The development of quantity implicatures in Mandarin-Speaking children

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Abstract

The present study reports a large, cross-sectional study of Mandarin-speaking children's ability to compute pragmatic inference. To chart the developmental trajectory of this pragmatic ability, we tested 225 Mandarin-speaking children aged between 4 to 8 years on three types of pragmatic implicatures: scalar, context-dependent and numeral implicatures. The results show that scalar implicatures posed difficulties for young Mandarin-speaking children and they did not exhibit a consistent success until age 6. In contrast, by 4 years of age this group was already able to compute context-dependent and numeral implicatures in an adult-like fashion. The implications of the current findings are discussed in relation to children's development of pragmatic inference as well as the relevance of cross-linguistic data in understanding pragmatic development.

Communication is a cooperative enterprise geared at jointly achieving certain conversational goals, and thus rational speakers in a conversation are expected to be cooperative. Grice operationalized the notion of “being cooperative” on the basis of four maxims – Quantity, Quality, Relation, and Manner (Grice, 1975). More specifically, rational speakers in a conversation ought to contribute to the conversation informatively, truthfully, relevantly, and perspicuously. If what a speaker says “flouts a maxim” blatantly, then in order to maintain the assumption that the speaker is rational and intends his/her utterances to be a meaningful contribution to the conversation, one must opt for a non-literal interpretation. This non-literal interpretation, which results from inferences about the speaker’s communicative intentions, is often referred to as the *implicature* of an utterance. In the present study, we focus on children’s knowledge of *quantity implicatures*, i.e., *implicatures* that result from a conflict between the maxims of quantity and quality.

Suppose a teacher asks a student “Have you finished your homework?” and the student responds by saying “I have done some of my homework.” It is generally acknowledged that the literal (logical) meaning of *some* is “at least one and possibly all.” Hence, on the literal meaning the student’s response is true in two situations: situations where the student did some but not all of his homework and situations where the student did all the homework. In the second situation, however, the student could have been more informative by saying “I have done all of my homework.” The student didn’t say so, presumably because he didn’t finish all of his homework, if we assume that the student was rational and cooperative. In this way, the use of a less informative utterance by the student indicates to the teacher that the student lacked evidence for

the more informative utterance, or even believed that the more informative utterance was false (e.g., Geurts, 2010; Horn, 1972).

This particular kind of quantity implicature (i.e., pragmatic inference from *some* to *not all*) used in the example is known as a *scalar implicature*. Scalar implicatures are so-called for being associated with expressions that evoke scales consisting of multiple expressions that are ordered by information strength. Information strength can be defined in terms of entailment relations. Statements containing informationally strong scalar terms entail statements containing informationally weak ones. For example, *some* and *all* are associated with the scale <*some, all*>, in which *all* is informationally stronger than *some*, because the statement containing the former (e.g., *I have done all of my homework*) entails the statement containing the latter (e.g., *I have done some of my homework*) but not vice versa. Scales that can give rise to scalar implicatures include, but are not limited to quantifiers <*some, all*>, logical words <*or, and*>, or modals <*might, must*> (Horn, 1972).

The computation of quantity implicatures such as scalar implicatures involves the interplay between semantics and pragmatics. Therefore, children's understanding of implicatures provides a good testing ground for investigating their abilities at the pragmatic and semantic interface. Much previous research has investigated children's computation of scalar implicatures. The findings are largely consistent: Children younger than 5 years of age are found to have difficulties in computing scalar implicatures (Gualmini et al., 2001; Guasti et al., 2005; Katsos & Bishop, 2011; Noveck, 2001; Papafragou & Musolino, 2003; Pouscoulous et al., 2007). Although there is a consensus that compared with adults, younger children are less likely to compute scalar implicatures, there is debate about the sources of the difference between children

and adults. In the next section of the introduction, we review leading accounts, and then in the subsequent section, we introduce the current study.

Theoretical accounts of children's difficulty with scalar implicatures

The literature on scalar implicatures has proceeded primarily by investigating children's difficulties. We briefly review three major accounts of children's difficulties in the interpretation of scalar implicatures (the task-based account, the processing limitation account, and the restricted alternatives account) before synthesizing our view of the literature. Although existing accounts present different explanations of these difficulties, they are not necessarily mutually exclusive – in principle, children could fail in particular scalar implicature tasks due to multiple different factors.

On the first account, children's difficulty in computing scalar implicatures is attributable to the nature of experimental tasks (Katsos & Bishop, 2011; Papafragou & Tantalou, 2004). Implicatures arise from conversations, where all the participants share the same contextual information and derive implicatures on the basis of this shared information. However, as pointed out by Papafragou and Tantalou (2004), participants' judgments on test sentences like *some giraffes have long necks* in Noveck (2001) were not based on conversational contexts but rather on their encyclopedic knowledge. If the participants evaluated the same test sentences against different background knowledge, then the difference between children and adults cannot be simply attributed to the difference in their ability to compute scalar implicatures.

In addition, many studies have used truth value judgment tasks or other binary judgment tasks. According to Katsos and Bishop (2011), children's true pragmatic ability might be masked by the use of binary judgment tasks where children were presented with questions or statements

and were asked to provide a “yes/no”, or “true/false” response. It is quite likely that in these tasks children were not fully satisfied with the under-informative scalar terms in the more informative contexts, but they did not treat the pragmatic under-informativeness as seriously as a logically false statement and thus were tolerant of it. This account is referred to as “pragmatic tolerance” by Katsos and Bishop (2011).

The processing limitation account provides an alternative explanation of children’s difficulties in the interpretation of scalar implicatures (Guasti et al, 2005; Huang & Snedeker, 2009; Pouscoulous et al., 2007). On this account, children’s difficulty in computing scalar implicatures is due to their limited processing capacity because it is hypothesized that the computation of scalar implicatures requires more processing resources than that of the basic logical interpretation. To test this hypothesis, Huang and Snedeker (2009) recorded children’s moment-to-moment processing of scalar implicatures as sentences unfold in real-time in a visual-world paradigm. 5-year-old children did not fixate implicature-consistent targets before hearing a disambiguating noun, indicating that they were not able to compute scalar implicatures in time to guide their eye-movements, presumably due to their limited processing resources.

A third account of children’s failures comes from an analysis by Barner, Brooks, and Bale (2011). They propose that children have difficulties generating the set of alternative utterances necessary to compute the scalar implicature, for example, “I have done *all*...” in the case where the actual utterance is “I have done *some*...”.

To test this “alternatives” account, Barner et al. (2011) compared children’s performance in making scalar implicatures (“Are *some* of the animals sleeping”) to their performance in an explicitly semantic task (“Are *only* some of the animals sleeping”). Surprisingly, children failed even in the “only” condition, suggesting that their failure was due to a failure to generate the

alternative “*all* are sleeping,” rather than just a failure to perform the pragmatic inference. Further evidence for this account comes from studies in which the alternatives associated with the scalar term were explicitly provided to children in the context. In these studies, children were found to consistently choose the more informative ones over the under-informative ones (Chierchia et al., 2001; Foppolo et al., 2012; Su, 2013; Tieu et al., 2016; Skordos & Papafragou, 2016).

This line of reasoning seems to be supported by studies investigating children’s computation of other types of implicatures: context-dependent implicatures (Barner et al., 2011; Guasti et al., 2005; Stiller, Goodman, & Frank, 2015) and numeral implicatures (Foppolo et al., 2012; Huang, Spelke, & Snedeker, 2013; Hurewitz et al., 2006; Musolino, 2004; Papafragou & Musolino, 2003). For example, Stiller et al. (2015) showed that 4-year-old children are already able to compute context-dependent implicatures (i.e., contextually derived “ad hoc” implicatures), where the relation between the alternatives depends on the context, further supporting the idea that children are more likely to compute implicatures when the alternatives are contextually available.

Although there is still some uncertainty surrounding the primary source of children’s difficulties, the empirical picture from the preceding studies is quite clear. 4- to 5-year-old English-speaking children have difficulty with computing scalar implicatures; in contrast, children of these age groups have already been able to generate the context-dependent implicatures, where the alternatives rely on the context, rather than on the scalar terms (Barner et al., 2011; Guasti et al., 2005; Stiller et al., 2015).

Most prior research focused on children speaking Indo-European languages, in particular English-speaking children. Only a few studies have examined children’s understanding of scalar

implicatures in Mandarin, a typologically distinct language (Su, 2013; Su & Su, 2015; Wu & Tan, 2009). Like their English counterparts, 4- and 5-year-old Mandarin-speaking children were found not able to compute implicatures associated with the scalar terms *youde* “some” (Wu & Tan, 2009), *youxie* “some” (Su & Su, 2015), and *huozhe* ‘or’ (Su, 2013); and they tended to assign the exact reading to numerals (Wu & Tan, 2009).

In terms of this ability that operates at the semantic and pragmatic interface, it is interesting to investigate the cross-linguistic data to see whether or not children from different language communities exhibit the same developmental pattern. Compared with other linguistic abilities, the issue of whether or not language background matters in the development of pragmatic abilities in children received less attention, though they are equally important. In the current study, we will turn our eyes on Mandarin and look at the development of quantity implicatures in Mandarin-speaking children.

The existing studies on Mandarin-speaking children focused on specific age groups without looking at the developmental trajectory of this pragmatic ability. In addition, no previous studies have investigated Mandarin-speaking children’s understanding of context-dependent implicatures. So, questions remain as to how the ability to compute pragmatic implicatures develops in Mandarin-speaking children and when children reach adult-like capacity. In the present study, we aim to chart the course of the development of this pragmatic ability in Mandarin-speaking children by comparing how 4- to 8-year-olds understand scalar implicatures versus context-dependent implicatures. We believe that testing a typologically distinct language is crucial towards a better understanding of the development of pragmatic implicatures in children.

The current study

We based our design on Horowitz, Schneider, & Frank (2017), who used a novel referent selection task to directly compare the computation of scalar and context-dependent implicatures in 4-year-old English-speaking children. In Horowitz et al. (2017) study, participants were introduced to a guessing game. On each trial, the participants were shown a picture with three book covers, each containing four items on it; after the experimenter uttered the test sentence, the participants were asked to select only one from the three book covers on the basis of the experimenter's description. Each participant was presented with context-dependent and scalar conditions. In the present study, we used a similar paradigm, but adopted a between-participants design.

Methods

Participants

225 monolingual Mandarin-speaking children participated in the study, including 61 4-year-olds (age range 4;0-4;11, mean age = 4;5), 61 5-year-olds (age range 5;0-5;11, mean age = 5;5), 40 6-year-olds (age range 6;0-6;11, mean age = 6;7), 21 7-year-olds (age range 7;0-7;11, mean age = 7;6), and 42 8-year-olds (age range 8;1-8;11, mean age = 8;7). The 4-year-olds and 5-year-olds were recruited from the Beijing Taolifangyuan Kindergarten. The 6-year-olds, 7-year-olds and 8-year-olds were recruited from the primary school attached to the Lianyungang Teachers' College Education Group. All the child participants had no reported history of speech, hearing or language disorders. In addition, 54 adult Mandarin-speakers were tested as controls. They were students from Tsinghua University and had no self-reported speech or hearing disorders.

Materials

Each trial consisted of a picture stimulus and a spoken sentence. The picture stimuli always contained three boxes. Two versions of picture stimuli were created. In one version, one box contained four animals of type A, one box contained four animals of type B, and one box contained two animals of type A and two of type C. An example picture stimulus of Version A is given in Figure 1, where the top right box contained four ducks, the bottom box contained four bunnies, and the top left box contained two ducks and two cats. In the second version, one box had four animals of type A, one had four animals of type B, and one had three animals of type A and one animal of type C. Figure 2 illustrates an example picture stimulus of Version B. Altogether 12 pictures of Version A and 12 of Version B were constructed. The positions of the three boxes in the picture stimuli were counterbalanced for both versions.

FIGURE 1 INSERT HERE

FIGURE 2 INSERT HERE

For the picture stimuli, four versions of spoken sentences were created, one containing the scalar term *youxie* ‘some’ (see (1)), one containing the verb phrase *zhuang-le* ‘contain’ (see (2)), one containing the existential verb *you* ‘have’ (see (3)), and one containing the numeral phrase *liang-zhi* ‘two’ (see (4)).

(1) Wo de hezi li **youxie** shi yazi.

I DE box inside some is duck

‘Some of the animals in my box are ducks.’

Scalar implicature: Some, but not all, animals in my box are ducks.

(2) Wo de hezi li **zhuang-le** yazi.

I DE box inside contain-ASP duck

‘My box contains ducks.’

Context-dependent implicature: My box contains only ducks.

(3) Wo de hezi li **you** yazi.

I DE box inside have duck

‘There are ducks in my box.’

Context-dependent implicature: There are only ducks in my box.

(4) Wo de hezi li you **liang-zhi** yazi.

I DE box inside have two-CL duck

‘There are two ducks in my box.’

Numeral implicature: There are exact two ducks in my box.

The four types of sentences generate different types of implicatures, as indicated underneath the sentences. The quantifier *youxie*, as in (1), is a typical existential quantifier in Mandarin (Tsai, 2003), and thus a typical scalar term, roughly corresponding to English ‘some’. Thus sentences

like (1) generate scalar implicatures. Both sentences containing the verb phrase *zhuang-le* ‘contain’, as in (2), and those containing the existential verb *you* ‘have’, as in (3), generate context-dependent implicatures. Both types of sentences were included in the study, because both structures are used in Mandarin to express the same existential meaning (‘at least one’). We were interested to see whether Mandarin-speakers compute the meanings of the two structures in a similar manner. Sentences containing the numeral phrase *liang-zhi* ‘two’, as in (4), generate a typical numeral implicature. We refer to the four types of sentences as (i) the scalar condition, (ii) the context-dependent *zhuang-le* condition, (iii) the context-dependent *you*-condition, and (iv) the numeral condition, respectively. Sentences in conditions (i), (ii) and (iii) were used as target sentences. Sentences in condition (iv) were included as control sentences. For conditions (i), (ii), and (iii), 12 target sentences were constructed each. For condition (iv), 12 control sentences were created.

The picture stimuli and the spoken sentences were divided into three experimental lists. List A consisted of the 12 target sentences in the scalar condition and the 12 control sentences in the numeral condition. List B consisted of the 12 target sentences in the context-dependent *zhuang-le* condition and the 12 control sentences in the numeral condition. List C consisted of the 12 target sentences in the context-dependent *you*-condition and the 12 control sentences in the numeral condition. In each list, half of the target sentences (n=6) and control sentences (n=6) were accompanied with pictures of Version A, and half of the target sentences (n=6) and control sentences (n=6) were accompanied with pictures of Version B. The 4-year-olds, the 5-year-olds and the adults were randomly assigned to one of the three experimental lists. The 6-year-olds, the 7-year-olds and the 8-year-olds were assigned to List A, but were not assigned to List B, because we found that the younger groups (the 4-year-olds and the 5-year-olds) already exhibited adult-

like performance in their computation of context-dependent implicatures for sentences containing the verb phrase *zhuang-le* ‘contain’ (List B). The 6-year-olds and the 8-year-olds were also assigned to List C.

Procedure

Both children and adults were tested using the referent selection task. The participants were told that they were going to play a guessing game with the puppet, the little pig, who appeared on a laptop computer screen. The little pig was going to show them lots of pictures, and every time he showed the participants a picture, he was going to ask the participants to guess whether his box was among the three boxes presented in the picture by telling them what was in his box. The participants’ task was, first, to tell the little pig whether his box was among the three boxes that they saw in the picture, based on their understanding of the little pig’s description of the box. If the participants believed that the little pig’s box was among the three boxes, then they were asked to point out which one.

At the beginning of each trial, a picture of the little pig occurred on the laptop computer to tell the participants that they should get ready for the game. Then, the picture stimuli were presented accompanied with a spoken sentence. The spoken sentences were prerecorded and were presented to the participants through the laptop computer connected to an external speaker to make it appear that the little pig was talking. The participants were asked to judge whether or not the little pig’s box was among the three boxes they saw in the picture, on the basis of their understanding of the spoken sentence. If they gave a ‘yes’ response, then they were asked to point out which one was the little pig’s box.

Participants were introduced to the task individually and were tested individually. In order to familiarize the child participants with the task, they were given 7 practice trials before the actual test session. On each practice trial, the participants saw a picture that was similar to the target picture stimuli as in Figures 1 and 2, and at the same time they heard a spoken sentence that did not involve implicatures of any kind. For instance, when the participants were presented with a practice picture as in Figure 1, they heard a spoken sentence as in (5).

(5) Wo de hezi li **zhi-you** tuzi.

I DE box inside only have bunny

‘There are only bunnies in my box.’

(5) contains the focus particle *zhi* ‘only’ and thus does not generate any implicatures. If the participants correctly interpreted the sentence, then they would be expected to tell the little pig that his box was among the three boxes in Figure 1 and pointed out that the bottom box was the one. If the participant failed on the first practice trial, the experimenter would help the participant to find the correct box. If the participant failed again on the second trial, then he/she was excluded from the test session. The adult participants only participated in the test session.

Predictions

If the participants were able to compute the relevant implicatures, the following performance should be expected in the four conditions. To illustrate, consider Figure 1 and the example spoken sentences in (1) to (4). In the scalar condition (scalar implicature), when hearing the spoken sentence in (1), the participants should choose the top left box in Figure 1, where some,

but not all, of the animals were ducks. In both the context-dependent *zhuang-le* condition and the context-dependent *you*-condition (context-dependent implicature), when presented with the spoken sentences in (2) and (3), the participants would be expected to choose the top right box in Figure 1, where all the animals were ducks. In the numeral condition (numeral implicature), when hearing the spoken sentence in (4), the participants should choose the top left box in Figure 1 which contained exact two ducks.

Results

The primary question of interest in our analyses was whether participants successfully computed the relevant implicature as measured by their choices between the target and the other two boxes in the visual display. We began our analysis by examining how participants responded to each implicature condition over development. Subsequently, we compared the developmental trajectories of these implicature conditions. We ended by examining whether and when the judgments of participants in each age group reflect their computation of the relevant implicature.

Means and standard deviations of the proportional looking to target in each implicature condition at different age groups are shown in Figure 3.

FIGURE 3 INSERT HERE

We used mixed-effects logistic regression models to quantify the effects of age and different conditions of implicatures on responding. In all of these models, we estimated the influence of these factors on the responses with random effects of participant and/or item (Gelman & Hill, 2006).

Scalar implicatures

Our first analysis considered only data from the scalar implicature trials and used a model that included age in years (continuous) as the only fixed factor. We found a significant main effect of age ($\beta = 1.06$, $SE=0.06$, $p < 0.0001$, $d=1.02$), indicating that participants became increasingly likely to choose the implicature-consistent target boxes over development. We next fitted a model treating age in years as a discrete variable to compare how children in different age groups varied in their interpretation of scalar implicatures. Results indicate that 5-year-olds were not significantly different from 4-year-olds in their responses to the scalar implicature condition ($\beta_{5vs.4} = -0.02$, $SE=0.20$, $p = 0.919$, $d=0.02$); however, 6-, 7- and 8-year-olds all chose the implicature-consistent target boxes significantly more frequently ($\beta_{6vs.4} = 1.90$, $SE=0.20$, $p < 0.0001$, $d=1.63$; $\beta_{7vs.4} = 2.57$, $SE=0.22$, $p < 0.0001$, $d=2.20$; $\beta_{8vs.4} = 4.38$, $SE=0.39$, $p < 0.0001$, $d=3.75$) than 4-year-olds. Therefore, starting from 6 years of age, children began to diverge from their original interpretation of sentences containing the scalar term *youxie* ‘some’.

Next, we examined the developmental trajectory of scalar implicatures after 6 years of age. We used the same model as before but only included data from 6-, 7- and 8-year-olds with age as a continuous factor. Results reveal a significant main effect of age ($\beta = 0.97$, $SE=0.07$, $p < 0.0001$, $d=0.93$), suggesting that between the ages of 6 and 8, children keep developing in their knowledge of scalar implicatures associated with *youxie* ‘some’.

We next included our adult data in the analyses. Treating age as a discrete variable, we compare how children in different age groups differ from adults in their responses to the scalar implicature condition. Setting adult as the reference level for the factor of age, we found that 4-, 5-, 6-, 7-year-olds ($\beta_{4vs.adult} = -5.51$, $SE=0.75$, $p < 0.0001$, $d=2.56$; $\beta_{5vs.adult} = -5.52$, $SE=0.74$, $p <$

0.0001, $d=2.56$; $\beta_{6\text{vs.adult}} = -3.61$, $SE=0.74$, $p<0.001$, $d=1.67$; $\beta_{7\text{vs.adult}} = 2.93$, $SE=0.75$, $p<0.0001$, $d=1.36$), but not 8-year-olds ($\beta = 1.05$, $SE=1.88$, $p=0.379$, $d=0.37$), were significantly different from the adult controls. These results indicate increasing developmental similarity to adults in children's capacity to compute scalar implicatures associated with *youxie* 'some'.

Context-dependent implicatures

Our first analysis of the context-dependent implicature conditions used the same logistic regression models as in the scalar implicature condition. Including age as the only fixed factor, we examined the developmental trajectory of children's responses to the context-dependent *you*-condition and the context-dependent *zhuang-le* condition, respectively. Treating age as a continuous variable and centered it at 4 years of age, we did not find a significant effect of age for the context-dependent *you*-condition ($\beta=0.05$, $SE=0.08$, $p=0.57$, $d=0.04$), indicating that children's computation of the context-dependent *you* implicature did not change significantly over the age range we tested. However, we found a significant effect of age for the context-dependent *zhuang-le* condition ($\beta=1.82$, $SE=0.90$, $p=0.042$, $d=0.82$). The positive coefficient indicates that 5-year-old children were more likely to compute the context-dependent *zhuang-le* implicature than 4-year-old children.

Next, we included our adult control data in the analyses and compared that with the responses of children at different age groups. Treating age as a discrete variable with the adult data as the reference level, we found that 4- and 8-year-olds significantly differed from adults ($\beta_{4\text{vs.adult}} = 1.17$, $SE=0.29$, $p<0.0001$, $d=0.58$; $\beta_{8\text{vs.adult}} = 1.35$, $SE=0.30$, $p<0.0001$, $d=0.67$) in their responses to the context-dependent *you*-condition but 5- and 6-year-olds did not ($\beta_{5\text{vs.adult}} = 1.17$, $SE=1.59$, $p=0.46$, $d=0.58$; $\beta_{6\text{vs.adult}} = 0.31$, $SE=0.22$, $p=0.16$, $d=0.15$). 4-year-olds did not

($\beta = 0.31$, $SE = 0.36$, $p = 0.40$, $d = 0.17$) but 5-year-olds did ($\beta = 1.92$, $SE = 0.59$, $p = 0.0012$, $d = 1.07$) significantly differ from adults in their responses to context-dependent *zhuang-le* condition. Moreover, the positive coefficients suggest that children were *more* likely to choose the implicature-consistent targets than adults.

Finally, we examined whether children responded differently to the context-dependent *zhuang-le* condition and the context-dependent *you*-condition over development. We thus tested a model for the developmental data that included age as a continuous factor, context-dependent implicature as a discrete factor with *zhuang-le* and *you* as the two levels, and the interaction between age and context-dependent implicature. We failed to find a significant interaction between context-dependent implicature and age ($\beta = -0.81$, $SE = 0.55$, $p = 0.15$, $d = 0.50$). Children's computation of context-dependent *zhuang-le* and context-dependent *you* implicatures could not be distinguished in our experiment.

Numeral implicatures

We used the same models as in the analyses of the previous two implicatures that included age as the only fixed factor and examined the developmental trajectory of the numeral implicature. Treating age as a continuous variable, we first examined the developmental data and found a significant effect of age ($\beta = 0.14$, $SE = 0.07$, $p = 0.029$, $d = 0.10$). Such an effect indicated that participants were increasingly likely to choose the implicature-consistent response over development. However, given the small effect size, it is uncertain whether the quantitative increase over age in children's implicature-consistent responses suggests a qualitative developmental change.

Next, we included our adult control data and treated age as a discrete variable to compare how participants in different age groups vary in their computation of numeral implicatures. Setting the 4-year-old data as the reference level, we found that none of the age groups were significantly different from the 4-year-olds in their responses. We also tested the same model by setting adults as the reference level and found that none of the age groups were significantly different from adults in their responses.

Scalar vs. Other implicatures

We next compared scalar implicatures with other implicature types. We tested a model that included age, implicature type (with scalar vs. context-dependent implicature *you*, or scalar vs. context-dependent implicature *zhuang-le*, or scalar vs. numeral implicature as the two discrete levels), and the interaction between age and implicature. We first ran this model with the developmental data and treated age as a continuous variable. Setting scalar implicature as the reference level for the factor of implicature type, we found a significant interaction between context-dependent implicature *you* and age ($\beta = -1.00$, $SE=0.09$, $p < .0001$, $d=0.76$), context-dependent implicature *zhuang-le* and age ($\beta = -0.91$, $SE=0.31$, $p = 0.004$, $d=0.65$), and numeral implicature and age ($\beta = -2.46$, $SE=0.45$, $p < .0001$, $d=0.55$). These results indicate that the scalar implicature associated with *youxie* diverges from all the other implicature types in its developmental trajectory. In addition, the negative coefficients in the interactions above suggest that as age increases, the divergence becomes smaller. A summary of the statistical results of the interactions between age and different implicature types for the developmental data can be found in the row of Table 1 where age is marked as continuous.

Next, we ran the model by including the adult control data and treating age as a discrete variable. Setting adults as the reference level for age and scalar implicature as the reference level for implicature type, we found significant interactions between 4-, 5-, 6- and 8-year-olds and the context-dependent *you* condition ($\beta_{4*you} = 6.67$, $SE=0.77$, $p < .0001$, $d=2.07$; $\beta_{5*you} = 6.80$, $SE=0.80$, $p < .0001$, $d=2.11$; $\beta_{6*you} = 3.99$, $SE=0.76$, $p < .0001$, $d=1.24$; $\beta_{8*you} = 2.38$, $SE=0.84$, $p = .005$, $d=0.74$). We also found significant interactions between 4- and 5-year-olds and the context-dependent *zhuang-le* condition ($\beta_{4*zhuang-le} = 6.06$, $SE=0.79$, $p < .0001$, $d=2.14$; $\beta_{5*zhuang-le} = 6.12$, $SE=0.81$, $p < .0001$, $d=2.34$). Similarly, we found significant interactions between 4- and 5-year-olds and the numeral condition ($\beta_{4*num} = 21.42$, $SE=3.63$, $p < .001$, $d=1.07$; $\beta_{5*num} = 19.39$, $SE=3.61$, $p < .001$, $d=0.98$). The positive coefficients in the interactions above suggest that children's computations of all other implicature types are more adult-like than their computation of scalar implicatures. A summary of the statistical results for the comparisons between the developmental data and adult control data can be found in Table 1.

TABLE I INSERT HERE

Taken together, the findings suggest that Mandarin-speaking children's ability to compute context-dependent and numeral implicatures develops earlier in life than their ability to compute scalar implicatures.

We finally compared the context-dependent implicature data with the numeral implicature data using the same models. We first ran the model with the developmental data and treated age as a continuous variable. Setting numeral implicature as the reference level, we found no significant interaction between implicature type and age for either context-dependent *you* and

context-dependent *zhuang-le*, suggesting that children's computations of numeral and context-dependent implicatures are similar in their developmental trajectories.

Next, we included the adult control data and treated age as a discrete variable. Setting adult as the reference level for age and numeral implicature as the reference level for implicature type, we first examined the context-dependent *zhuang-le* condition and found a significant main effect of implicature type ($\beta = -2.07$, $SE=0.57$, $p=.0003$, $d=0.39$), suggesting that adults provided implicature-consistent responses significantly lower in the context-dependent *zhuang-le* condition than in the numeral condition. However, the small effect sizes indicate that the difference between the context-dependent *zhuang-le* and numeral implicature is relatively minor. Besides, we found a significant interaction between 5-year-olds and implicature type ($\beta = 3.38$, $SE=0.83$, $p < .0001$, $d=0.63$), indicating that responses to the numeral condition at this age group are less adult-like than responses to the context-dependent *zhuang-le* conditions.

No interaction was found between age and implicature type for the context-dependent *you* condition, suggesting that different age groups of participants similarly and consistently responded to context-dependent *you* and numeral implicatures.

Evidence for the computation of pragmatic implicatures

In this section, we adopted an alternative analytic approach to investigate whether and when participants' responses in different implicature conditions yield evidence for the computation of pragmatic implicatures. As shown in Figure 2, each trial in our study included three different pictures in the visual display, with one picture containing none of the target items, one exclusively containing the target items, and the last one containing items of another type in addition to the target items. Thus, our data could be conceived as a sample from a typical

trinomial distribution with chance responding being 33.33%. Considering the data in this light, in the scalar implicature condition, the implicature-consistent responses of the 4-year-olds and 5-year-olds were close to random (0.33); the implicature-consistent responses of the 6-year-olds were noticeably higher than the chance level, and this pattern was even stronger for children older than 6. For the context-dependent and numeral implicature conditions, the implicature-consistent responses were consistently above the chance level for all the age groups.

We attempted to analyze these proportional responses against the chance level using a simple linear regression model. The dependent measure of the models was the difference score between the proportional looking to target and the chance level of 0.33. The independent variable was age, treated as a discrete variable. The rationale of this model is that individual participants could show clear evidence of greater-than-chance responding by choosing the target box at above chance levels. Thus, a positive coefficient would be a signal of the computation of pragmatic implicatures. We examined the effect of age independently for each implicature condition. Statistical results are presented in Table 2.

TABLE 2 INSERT HERE

As shown in Table 2, it was not until 6 years of age that participants showed a significant bias to choose the target box ($\beta_6 = 0.44$, $SE=0.10$, $p < 0.001$, $d=0.51$) for the scalar implicature condition. However, for all other implicature types, the 4-year-olds already showed a bias to choose the target box. Older children in these conditions were not significantly different from 4-year-olds.

General Discussion

Although pragmatic inference is a core part of adults' linguistic abilities, children struggle with scalar implicatures specifically. These failures are well-documented in the literature, but previous studies have typically target individual developmental groups, a relatively small set of comparison tasks, and Indo-European languages (typically English). In contrast, we reported the results of a large, cross-sectional study of Mandarin-speaking children's implicature abilities. We included comparisons to context-dependent (ad-hoc) implicature and numeral implicature, and tested 4- to 8-year-old children.

In our study, scalar implicatures associated with *youxie* 'some' were difficult for children and we did not see consistent success until age 6, while all three other comparison tasks showed performance closer to ceiling in 4-year-olds. These findings replicate and extend previous work in a number of ways. First, the age at which we see success in the scalar task is similar to previous reports (e.g., Guasti et al., 2005; Horowitz et al., 2017; Pouscoulous et al., 2007). Thus, this pattern appears to be consistent across languages and language families. Precise developmental comparison is of course complicated by differences in task across studies, but we do not see evidence here that would cause us to doubt the general cross-linguistic parallels in developmental trajectory.

Second, we see strong performance on context-dependent implicatures even in 4-year-olds (Papafragou & Tantalou, 2004; Barner et al., 2011; Stiller et al., 2015). Together with previous direct comparisons (e.g., Horowitz et al., 2017), these findings further suggest that the same children who succeed on context-dependent implicature also fail on scalar implicatures. Thus, the locus of failure in scalar implicature is likely to be specific to the use of quantifiers, rather than general to pragmatic inference more broadly.

Although they do not provide a definitive resolution to the theoretical debate discussed above in the Introduction, they provide some leverage. Since we used the same task in context-dependent and scalar implicature conditions, task-demand accounts of children's difficulties are not a parsimonious account of our data. In general, such accounts are better designed to explain failures in felicity judgment paradigms, rather than reference resolution paradigms like ours. In contrast, accounts that posit specific processing issues with scalar items or specific issues with the generation of scalar alternatives could account for our data more plausibly (e.g., the restricted alternatives account).

In addition, our findings on numeral implicatures are consistent with prior research: children as young as 4 years of age assign the exact/enriched meaning to numerals in the same way as adults do (e.g., *two* is *exact two* and not *three*) (Foppolo et al., 2012; Huang, Spelke, & Snedeker, 2013; Hurewitz et al., 2006; Musolino, 2004; Papafragou & Musolino, 2003). Numerals, like quantifiers, denote properties of sets, and thus are a paradigmatic instance of a scale (Levinson, 1983). Under the assumption that the exact meaning of numerals is derived via the same mechanism as other scalar implicatures (Barner & Bachrach, 2010), the findings that children acquire numeral implicatures earlier than other scalar implicatures seem to support the restricted alternatives account. It is generally acknowledged that early in the development, children are taught the count list <one, two, three, four, five...>, and through this counting practice they know that *three* is an alternative to *two* and *four* is an alternative to *three*, thus, enabling them to generate the set of alternatives on the numeral scale and compute the numeral implicatures. Alternatively, one can propose that numerals are fundamentally different from other scalar terms like quantifiers (Katsos et al., 2016). On this account, numerals have an exact semantics (the upper bound meaning), and therefore the computation of the exact meaning does not involve the

generation of a scalar implicature. This can explain the early acquisition of the exact meaning of numerals by children as well.

Although our work broadens the available data on cross-linguistic implicature development, it has a number of limitations. Our use of a reference-resolution paradigm facilitated comparison between different implicature types and reduced task demands (cf. Stiller et al., 2015), but much of the previous literature has used felicity judgment paradigms, so comparability is somewhat limited. In addition, the paradigm we created was designed to be relatively easy for children but there may be contexts in which scalar implicature is further facilitated (e.g., Skordos & Papafragou, 2016). Finally, like previous work our sample of children is recruited from highly-educated families and does not represent a broad population-level sample, so inferences at the population level should be made with caution.

Children's developing ability to make pragmatic inferences is an important part of their broader linguistic capacity. Young children show early competence using context-dependent communicative signals like pointing and gesture, and despite early abilities in using common ground (Clark & Amaral, 2010). Despite these abilities, they struggle with more prototypically linguistic implicatures such as the scalar implicatures we studied here. Understanding this developmental picture will require both a theory of how implicature relates to – and differs from – these other aspects of context-dependent communication. Further, it will require a cross-linguistic picture of the diversity and consistency of children's paths into pragmatic competence.

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Tables and Figures

Table 1. Interaction Coefficients between Age and Different Implicature Types⁺

	Context-dependent				Context-dependent				Numeral			
	<i>zhuang-le</i>				<i>you</i>							
<i>age</i>	<i>mean</i>	<i>SD</i>	<i>p</i>	<i>d</i>	<i>mean</i>	<i>SD</i>	<i>p</i>	<i>d</i>	<i>mean</i>	<i>SD</i>	<i>p</i>	<i>d</i>
cont.	-0.9	0.3	0.037	0.65	-1	0.1	<.001	0.8	-2.46	0.5	<.001	0.55
4	6.06	0.8	<.001	2.14	6.67	0.8	<.001	2.1	21.42	3.6	<.001	1.07
5	6.62	0.8	<.001	2.34	6.8	0.8	<.001	2.1	19.39	3.6	<.001	0.97
6	--	--	--	--	3.99	0.8	<.001	1.2	3.62	3.4	0.291	0.18
7	--	--	--	--	--	--	--	--	2.95	3.4	0.398	0.15
8	--	--	--	--	2.38	0.8	0.005	0.7	1.5	3.5	0.675	0.07

⁺Scalar implicature is the reference level for the factor of implicature type. Adult is the reference level for the fact of age if age is treated as a discrete variable in the regression models.

Table 2. Analytical Results for Evidence of Pragmatic Inference for Each Implicature Condition

Scalar					Context-dependent			
<i>you-xie</i>					<i>zhuang-le</i>			
<i>age</i>	<i>mean</i>	<i>SD</i>	<i>p</i>	<i>d</i>	<i>mean</i>	<i>SD</i>	<i>p</i>	<i>d</i>
4	-0.05	0.07	0.511	0.05	0.57	0.06	<0.001	3.24
5	0	0.10	0.967	0.01	0.9	0.08	<0.001	0.08
6	0.44	0.10	<0.001	0.51	--	--	--	--
7	0.55	0.10	<0.001	0.64	--	--	--	--
8	0.68	0.10	<0.001	0.80	--	--	--	--
Adult	0.71	0.11	<0.001	0.82	0.82	0.2	<0.001	0.42

Context-dependent					Numeral			
<i>you</i>								
<i>age</i>	<i>mean</i>	<i>SD</i>	<i>p</i>	<i>d</i>	<i>mean</i>	<i>SD</i>	<i>p</i>	<i>d</i>
4	0.57	0.1	<0.001	1.75	0.6	0.02	<0.001	3.63
5	-0.09	0.1	0.256	0.30	-0.09	0.03	<0.001	0.56
6	0.8	0.4	0.236	0.31	0.94	0.12	0.658	0.08
7	--	--	--	--	0.96	0.14	0.423	0.18
8	0.08	0.2	0.850	0.05	0.95	0.13	0.456	0.13
Adult	0.74	0.4	0.070	0.48	0.91	0.16	0.609	0.09

*The 4-year-olds are considered as the reference level in the regression models. Regression coefficients of other age groups indicate the deviations from 4-year-olds in the responses to target.

Figure captions

Figure 1. An example picture stimulus, Version A.

Figure 2. An example picture stimulus, Version B.

Figure 3. Average proportional responses to target in each implicature condition at different age groups. Error bars show 95% confidence intervals computed via subject-wise non-parametric bootstrap.

Figure 1.

Figure 2.

Figure 3.