact') interpretation of numerals. By contrast, studies of quantificational expressions like *some*, and logical connectives like disjunction, have concluded that children fail to derive the stronger interpretations ('some, but not all,' 'A or B, but not both') until they have reached the age of six or seven (e.g., Papafragou and Musolino, 2003; Musolino, 2004; Huang and Snedeker, 2009; Huang, Spelke and Snedeker, 2012; Guasti, Chierchia, Crain, Foppolo, Gualmini and Meroni, 2005). Further evidence has been reported in Barner, Chow and Yang (2009) showing that numerals and quantifiers are analyzed differently by young children. These researchers found that two-year-old two-knowers responded differently to the indefinite article *a*, as compared to the numeral *one*. More specifically, two-knowers consistently answered 'Yes' to the question "Is there *a* banana in the circle?" in a situation in which two bananas were in the circle, but answered 'No' to the question "Is there *one* banana in the circle?" in the same situation.

This pattern of behavior invites us to ask whether children who lack sensitivity to the scalar implicatures associated with logical expressions like *some* and *or* also lack sensitivity to the 'at least' meaning of numerals. Some studies suggest a negative answer to this question. First, Papafragou and Musolino (2003) showed that contextual factors can be manipulated so as to (at least temporarily) boost the performance of 4-5 year old children in deriving scalar implicatures for the quantifier *some* and, second, Musolino (2004) showed that 4-5 year old children also derive the 'at least' interpretation of numerals when provided with supporting context. Thus, children appear to possess the pragmatic competence to compute the enriched meanings of both quantifiers and numerals, but only if this computation is facilitated by contextual cues. In any event, the findings provide circumstantial evidence in favor of accounts in which the 'at least' interpretation is pragmatically derived from the 'exact' reading, as proposed for example by Breheny (2008). However, accounts of this kind abandon the generalization that pragmatic enrichment tends to proceed from weaker terms to stronger terms for quantificational expressions. Numerals would buck the trend, with pragmatic enrichment proceeding from the stronger meaning ('exactly N') to the weaker meaning ('at least N').

In addition to this theoretical incongruity, there are some empirical findings from experimental studies that challenge the view that pragmatic enrichment for numerals proceeds from strong to weak. We saw that the derivation of scalar implicatures is based on information strength, where a strengthened (derived) meaning constitutes a denial of the stronger alternatives. This happens in upward entailing contexts, for example. However, scalar implicatures are rendered inert in downward entailing linguistic environments, due to the reversal of entailment relations engendered by these environments. Building on the theory advanced by Chierchia, Fox and Spector (2008), Panizza, Chierchia and Clifton (2009) investigated the interpretations adults assign to numerals in upward entailing and downward entailing contexts. The upward entailing contexts introduced numerals in affirmative sentences like (1a-b): *John caught two/some butterflies*. In these contexts, the computation of a scalar implicature leads to a stronger meaning, which rules out the truth conditions in which John caught three/all of the butterflies. The downward entailing contexts contained numerals in the antecedent of conditional statements, in negative sentences and in the first argument of *every* (e.g. *Every boy who catches two butterflies will receive a prize)*. In these contexts the entailment relations are the reverse of those in affirmative sentences like (1a-b). In downward entailing contexts, the linguistic expressions *three* and *all* become the weaker terms, as compared to the expressions *two* and *some*. The Panizza et al. study found that adults adopted significantly fewer 'exact' interpretations of numerals in downward entailing contexts than in upward entailing contexts. Similar results have been reported in other offline studies with other scalar triggers (Noveck, Chierchia, Chevaux Guelminger and Sylvestre, 2002; Frazier, 2009). In short, a parallelism between numerals and other logical expressions (e.g. disjunction) has been uncovered in several studies with adults, once the entailment relations of the linguistic contexts in which these expressions appear are taken into account. These findings advocate a reinstatement of the generalization that is abandoned by accounts such as the one advanced by Breheny (2008), but which is favored by neo-Gricean approaches, according to which the weaker 'at least' interpretation is the basic meaning of numerals, and the stronger 'exact' meaning is derived (for discussion, see Panizza et al. 2009).

In another study, Panizza, Huang, Chierchia and Snedeker (2011) directly compared the interpretation of the quantificational expression *some* and numerals using a visual world paradigm experiment. As in the Panizza et al. (2009) study, they found that adults generated more 'exact' readings of numerals and 'some, but not all' interpretations of *some* in upward entailing contexts than in downward entailing contexts. Nevertheless, analysis of the online data revealed that subjects initially adopted the 'exact' reading of numerals in both upward entailing and downward entailing contexts, and there was also evidence that the derivation of the ‘some, but not all’ interpretation of *some* was substantially delayed in online processing (also see Huang and Snedeker, 2009). This pattern suggests that the basic meaning of numerals is the ‘exact’ reading, and that the ‘at least’ meaning of quantifiers may be computed as the semantic interpretation of the sentence is composed (cf. Landman, 2003; Ionin and Matushansky, 2006).

We will return to this dispute in the general discussion. A puzzle has arisen, however, in view of the findings we have reported so far. Here are the three puzzle pieces: First, children consistently adopt the ‘exact’ reading as the basic meaning of numerals. Second, adults seem to derive the ‘exact’ meaning of numerals by invoking a scalar implicature. Third, children are less sensitive to scalar implicatures than adults are. Something has gone awry. One way to resolve the dilemma would be to adopt a discontinuity hypothesis, as stated in (4).

(4) Children and adults employ different semantic/pragmatic representations and/or operations in interpreting numerals.

We will seek to confirm or disconfirm the discontinuity hypothesis in the experiment that follows, by seeing whether or not children’s interpretation of numerals is influenced by the entailment relations established by the linguistic environment. If children's interpretation of numerals is not affected by the entailment patterns of local expressions, then this will be taken as evidence in support of the discontinuity hypothesis (4). On the other hand, if children’s interpretation of numerals is influenced by entailment patterns in the same way as it is for adults, then we will reject the discontinuity hypothesis in (4). In that case, another solution to the puzzle is required. We return to this in the final section. The next section introduces the experiment that was designed to help sort out the puzzle pieces that have been uncovered in previous research.

5. The experiment: Kermit's race game

The experiment was designed to investigate the sensitivity of 3-5-year-old children to the entailment contexts in which numerals occur. A preliminary question worth asking is whether children are sensitive to entailment patterns in interpreting other constructions. Evidence affirming this comes from a study in which 3-6-year-old children's interpretation of disjunction in the two arguments of *every* was investigated (Chierchia, Crain, Guasti, Gualmini and Meroni, 2001). The first argument of *every* is downward entailing, whereas the second argument is upward entailing. Chierchia et al. found that children assigned an exclusive interpretation to disjunction more often (50% of the time) when it occurred in the second argument of *every* (e.g. *Every boy [chose a skateboard **or** a bike]*), than when it appeared in the first argument (e.g. *[Every boy who chose a skateboard **or** a bike] received an ice-cream*) (8.4% of the time). Adults’ responses displayed a similar, but more prominent, pattern: 100% of exclusive interpretations in upward entailing contexts vs. 4.5% in downward entailing contexts. Here, the exclusive interpretation of *or* is argued to arise through a scalar implicature. Given, then, that children seem to be sensitive to entailment patterns, and knowing that they are able to adopt the 'at least' interpretation of numerals if provided with pragmatic facilitation (Musolino, 2004), it is reasonable to ask how entailment patterns (upward entailment vs. downward entailment) interact with children's interpretation of numerals ('exact' vs. 'at least'). In the next section we discuss how the experiment addressed this question.

5.1 Participants, design and procedure

Thirty-three children between the ages of 3;4 and 5;6 (mean age 4;7) participated in the experiment. The participants were recruited in two daycare centers at Macquarie University (Sydney, Australia) and were tested individually in a quiet room on site, using a truth value judgment task (TVJT). The TVJT is designed to investigate which meanings children can and cannot assign to sentences (Crain and Thornton, 1998). The task involves two experimenters: one acts out short stories using toy characters and props, and the other plays the role of a puppet. At the end of each story, the puppet explains what he thinks happened in the story. The child's task is to decide whether the puppet said the right thing or not.

In our study, the puppet was Kermit-the-Frog (played by a native English-speaker), and Kermit wanted to organize some races between animals or vehicles. He enlisted the help of three boy characters to help him recruit three contestants for each race, as well as three prizes to be handed out after each race. In order to facilitate the 'at least' interpretation of numerals, we constructed scenarios based on a context of need, roughly along the lines of the protocol described in Musolino (2004). Kermit would pretend to whisper to each boy what was needed for each race. Then Kermit covered his eyes with a blindfold. This meant that he had to ask the child to confirm whether the boys had recruited the contestants or prizes that were needed for the race. For example, after the boys brought the contestants for a race, the child was asked to name them, to establish the name that the child assigned to each object. Then Kermit, still blindfolded, uttered either a sentence like (5) or (6) about each boy in turn. The crucial test sentences, containing a numeral, are highlighted in bold. The child's task was to reward Kermit's boy helpers with a coin, but only if Kermit's sentence correctly described what had happened in the story.

(5) I remember what I told this boy I needed: two butterflies. I think this boy brought me what I need. **I think this boy brought two butterflies**. **Give him a coin if I'm right**. Otherwise don't give him anything.

(6) I remember what I told this boy I needed: two butterflies. If this boy brought me what I need, **if this boy brought two butterflies, give him a coin**.

Otherwise don't give him anything.

Critically, in (5) the numeral *two* is embedded under the verb *think*, which generates an upward entailing context. In (6), instead, *two* is embedded in the antecedent of a conditional, which is a downward entailing context. The experimental manipulation was between-participants: half of the children were presented with sentences such as (5), whereas the other half were presented with sentences such as (6).

Once the child had judged all three boys' performance, Kermit removed his blindfold to see the race contestants and, regardless of whether the helpers had been rewarded by the child, Kermit asked the child to put the contestants on the racetrack. The child was then asked to actively race one of the contestants against the experimenter and the contestant acted by the child always won. This was done to break up the task, and make the racing game more engaging for the child. After each race the same procedure was repeated, but this time with Kermit asking his boy helpers to collect the necessary prizes to reward the race contestants with.

Each child listened to one warm-up story, followed by 8 experimental stories (in which the boy helpers either brought none, one, or three of the required contestants or prizes) and 2 filler stories (in which the boy helpers either brought none, one, or two of the required contestants or prizes). The different possible combinations of these options, and the order in which they were presented, were balanced across the stories. Every story contained three trials, one for each helper (for a total of 30 trials). On two of the three trials Kermit uttered an experimental sentence like (5) or (6), while on the third trial he uttered a similar sentence containing the indefinite *a*, rather than a numeral (e.g. "If this boy brought me *a* dragonfly, give him a coin."). The order of presentation of the three utterances was always different.

Each testing session included 8 critical trials. These critical trials were ones in which a boy had brought three of the necessary objects, when Kermit had asked for two. On these trials, 'reward' and 'no reward' responses can reveal which interpretation a child has assigned to the numeral: if a child interprets *two* as meaning 'at least two', they should reward the boy helper, whereas if the child interprets *two* as meaning 'exactly two', they should not. In addition, each session contained 22 filler trials: 10 true, and 12 false. True fillers either displayed an object match (e.g. Kermit asked for a dragonfly and the helper brought it), or a number match (e.g. Kermit asked for two butterflies and the helper brought exactly two butterflies). False fillers either displayed an object mismatch (e.g. dragonfly/butterfly), or a number mismatch (e.g. Kermit asked for two butterflies but the helper brought only one or nothing at all). These filler trials were included to make sure that a) the children knew the correct meaning of the numerals, b) that they understood the task correctly, and c) to identify children with a bias to always reward the helpers. Child participants who provided more than one reward for the wrong object or more than one reward for the wrong number were excluded from the analysis.

5.2 Results and discussion

Nine of the 33 participants were excluded from the analysis (five in the DE condition and four in the UE one) because they failed more than one filler item. All these participants rewarded the helpers in cases where they brought the wrong kind or number of contestants or prizes. Our rejection rate may have been high because we could not train the children in the warm-up task using trials containing numerals, otherwise we would have biased their behavior in the critical trials.

The remaining 24 participants responded as follows on critical trials. The 12 participants in the UE condition (i.e. sentence (5)), who ranged in age from 3;8 to 5;6 (mean 4;6), rewarded the boys 9% of the time. The 12 participants in the DE condition (i.e. sentence (6)), who ranged in age from 3;4 to 5;3 (mean 4;8), rewarded the boys 40% of the time. Recall that reward responses on critical trials indicate that a child has interpreted *two* as meaning 'at least two'. A Generalized Linear Mixed Model with *item* and *subject* as random factors and *condition* (UE vs. DE) as the fixed factor revealed the factor of condition to be significant ($z = 2.29$, $p. < 0.5$).

Given that our experimental sentences were identical across conditions except for the presence of the verb *think* vs. the presence of the conditional *if,* we claim that the difference we found in interpreting *two* in the two conditions is due to the entailment patterns of the embedding proposition. In addition, because our experiment design controlled for any children who may have had a response bias to reward helpers, we can be confident that our results are due to the structural influence of the two sentential environments presented to the children. From these results we conclude that 3- to 5-year-old children's interpretation of numerals is sensitive to the entailment patterns of the sentences in which they occur, as has been previously found with adults. The final section discusses the implications of the findings.

6. General discussion

The main question addressed in this study was whether 3-5-year-old children are sensitive to the entailment patterns of sentences that contain numerals, as adults are. Previous studies have demonstrated that young children typically assign the stronger 'exact' meaning to numerals, but that they are capable of deriving the 'at least' interpretation if this meaning is supported by the context. The results from the present study indicate that children, like adults, consistently interpret numerals like *two* with the 'exact' interpretation when *two* occurs in an upward entailing context. However, children assign this interpretation significantly less often to numerals appearing in a downward entailing linguistic environment, namely in the antecedent of a conditional statement. Based on the findings of previous studies of the influence of entailment patterns on numerals for adults (cf. Panizza et al., 2009; Panizza et al. 2011), we conclude that children exhibit the same sensitivity to entailment relations as adults do in interpreting numerals. In short, there is continuity in the performance of children and adults in the interpretation of numerals. We would infer from this that the linguistic representations assigned to numerals by 3-year-old children are the same as those of adults.

This finding has further implications. First, it rules out the kinds of discontinuity stated in hypothesis (4). It does not appear that the problems children experience in assigning an 'exact' meaning to numerals is due to the fact that they use different linguistic representations or invoke different linguistic operations. Instead, the linguistic apparatus of children appears to closely resemble that of adults. Both children and adults are sensitive to the abstract logical properties of entailment, and both invoke the same principles to derive the meaning of numerals, by maximizing informativeness. A similar conclusion was reached in Chierchia et al. (2001) for the assignment of meaning to disjunction. Here we offer evidence from a different domain, that of numeral expressions.

If the discontinuity hypothesis (4) is ruled out, however, then how can we account for the different behavioral responses by children and adults in their interpretation of other scalar terms? On the one hand, children are known to have trouble deriving such pragmatic inferences, yet they readily adopt the stronger reading of numerals, just as adults do. On the other hand, children are less likely than adults to compute scalar inferences for disjunction, or for the quantifier *some*, for example. There is more than one way to resolve this dilemma, depending on which theoretical account of numerals we assume.

If we maintain that the interpretation of numerals is determined by scalar implicatures, this would enable us to account for why numeral and scalar quantifier interpretations are affected by entailment relations in the same way. On this view, we are left puzzled by the finding that children are less likely than adults to compute scalar implicatures with quantifiers, whereas they appear to be the equals of adults in computing scalar implicatures with numerals. One possible explanation is that the alternatives are always active in the case of numerals, but they are not in the case of quantifiers. Because numerals are ordered on a scale (the number line), the use of one numeral could automatically call to mind both (some of the) preceding and subsequent numerals. To compute a scalar implicature upon hearing the quantifier *some*, by contrast, may not automatically activate the relevant alternative (i.e. *all*). For quantifiers, the alternative may require "activation" by the surrounding context; simply encountering *some* may not automatically call to mind the entire set of elements (*all*).

Another possible explanation is not incompatible with the one just put forward. Here the idea is that children gain experience in generating scalar implicatures with numerals early in the course of language acquisition, as soon as they become one-knowers. This hypothesis is in line with recent work by Barner and Bachrach (2010), who observe that one-knowers' competence in dealing with *two*, and in general N-knowers' competence with numerals N+1, is more advanced than their knowledge of higher numerals. To explain this, Barner and Bachrach advance the hypothesis that young children acquire the exact meaning of cardinalities by exploiting a Gricean algorithm (i.e. scalar implicatures) with numerals very early in life.

Another possibility is to maintain that the ‘exact’ meaning of numerals is basic, and that the 'at least' interpretation is derived via another kind of pragmatic enrichment (e.g. domain widening, cf. Panizza et al., 2011; Breheny, 2008). This would also explain why children consistently interpret numerals with the ‘exact’ reading. However, this solution would require us to postulate that pragmatic inferences similar to scalar implicatures are operative in children’s language, but they operate in the opposite direction. This further assumption is not problematic *per se*, although one is left wondering why numerals are the only linguistic construct to invoke the reverse implicature, as compared to quantificational expressions and logical connectives. Finally, the proposal that numerals are lexically ambiguous or underspecified would not explain why children and adults prefer the ‘exact’ interpretation of numerals over the ‘at least’ reading and why their interpretation is affected by the entailment patterns of other expressions in the same sentences, unless further stipulations are introduced.

It is time to take stock. This study investigated children’s understanding of the interplay between the interpretation of numerals and the entailment relations expressed in the linguistic environments in which they occur. Our conclusion is that in this arena of linguistic knowledge, children are as logical as adults. The linguistic system of children appears to be fully mature by the age of three, and shows a striking continuity with that of adults in assigning interpretations to numerals. There are important issues that we have mentioned only briefly, and many that we have not touched on at all, such as how numerals are initially acquired and whether or not their semantic properties are innately specified, or acquired through experience. We must leave these issues for future research, but hopefully we are a step closer to solving the puzzles about children’s interpretation of numerals.

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