

# Semantic Meaning and Pragmatic Interpretation in 5-Year-Olds: Evidence From Real-Time Spoken Language Comprehension

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Recent research on children's inferencing has found that although adults typically adopt the pragmatic interpretation of *some* (implying *not all*), 5- to 9-year-olds often prefer the semantic interpretation of the quantifier (meaning possibly *all*). Do these failures reflect a breakdown of pragmatic competence or the metalinguistic demands of prior tasks? In 3 experiments, the authors used the visual-world eye-tracking paradigm to elicit an implicit measure of adults' and children's abilities to generate scalar implicatures. Although adults' eye-movements indicated that adults had interpreted *some* with the pragmatic inference, children's looks suggested that children persistently interpreted *some* as compatible with *all* (Experiment 1). Nevertheless, both adults and children were able to quickly reject competitors that were inconsistent with the semantics of *some*; this confirmed the sensitivity of the paradigm (Experiment 2). Finally, adults, but not children, successfully distinguished between situations that violated the scalar implicature and those that did not (Experiment 3). These data demonstrate that children interpret quantifiers on the basis of their semantic content and fail to generate scalar implicatures during online language comprehension.

*Keywords:* language development, semantics, pragmatics, scalar implicature, quantifiers

To become linguistically competent, children must be able not only to understand the literal content of utterances but also to make appropriate inferences that capture the speaker's intended meaning. For example, in the dialogue in (1), we can infer from Mother's response that the child is not allowed to eat the entire cake.

- Child:* Can I please eat the cake? (1)  
*Mother:* You can have a slice.

Nevertheless, eating a slice of cake does not rule out the possibility of finishing it. In fact, one event typically precedes the other. Thus, we can imagine a situation where our initial inference (I ate a slice but no more) is explicitly canceled by a subsequent statement in (2).

- Mother:* Did you eat a slice of the cake? (2)  
*Child:* Yeah, I ate a slice. In fact, I ate the whole thing.

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This division between a linguistically encoded meaning and the inferences that we can derive from it was made prominent by Grice (1957, 1975). *Semantics* refers to the aspects of the interpretation that can be directly calculated from the meanings of words and the structural relationships between them. In contrast, *pragmatics* refers to the aspects of interpretation that are inferred through an analysis of the context and the communicator's goals. Grice proposed that though pragmatic inferences make use of the semantic content of an utterance, they are distinct from truth conditional meaning because they are frequently defeasible, as in (2).

What role does this distinction play in children's language comprehension? Recent research has begun to examine how children derive pragmatic inferences that go beyond an initial semantic meaning. For example, when the child hears Mother's response in (1), can she correctly infer that she has been prohibited from eating the entire cake? Surprisingly, researchers have found that even school-age children can be quite literal in their interpretation of utterances and that they often fail to generate robust inferences (Bernicot, Laval, & Chaminaud, 2007; deVilliers, deVilliers, Cole-White, & Carpenter, 2008; Harris & Pexman, 2003; Noveck, 2001; Papafragou & Musolino, 2003; Vosniadou, 1987). One might surmise that children are simply pragmatically incompetent or uninterested in speakers' intentions. But this broad interpretation is difficult to reconcile with the ample evidence that even young toddlers can make sophisticated inferences about the communicative intentions of others during word learning (Baldwin, 1993; Tomasello, 1992).

How then do we make sense of this tension between the pragmatic sophistication of early toddlers and the stubborn adherence to literal meaning of school-age children? In this paper, we seek to understand the nature of children's surprising failures by exploring children's behavior using a more naturalistic measure of comprehension. The experiments described here recruited children's eye movements as an implicit indication of children's ability to gen-

erate postsemantic inferences. Because eye movements are tightly linked to the processing of spoken language, they can also potentially provide a fine-grained measure of how interpretations unfold over time. Following prior research, we focus on the relationship between word meaning and ultimate interpretation by examining a test case in which the division between semantic meaning and pragmatic inference is sharply defined: the interpretation of scalar quantifiers. In the remainder of the Introduction, we flesh out an account of the semantics of scalars and briefly review recent studies on children's understanding of scalar terms. We also discuss possible limitations of previous tasks and describe a series of experiments designed to probe the development of pragmatic interpretation through an implicit measure of language processing.

### The Gricean Theory of Scalar Interpretations

Linguists have noted that scalar quantifiers, like *some*, have two distinct interpretations. Typically, sentences such as the child's response in (3) will imply that the child ate some but not all of the spinach.

*Mother:* Did you eat your spinach? (3)

*Child:* I ate some of it.

However, on occasion *some* can be used in a context that does not exclude the total set. For example, Popeye asserts in (4) that he has eaten some of the spinach but then goes on to explain that he ate all of it.

*Olive Oyl:* If you ate some of the spinach, I won't have enough for dinner! (4)

*Popeye:* I ate some. In fact, I needed me strength, so I ate it all.

Formal treatments of natural language have suggested these two interpretations of *some* are actually the result of a single meaning (Gadzar, 1979; Horn, 1972, 1989). As Figure 1 illustrates, the *some* and *all* can be ordered on a scale with respect to the strength of the information that they convey. On this theory, the meaning of the weaker term (*some*) is consistent with all values greater than a lower boundary (*some* is greater than *none*) up through and including the maximum (*all*). In sentences such as (4), this meaning is transparent. Interpretations such as this are termed *lower*

*bounded*, because the scalar term has a lower boundary but no upper bound.

However, *some* is typically interpreted as having an additional boundary that excludes referents that are compatible with *all*. This happens via a pragmatic inference called a *scalar implicature*. According to Grice, the participants in a conversation expect that each will tailor his or her contribution to be as informative as required but no more informative than required (quantity maxim). To see how this might occur, one can imagine a situation in which the child had actually polished off the spinach and uttered (5).

*Child:* I ate all of the spinach. (5)

The existence of this more informative alternative means that if the speaker chooses instead to use a weaker scalar term, as in (3), the listener can apply the quantity maxim and infer that this was a situation in which the stronger scalar term was not true. This interpretation is called *upper bounded*, because it imposes an additional boundary on the upper end of the scale. Thus we can infer that if the child had eaten all of the spinach, she would have simply said so. But, as she did not, she must have eaten only some and not all of it.

This logic can be extended to any set of terms that can be placed on an ordinal scale and that differ in their strength (Horn, 1972, 1989; Levinson, 2000). Parallel inferences have been noted for a wide range of expressions that include scalar adjectives (*warm* vs. *hot*), aspectual verbs (*start* vs. *finish*), and logical operators (*or* vs. *and*). Scalar implicatures can even be generated in cases where alternatives are ordered solely by virtue of the context or our knowledge of common practices (Hirschberg, 1985; Katsos & Bishop, 2008; Papafragou & Tantalou, 2004). For example, in (1) our knowledge of the part-whole relationship establishes a scale where Mother's use of the weaker alternative (slice of cake) leads us to infer that the stronger alternative is not true (entire cake).

Although this division between semantic content and pragmatic inference has been widely accepted, there are divergent theories about the nature of these two levels of representation and their relation to one another (Levinson, 1983, 2000; Recanati, 2003; Sperber & Wilson, 1986/1995). More recent Neo-Gricean accounts have argued that the habitual generation of implicatures could result in their automatization and lead to rapid deployment of the restricted meaning during conversation (Levinson, 1983, 2000). Another proposal links the generation of scalar implicatures to the grammatical properties of the sentence (Chierchia, 2004). Finally, according to the Relevance theory, the calculation of scalar implicatures is associated with the trade-off between the possible gains associated with generating an inference and the amount of cognitive effort necessary to derive it (Carston, 1998; Recanati, 2003; Sperber & Wilson, 1986/1995). All these accounts acknowledge that though many aspects of utterances are tightly linked to word meaning and syntactic structure, other facets are clearly added by context-sensitive, inferential processes. This paper explores this dichotomy by testing children's ability to make this simple, pragmatic inference during real-time language comprehension.

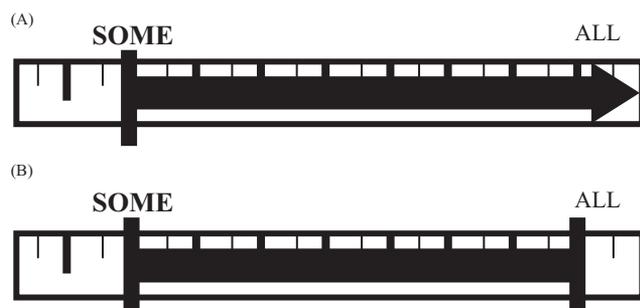


Figure 1. Two interpretations of *some*. (A) Lower bounded reading: The semantics of *some* can be described as referring to a ray along a quantity scale. (B) Upper bounded reading: *Some* is typically interpreted with a pragmatic inference that excludes *all*.

### Previous Research on the Development of Scalar Implicatures

*Some* and *all* are among the first quantifiers that children produce (Dale & Fenson, 1996). Nonetheless, developmental research has demonstrated profound differences in adults' and children's comprehension of these terms. When presented with a weaker term, like *some*, adults consistently favor the upper bounded reading and children prefer the lower bounded one (Barner, Chow, & Yang, 2009; Noveck, 2001; Papafragou & Musolino, 2003; Pouscoulous, Noveck, Politzer, & Bastide, 2007; Scafton & Feeney, 2006; Smith, 1980). The same curious pattern emerges across a variety of scalar terms that includes conjunctions, modals, and predicates (Braine & Rumain, 1981; Chierchia, Crain, Guasti, Gualmini, & Meroni, 2001; Noveck, 2001; Papafragou & Musolino, 2003; Paris, 1973).

Although this work seems to suggest that children have a global inability to calculate scalar implicatures, some researchers have argued that these studies vastly underestimate early pragmatic competence (Papafragou, 2006; Papafragou & Tantalou, 2004). In particular, two features of prior tasks may limit the conclusions we can draw. First, most of these studies employ judgment tasks that require children to explicitly reason about another character's statement. For example, in Papafragou and Musolino (2003, Experiment 1), adults and children saw a scene in which a girl finished a puzzle and heard a puppet utter the statement "The girl started the puzzle." Participants were then asked to evaluate whether this puppet "answered well" in its description of the situation. Thus, rather than directly assess whether the use of *started* led children to infer *not finished*, these tasks measured the participants' ability to reason about the felicity of the puppet's use of the weaker term. Such judgments may require significant metalinguistic awareness, an ability that develops slowly over the school years (Papafragou, 2006; Papafragou & Tantalou, 2004; Pouscoulous et al., 2007).

Second, these judgment paradigms frequently rely on the use of underinformative sentences. For example, in Smith's (1980) original study, adults and preschoolers were asked to agree or disagree with statements such as "Some elephants have trunks." Here the weaker term is used to describe situations in which all members of the category share a particular property. Similarly, Noveck (2001) asked adults and 7-year-olds whether the puppet's statement "There *might* be a parrot in the box" was correct in a context where they knew that it *must* be so. In both cases, participants' spontaneous judgments revealed participants' interpretation of the sentence: Rejections indicated an upper bounded reading, and acceptances indicated a lower bounded one. Notice, however, that both true and false judgments correspond to semantically valid uses of the quantifier. Thus, in order to succeed, participants needed to recognize that the goal of the task relates to assessing the pragmatic felicity of an utterance and not its truth-value. Adults may grasp this subtlety with minimum instruction, but children may be less able to do so.

More recent studies have suggested that children can generate scalar implicatures under some circumstances. For example, Papafragou and Musolino (2003, Experiment 2) encouraged children to assess the felicity of an utterance by telling them that the speaker says "silly things" and that the researchers' goal was to help the children "say them better." The children were given

several practice trials in which the puppet labeled things either as the children probably would ("a dog") or in an unnatural way ("an animal with four legs"). After this training, children were more likely to reject underinformative statements (*started* when *finished* is true). This finding suggests that they may have calculated an implicature (48% post-training compared to 10% without training). Similarly, Papafragou (2006), following Papafragou and Tantalou (2004), asked children to reward the puppet for completing particular tasks (building the school). When the puppet subsequently stated "I started to build it," Papafragou (2006) found that children often correctly withheld the prize (47% of the time). These findings suggest that children are more likely to generate scalar implicatures in situations where the stronger alternative is made more salient.

Recently, Pouscoulous et al. (2007) examined whether children are more likely to calculate implicatures when the cognitive demands of doing so are minimized. They used an act-out task ("make some boxes contain a token") and varied processing costs by manipulating linguistic and task-related variables. They found that children had less difficulty generating implicatures when less complex scalar expressions were used and when the task involved a smaller number of distractors. Pouscoulous et al. also observed that children were more likely to interpret *some* with an implicature in this act-out task than they had been in prior judgment tasks. Altogether, these findings suggest that the degree to which children will generate scalar implicatures varies depending on cognitive load. They also suggest that the developmental difference between children and adults in previous studies on implicature could be driven by children's more limited processing abilities.

This raises the intriguing possibility that if all extraneous task demands were removed—and no action or judgment were required—children's comprehension might be quite similar to that of adults. In the current study, we examined children's ability to calculate scalar implicatures in a naturalistic task in which eye movements were used as a spontaneous measure to track interpretation during real-time language processing. Unlike those in prior studies, this paradigm removed all overt task demands and used sentences that are globally unambiguous. Under these circumstances, would the pragmatic skills of children more closely approximate those of adults?

### Constructing a Naturalistic Method for Assessing the Interpretation of Scalar Terms

We examined children's sentence comprehension in the following experiments using the visual-world eye-tracking paradigm (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). In this procedure, participants are presented with spoken instructions asking them to manipulate objects within a visual reference world while their eye movements to those objects are being measured. This indirect measure of comprehension has several advantages for exploring the development of the semantic and pragmatic interpretations. First, because eye movements are typically made without conscious reflection, they provide a more implicit measure of comprehension prior to any overt strategic judgments. Second, because eye movements are rapid, frequent, and tightly linked to the processing of spoken language, they can potentially provide a fine-grained measure of how interpretations unfold over time.

In the following experiments, 5- and 6-year-olds heard stories in which two types of objects were divided up between four characters. These stories were accompanied by a visual display. In Experiment 1, the items were always divided such that one of the critical characters (the girls) had a proper subset of one item (the socks) and the other critical character had the total set of second item (the soccer balls). In the critical condition, children were given instructions such as “Point to the girl that has some of the socks,” and their eye movements were recorded. These trials contained a period of semantic ambiguity, beginning at the onset of the quantifier, during which the referent of a lower bounded reading of *some* is compatible with both characters. Nevertheless, at any point during this time, a scalar implicature can be generated to rule out the girl with the total set (the Distractor) in favor of the girl with the subset (the Target).

We compared eye movements to the Target in this some condition to those in trials asking for “all of the socks” (when the Target has all the socks and the Distractor has a subset of the soccer balls). Because the Distractor in the all trials is inconsistent with the semantics of the quantifier, we predicted quick referential disambiguation in these trials. To ensure that differences between these trials were not simply due to preferences for larger quantities or greater difficulties in calculating upper bounds relative to lower bounds, we also used terms from a number scale. Like *all*, *two* and *three* do not require a pragmatic inference to specify exact quantities, and thus they do not have the same temporary semantic ambiguity as *some* (Papafragou & Musolino, 2003). Performance on the two trials provides a particularly crucial comparison, because its meaning rules out the same Distractor as *some* would once the implicature is calculated. By comparing these trials we can examine whether children can restrict reference via semantic content as well as pragmatic implicature.

## Experiment 1

### Method

**Participants.** Twenty adults and twenty 5-year-olds (ranging from 5 years 2 months to 6 years 1 month; mean age 5 years 7 months) participated in this study. For all three experiments, the adult participants were undergraduates at Harvard University who received course credit for their participation. Their performance served as a comparison for children’s abilities in this task. Full presentation of their data in Experiments 1 and 2 appears in Huang and Snedeker (2009). The children were recruited from the database of the Laboratory for Developmental Studies, which enrolled participants through birth records and the distribution of pamphlets in the Boston area. Information on participants’ ethnicity, parental education, income, and occupation was never recorded, but prior work with this population suggests that participants predominantly come from middle-and-high socioeconomic status homes and are primarily Caucasian. This age-group was selected because much of the previous work on children’s calculation of scalar implicatures has targeted this age range. All participants in every experiment were native monolingual English speakers.

**Procedure.** Participants sat in front of an inclined podium divided into four quadrants, each of which contained a shelf on which pictures could be placed. A camera at the center of the display was focused on the participant’s face and recorded the

direction of gaze while the participant was performing the task. A second camera recorded both the participant’s actions and the location of the items in the display. At the beginning of the study, the experimenter took out pictures of four characters, placed them on each shelf in a prespecified order, and told the participants that “these boys and girls would receive different things during the game.” Every trial consisted of the experimenter acting out a scripted story using pictures of the relevant objects. This was followed by an utterance that instructed the participants to pick up a particular character. Once the participants did this, the trial ended, the objects were removed from the display, and the next trial began.

**Materials.** The four quantifiers represented the cells of  $2 \times 2$  design in which the first factor, quantifier scale, contrasts terms derived from the critical Gricean scale (*some* and *all*) with terms from the control number scale (*two* and *three*). The second factor, quantifier strength, contrasts the weaker quantifiers (*some* and *two*) with the stronger ones (*all* and *three*).

The visual displays featured four characters that were aligned in the following clockwise order, beginning from the upper-left quadrant: Craig, Judy, Cheryl, and Pat. This arrangement ensured that the vertically adjacent characters matched in gender and that the horizontally adjacent characters did not (see Figure 2). We constructed 16 stories such as (6) below. In each story, two types of objects were introduced and distributed among the pairs of boys and girls.

The boys and girls on the soccer team were getting socks and soccer balls from the coach. The coach gave socks to Judy and socks to Craig [experimenter places two socks next to the girl on the upper right and two socks next to the boy on the upper left]. The coach knew that Pat was already a very good soccer player but he thought that Cheryl needed a lot of practice [experimenter places a blank card next to the boy on the lower left and three soccer balls next to the girl on the lower right]. (6)

The distribution of objects among the characters differed according to the quantifier scale. For some and all trials, one set of four items was split evenly between a horizontally adjacent pair (girl with two socks and boy with two socks) and another set of three items, which was given to one child from the remaining pair (girl with three soccer balls and boy with no soccer balls). For two and three trials, the first set was again evenly split between one boy–girl pair, but the second set now included a fourth item given to the character who had previously received nothing (boy with one soccer ball). This difference between the number and quantifier trials was necessary to ensure that the verbal descriptions were felicitous for all trial types. Saying “three of the socks” would be odd when there are only three socks in total, but adding an extra object to the character of opposite gender makes the utterance felicitous without changing the visual properties of the critical Target or Distractor characters (Huang & Snedeker, 2009c).

Introducing the objects as part of a single large set and then dividing that among the characters established a frame of reference that constrained the interpretation of the quantified phrases. For example, “all of the soccer balls” most naturally referred to all the soccer balls that the coach has rather than all of the soccer balls in the known universe or all of the soccer balls that Cheryl has. In addition, the stories ensured that children knew the labels that they would be using for each object. These objects were referred to with

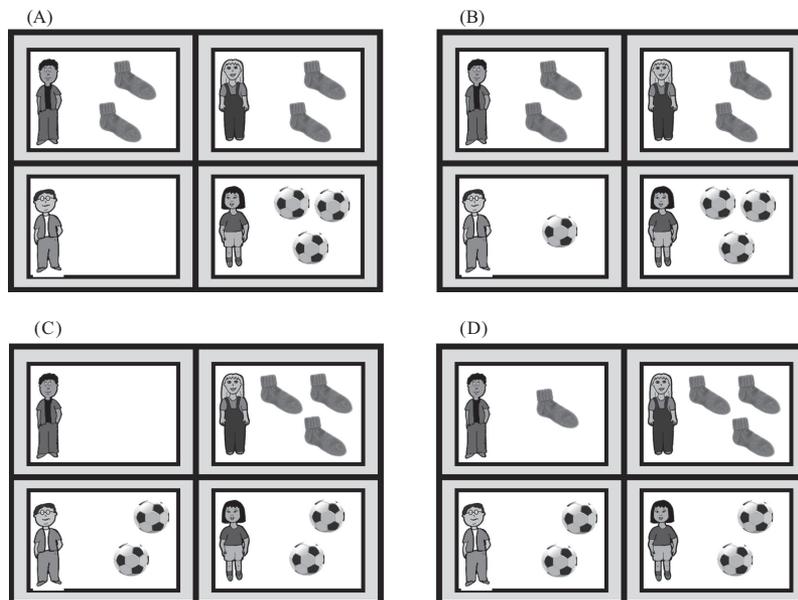


Figure 2. In Experiment 1, examples of visual-world displays for (A) some, (B) two, (C) all, and (D) three trials. Participants here were instructed to “Point to the girl that has \_\_\_\_ of the socks.” The girl with socks was the Target, and the girl with soccer balls was the Distractor.

definite noun phrases (e.g., *the socks*) or bare plurals (e.g., *socks*) to ensure that children were not primed to associate a particular subset with the numbers and quantifiers used in the instructions. In a separate task, these contexts were verified to successfully establish expectations that (a) quantifiers would refer specifically to the sets in the display, (b) objects would be identified by basic-level labels, and (c) *some* would be interpreted with a scalar implicature (Huang & Snedeker, 2009c).

For each story, we created a quartet of target sentences, like those shown in (7).

Point to the girl that has some/all/two/three of the socks. (7)

The target sentences in each condition were identical except for the gender of the child that was requested and the identity of the final word. The gender of the child was linked to the content of the story: If the set of three objects had been given to a girl, then a girl was requested. The names of the two items that were distributed always had the same onset (e.g., socks and soccer balls), and this created a brief period of ambiguity during which the identity of this noun was uncertain. A complete list of the materials for all experiments may be obtained from Yi Ting Huang. Target sentences were recorded by a female actor, and the digital waveforms were examined to ensure that they had a consistent unmarked prosody. The sound files were edited to equate the lengths of two critical regions: (a) from sentence onset to the gender cue (“Point to the”) and (b) from the onset of the gender cue to the onset of the quantifier (“girl that has”). We used four versions of each base item to create four presentation lists, such that each list contained four items in each condition and each base item appeared just once in every list.

*Coding.* Trained research assistants watched videotapes of the participants’ actions and coded them based upon selection of one

of the four characters. Across all experiments, we included only those trials in which participants correctly selected the Target in subsequent analyses of eye movements. Approximately 9.6% of child trials were excluded on this basis. An additional 0.9% of adult trials and 1.0% of child trials were excluded from further analyses because of experimenter error.

Eye movements were coded by a research assistant, who was blind to the location of each object, using frame-by-frame viewing of the participant’s face on a Sony digital VCR. Each recorded trial began at the onset of the instruction and ended with completion of the corresponding action. Each change in direction of gaze was coded as toward one of the quadrants, at the center, or missing due to looks away from the display or blinking. These missing frames accounted for 2.0% of coded frames in adults and 12.4% of coded frames in children. Afterward, these looks were recoded on the basis of their relation to the final instruction: (1) Target, (2) Distractor, or (3) other characters that did not match gender cues. Twenty-five percent of the trials were checked by a second coder, who confirmed the direction of fixation for 93.6% of coded frames in adults and 97.3% of coded frames in children. Any disagreements between the two coders were resolved by a third coder.

## Results

Across all experiments, we first conducted a coarse-grained analysis of adults’ and children’s fixations as the target utterance unfolded. The dependent measure was total looking time to the Target as a proportion of looking time to the Target and the Distractor. This score ranged from zero (exclusive looks to the Distractor) to one (exclusive looks to the Target). Fixations to the other characters after onset of the gender cue accounted for less than 10% of total looks across all experiments and were not included in subsequent analyses.

Each period was analyzed with subjects and items analyses of variance (ANOVAs) with quantifier scale (number vs. scalar) and quantifier strength (lesser vs. greater) as within-subject and -item variables and list/item group as a between-subjects and -items variable.

Table 1 lists the duration of the five time windows that were analyzed. Each period is shifted 200 ms after the relevant marker in the speech stream to account for the time it would take to program a saccadic eye movement (Allopenna, Magnuson, & Tanenhaus, 1998; Matin, Shao, & Boff, 1993). The first two regions, the baseline phase ("Point to the") and the gender phrase ("girl that has"), provide comparisons of looks to the Target and Distractor before the introduction of any quantifier information. Among adults, there were no reliable effects of quantifier scale or quantifier strength during these periods ( $F_s < 4.00$ ,  $p_s > .05$ ). However, among children the Target looks differed across the trial types even prior to the onset of the quantifier (see Figure 3). There was a greater preference to look at the Target in the three and all trials relative to the two and some trials, leading to a significant effect of quantifier strength in both the baseline phase,  $F_1(1, 19) = 25.19$ ,  $p < .01$ ,  $\eta^2 = .57$ ;  $F_2(1, 15) = 13.85$ ,  $p < .01$ ,  $\eta^2 = .48$ , and the gender phase,  $F_1(1, 19) = 10.66$ ,  $p < .01$ ,  $\eta^2 = .35$ ;  $F_2(1, 15) = 8.63$ ,  $p < .01$ ,  $\eta^2 = .37$ . This indicates that children had a bias to look at the character with the larger quantity of items: the person with 3 in the number trials and the person with the total set on the quantifier trials.

*Adults: Post-quantifier saccade analysis.* In order to isolate differences that emerged following the onset of the quantifier, we conducted an additional analysis of saccades initiated after quantifier onset. In these saccade analyses, we separated the trials on the basis of the object that the participant was fixating in the previous frame (Target or Distractor) and calculated the probability of switching to the other object following the onset of the quantifier. Analyses of this kind have been used extensively in research on the development of word recognition (Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998; Swingley & Fernald, 2002; see also Altmann & Kamide, 2004) and allowed us to factor out early differences in fixation patterns by specifically comparing trials on which participants were looking at the same objects when the quantifier began.

We began by examining Target and Distractor saccades during the quantifier phase. This critical period begins from the onset of the quantifier and ends prior to the onset of the disambiguating phoneme ("some/all/two/three of the soc-"). This region averaged 667 ms in length. Our initial coarse-grained analysis examined all switches that occurred during this time period. Adults exhibited equal looks to the Target ( $M = 32\%$ ,  $SE = 4\%$ ) and Distractor ( $M = 30\%$ ,  $SE = 4\%$ ) across all conditions immediately prior to the region,  $t_1(19) = 0.38$ ,  $p > .70$ ,  $\eta^2 = .01$ ;  $t_2(15) = 0.29$ ,  $p >$

$.70$ ,  $\eta^2 = .01$ . However, following the onset of the quantifier, we found that adults' switches varied across conditions. Although switches to the Target exceeded switches to the Distractor in the two ( $M = 36\%$ ,  $SE = 5\%$  vs.  $M = 17\%$ ,  $SE = 4\%$ ), three ( $M = 37\%$ ,  $SE = 6\%$  vs.  $M = 12\%$ ,  $SE = 3\%$ ), and all trials ( $M = 34\%$ ,  $SE = 5\%$  vs.  $M = 17\%$ ,  $SE = 4\%$ ,  $p_s < .05$ ), they did not differ from each other in the some trials ( $M = 17\%$ ,  $SE = 4\%$  vs.  $M = 8\%$ ,  $SE = 3\%$ ,  $p > .30$ ). This led to a significant Quantifier Scale  $\times$  Quantifier Strength interaction during this period,  $F_1(1, 19) = 6.34$ ,  $p < .05$ ,  $\eta^2 = .25$ ;  $F_2(1, 15) = 0.32$ ,  $p < .60$ ,  $\eta^2 = .02$ .

To explore these differences more closely, we calculated the probability of switching to the other object during each 200-ms time window following the quantifier. Thus, for each time window, we redivided the trials on the basis of the object fixated in the prior frame. This allowed us to isolate the moment at which new eye movements to the Target outnumbered new eye movements to the Distractor. During the 400-ms time window, we found a robust Target preference in shifts for the two ( $M = 17\%$ ,  $SE = 4\%$  vs.  $M = 8\%$ ,  $SE = 3\%$ ), three ( $M = 23\%$ ,  $SE = 6\%$  vs.  $M = 3\%$ ,  $SE = 2\%$ ), and all trials ( $M = 24\%$ ,  $SE = 6\%$  vs.  $M = 6\%$ ,  $SE = 3\%$ ). This preference demonstrated rapid rejection of the Distractor when it was inconsistent with the semantics of these terms ( $p_s < .05$ ). In contrast, in the some case, where the semantics of the quantifier was consistent with both characters, the preference for shifting to the Target did not emerge until the 600-ms time window ( $M = 25\%$ ,  $SE = 6\%$  vs.  $M = 7\%$ ,  $SE = 4\%$ ),  $t_1(19) = 2.38$ ,  $p < .05$ ,  $\eta^2 = .23$ ;  $t_2(15) = 0.71$ ,  $p < .50$ ,  $\eta^2 = .03$ . This suggests that the scalar implicature with which to rule out the Distractor was not available during the earliest stages of processing. Nevertheless, the fact that this 600-ms time window occurred before the point of phonological disambiguation demonstrates that adults calculated the scalar implicature online in this task.

*Children: Post-quantifier saccade analysis.* Among the children, we found relatively equal looks to the Target ( $M = 45\%$ ,  $SE = 3\%$ ) and Distractor ( $M = 38\%$ ,  $SE = 2\%$ ) across all conditions immediately before the onset of the quantifier,  $t_1(23) = 1.46$ ,  $p > .15$ ,  $\eta^2 = .08$ ;  $t_2(15) = 0.70$ ,  $p > .40$ ,  $\eta^2 = .03$ . However, Figure 4 illustrates that during the quantifier phase, Target switches exceeded Distractor switches in the two ( $M = 16\%$ ,  $SE = 3\%$  vs.  $M = 8\%$ ,  $SE = 3\%$ ), three ( $M = 28\%$ ,  $SE = 5\%$  vs.  $M = 12\%$ ,  $SE = 3\%$ ), and all trials ( $M = 28\%$ ,  $SE = 4\%$  vs.  $M = 13\%$ ,  $SE = 3\%$ ,  $p_s < .05$ ), whereas in the some trials, Distractor switches exceeded Target switches ( $M = 8\%$ ,  $SE = 3\%$  vs.  $M = 24\%$ ,  $SE = 6\%$ ,  $p < .05$ ). This led to a significant Quantifier Scale  $\times$  Quantifier Strength interaction,  $F_1(1, 23) = 5.11$ ,  $p < .05$ ,  $\eta^2 = .18$ ;  $F_2(1, 15) = 9.63$ ,  $p < .01$ ,  $\eta^2 = .39$ . Fine-grained analyses of 200-ms time windows revealed a robust Target preference in shifts for the three ( $M = 10\%$ ,  $SE = 3\%$  vs.

Table 1  
Duration of the Time Windows for the Course-Grained Analysis (Experiments 1–3)

Experiment	Baseline phase ("Point to the")	Gender phase ("girl that has")	Quantifier phase ("— of the soc—")	Disambiguation phase ("—ks")	End phase (silence)
1	467 ms	533 ms	667 ms	333 ms	900 ms
2	533 ms	600 ms	733 ms	400 ms	733 ms
3	567 ms	733 ms	700 ms	467 ms	700 ms

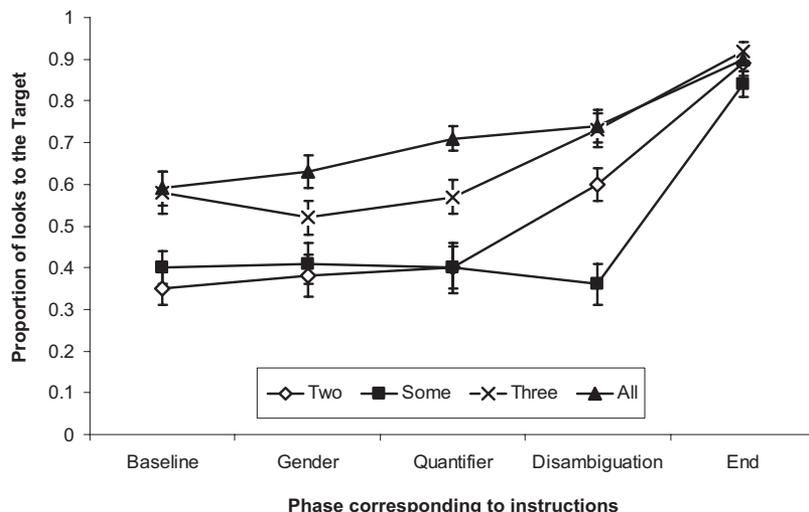


Figure 3. Experiment 1, children. Looks to the Target for the four trial types in coarse-grained time windows. Vertical lines represent standard error of the means.

$M = 4\%$ ,  $SE = 2\%$ ) and all trials ( $M = 23\%$ ,  $SE = 6\%$  vs.  $M = 4\%$ ,  $SE = 2\%$ ) in the 400-ms time window; two trials ( $M = 10\%$ ,  $SE = 4\%$  vs.  $M = 1\%$ ,  $SE = 0.5\%$ ) followed in the 600-ms time window ( $ps < .05$ ). For children, unlike adults, the Target preference in the some trials did not exceed the Distractor preference until the 1,200-ms time window ( $M = 32\%$ ,  $SE = 6\%$  vs.  $M = 4\%$ ,  $SE = 2\%$ ),  $t_1(23) = 4.24$ ,  $p < .05$ ,  $\eta^2 = .44$ ;  $t_2(15) = 2.80$ ,  $p < .05$ ,  $\eta^2 = .34$ . Because this period occurs well past the point of phonological disambiguation, these results suggest that the scalar implicature was not available during children's online processing.

*Comparisons between adults and children.* Finally, we directly compared adult and child saccades following the onset of *some* through a series of ANOVAs with initial look (Target vs. Distractor) as a within-subject variable and age (adult vs. child) as a between-subjects variable. We found that, during the quantifier phase, adults were more likely to switch their looks to the Target than to the Distractor, whereas children were more likely to switch their looks to the Distractor than to the Target. This led to a significant interaction of Age  $\times$  Initial Look,  $F_1(1, 42) = 5.37$ ,  $p < .05$ ,  $\eta^2 = .11$ ;  $F_2(1, 30) = 4.81$ ,  $p < .05$ ,  $\eta^2 = .13$ . A closer examination revealed that this interaction emerged prior to phonological disambiguation in the 600-ms time window,  $F_1(1, 42) = 10.02$ ,  $p < .01$ ,  $\eta^2 = .19$ ;  $F_2(1, 30) = 3.68$ ,  $p < .10$ ,  $\eta^2 = .11$ , and continued following the disambiguating phoneme into the 1,200-ms time window,  $F_1(1, 42) = 6.73$ ,  $p < .05$ ,  $\eta^2 = .14$ ;  $F_2(1, 30) = 16.34$ ,  $p < .01$ ,  $\eta^2 = .35$ . These results demonstrate that although adults are able to generate a scalar implicature during online processing, children delay their reference restriction until after the disambiguating phoneme.

### Discussion

In Experiment 1, we found that children's reference resolution was strongly affected by the term they heard. Following the onset of the quantifier, we found increased looks to the Target for the two, three, and all trials but not for the some trials. These results demonstrate that when lexical semantics is sufficient for identify-

ing the Target, disambiguation is quite rapid. However, when semantic analysis is not sufficient, reference resolution is substantially delayed. Children in the some trials, unlike adults, failed to show a reliable Target preference until the end of the instruction. This suggests that rather than calculating the implicature, they simply waited until the correct referent was specified by the disambiguating phoneme (i.e., used *-ks* to select *socks* rather than *soccer balls*).

Could the delays that were observed in the some conditions be accounted for by some process other than scalar implicature? One might argue that the differences between the gaze time patterns for *some* and *two* are attributable to differences in the verification conditions for numbers and scalar quantifiers. The applicability of a number can be verified solely by looking at the set of objects owned by the character in question (*Does the girl have exactly two socks?*). In contrast, to determine whether the upper bounded reading of *some* applies, a child would have to examine both the set of objects belonging to the character in question and the set of those objects belonging to the adjacent character (*Does the girl have some socks and does the adjacent boy have at least one as well?*). This might require additional processing and perhaps additional eye movements as well, explaining why looks to the Target were slower for *some* than for *two*.

We think this account is unlikely for a couple of reasons. First, it incorrectly predicts that we should see parallel delays for *all*. As for *some*, the verification conditions for *all* involve the set of objects that the Target has and the set owned by the adjacent character (*Does the girl have some socks and does the boy have none?*). Yet we found that the referent for *all* was disambiguated as rapidly as the referent of *three*, a result that suggests that this difference created no measurable delay. Second, the children's eye movements do not suggest that the children were overtly verifying the sentences in this way. Looks to the adjacent character were rare in all conditions and accounted for only 9% of total looks after the onset of the quantifier. The proportion of such fixations did not differ across

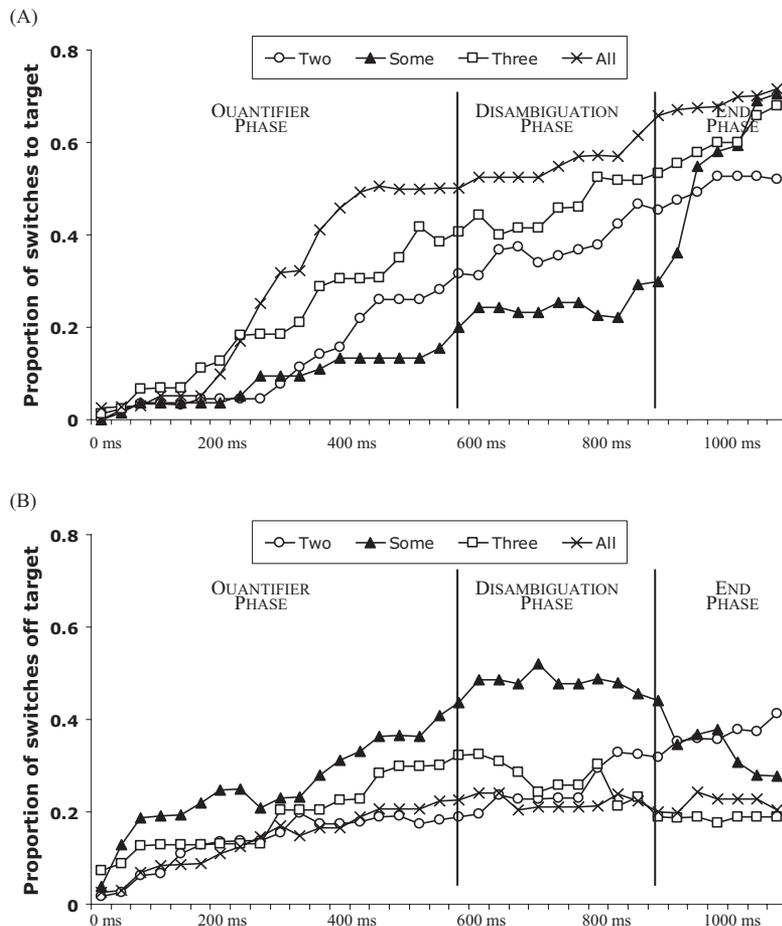


Figure 4. Experiment 1, children. Trials were separated based on fixations prior to the onset of the quantifier. (A) Distractor-initial trials: proportion of switches to the Target. (B) Target-initial trials: proportion of switches off the Target.

conditions, suggesting no privileged strategy for *some* relative to other quantifiers ( $ps > .20$ ).

There is, however, yet another interpretation of these data. Perhaps the delay that we observed is attributable to general difficulties in processing *some* rather than to sluggish use of scalar implicature. Unlike the other terms, *some* lends itself to two readings. The simultaneous activation and competition of both meanings may have resulted in a stalemate that prevented children from interpreting the relative clause and using it to restrict reference. Such a strategy might also lead participants to delay looking to the Target until the arrival of disambiguating phonological information. Experiment 2 tested this hypothesis. We reasoned that if hearing *some* automatically activates multiple competing meanings, there should be delays even when the Distractor is inconsistent with both the lower and upper bounded interpretations (e.g., a girl with no socks or soccer balls). In contrast, if prior delays reflect a failure to generate the implicature, they should disappear when the semantics of the term is sufficient for reference resolution.

As in Experiment 1, children in one set of some trials were presented with a girl character that had some but not all of the socks

and another that had all of the soccer balls. We identify these as “two-referent trials,” because there are two referents that are consistent with the semantics of the quantifier. These trials were compared to a second set of some trials in which children were presented with a girl character that had some but not all of the socks and another that had nothing. These are identified as “one-referent trials,” because there is only one referent that is consistent with the semantics of *some*. In these trials, the Target can be resolved solely by the semantics of the term rather than by a scalar implicature. Thus, if pragmatic processing is delayed relative to semantic processing, children should be considerably faster at disambiguating the Target in these trials. If, however, competition between the two readings accounts for the slower resolution of the referent of *some*, this processing delay should still be present in the one-referent as well as the two-referent trials.

### Experiment 2

#### Method

**Participants.** Twenty adults and twenty-four 5-year-olds (ranging from 5 years 5 months to 6 years 9 months; mean age 6

years 0 months) participated in this study. The children were recruited from Roberts Elementary School in a suburb of Boston. Information on participants' ethnicity, parental education, income, and occupation was never recorded, but information from the 2000 Census in this community suggests that participants predominantly came from middle socioeconomic homes and were primarily Caucasian.

**Procedure and materials.** The materials compared the interpretation of *some* in two different referential contexts (see Figure 5). In the one-referent trials, we introduced participants to displays that contrasted a subset quantity of one item with its empty set. Participants heard four new stories, like (8) below, in which a single set of objects was introduced and distributed among the boy–girl pairs.

The boys and girls on the soccer team were getting socks from the coach. The coach gave socks to Judy and socks to Craig and socks to Pat [experimenter places three socks next to the girl on the upper right, three socks next to the boy on the upper left, and three socks next to the boy on the lower left]. But these socks were too big for Cheryl's feet [experimenter places a blank card next to the girl on the lower right]. (8)

On these trials, three characters evenly shared nine items (girl and two boys with three socks) and a fourth character received nothing (girl with no socks). In the two-referent trials, we again introduced

participants to stories and displays that contrasted a subset quantity of one item with the total set of another (see Experiment 1). Following each story, participants heard instructions asking them to “Point to the girl that has some of the socks.”

We also included an equal number of filler trials to prevent children from predicting the Target prior to the onset of the quantifier. These filler trials used the same displays as did the critical trials above but used quantifiers that were consistent with the Distractor set. For the two-referent displays, participants were asked to select the girl that has “all of the socks,” and for the one-referent displays, they were asked for a girl with “none of the socks.” As in previous experiments, four items of each type were presented over the course of 16 randomized trials. The presentation of materials was counterbalanced by creating four lists, such that each item appeared just once on every list and every item appeared in all four conditions across lists.

**Coding.** Approximately 0.3% of adult trials and 4.2% of child trials were excluded from further eye-movement analyses because of incorrect action responses. Approximately 0.3% of adult trials and 0.8% of child trials were excluded due to experimenter error. Missing frames due to blinks or looks away accounted for 4.0% of all coded frames in adults and 5.3% of all coded frames in children. Intercoder reliability was 94.1% in adults and 92.4% in children.

## Results

Initial examination of the proportions of Target looks in adults revealed no significant differences between one-referent and two-referent trials during the baseline and gender phases ( $ts < 1.50$ ,  $ps > .15$ ). Similarly, Figure 6 illustrates that although Target looks were slightly below chance across both conditions, there were no reliable differences between the two trial types during the baseline and gender phases ( $ts < 1$ ,  $ps > .70$ ).

**Adults: Post-quantifier switch analysis.** To explore eye movements generated after the quantifier, we conducted a saccade analysis for the quantifier phase. Prior to the onset of the quantifier, adults were equally likely to be looking at the Target ( $M = 42\%$ ,  $SE = 3\%$ ) and Distractor ( $M = 40\%$ ,  $SE = 2\%$ ) across both conditions,  $t_1(19) = 0.53$ ,  $p > .50$ ,  $\eta^2 = .01$ ;  $t_2(15) = 0.50$ ,  $p > .60$ ,  $\eta^2 = .02$ . However, during the quantifier phase, the pattern of switches to the Target and the Distractor differed across conditions. Switches to the Target exceeded switches to the Distractor in the one-referent trials ( $M = 59\%$ ,  $SE = 5\%$  vs.  $M = 7\%$ ,  $SE = 2\%$ ,  $p < .01$ ) but did not in the two-referent trials ( $M = 29\%$ ,  $SE = 7\%$  vs.  $M = 39\%$ ,  $SE = 6\%$ ,  $p > .30$ ). This led to a significant interaction between condition and type of switch,  $F_1(1, 19) = 23.85$ ,  $p < .01$ ,  $\eta^2 = .56$ ;  $F_2(1, 15) = 77.40$ ,  $p < .01$ ,  $\eta^2 = .84$ .

Next, we explored how this difference emerged over time with a fine-grained analysis. Our goal in this analysis was to understand when the difference between the one-referent and two-referent conditions became reliable. In contrast, our goal in Experiment 1 had been to understand when saccades from the Distractor exceeded saccades from the Target. Thus, we used a different analysis for this experiment: a switch analysis. Rather than use a new baseline for each time window, we used a single baseline (the frame before quantifier onset) and for each time window measured the proportion of participants on Target-initial trials who were now

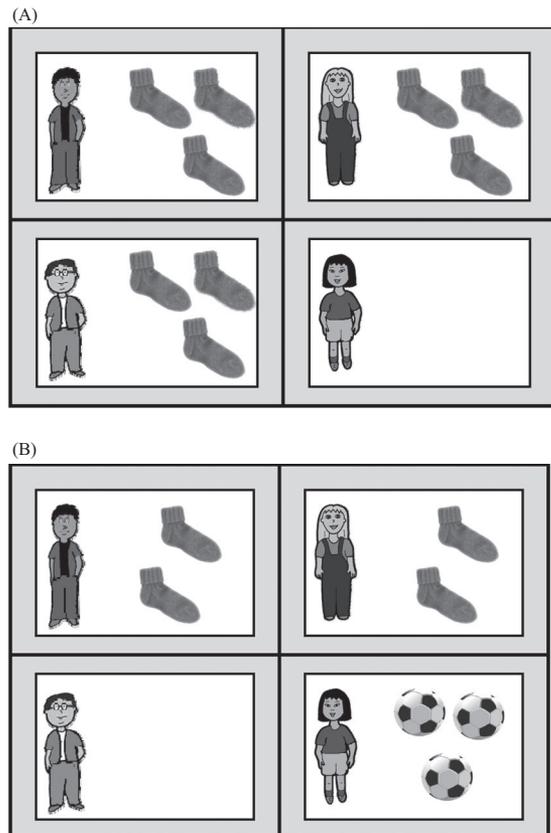


Figure 5. In Experiment 2, example of a visual-world display for the (A) one-referent trials and (B) two-referent trials. Participants were instructed to “Point to the girl that has some of the socks.”

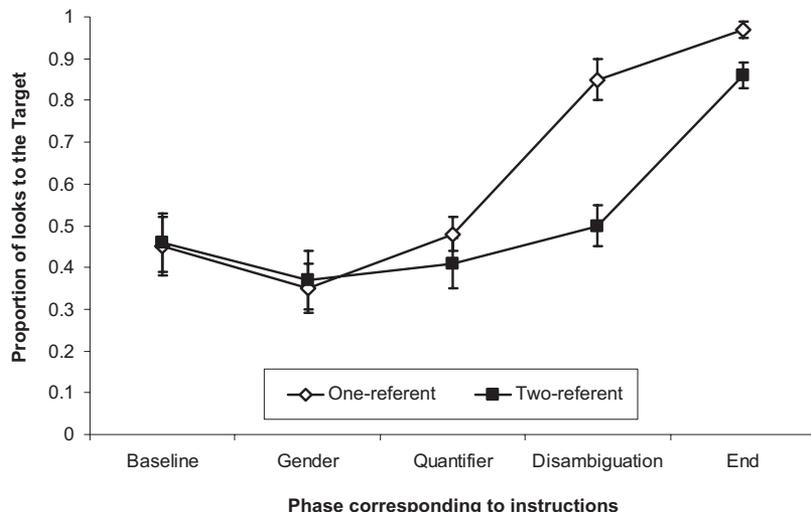


Figure 6. Experiment 2, children. Looks to the Target for the two trial types in coarse-grained time windows. Vertical lines represent standard error of the means.

fixating the Distractor and the proportion of participants on Distractor-initial trials who were now fixating the Target.

In trials where adults were initially looking at the Target, we found fewer switches to the Distractor in the one-referent trials, presumably because it was inconsistent with the semantics of *some*. In contrast, adults in the two-referent trials were more likely to switch their looks to the total set, which was consistent with the meaning of the quantifier. This led to a significant difference between trial types that began 300 ms after quantifier onset ( $M = 13%$ ,  $SE = 7%$  vs.  $M = 42%$ ,  $SE = 9%$ ),  $t_1(19) = 2.64$ ,  $p < .05$ ,  $\eta^2 = .27$ ;  $t_2(15) = 3.42$ ,  $p < .01$ ,  $\eta^2 = .44$ , and continued into the 900-ms time window ( $M = 10%$ ,  $SE = 5%$  vs.  $M = 28%$ ,  $SE = 8%$ ),  $t_1(19) = 2.15$ ,  $p < .05$ ,  $\eta^2 = .20$ ;  $t_2(15) = 2.14$ ,  $p < .05$ ,  $\eta^2 = .23$ . In trials where adults were initially looking at the Distractor, we found greater switches to the Target item in the one-referent trials, presumably because the semantics of *some* ruled out the Distractor with the empty set. In contrast, adults in the two-referent trials were more likely to continue looking at the Distractor with the total set. Again, this demonstrates an initial delay in calculating the scalar implicature. This delay led to a significant difference between trial types that began 400 ms after quantifier onset ( $M = 52%$ ,  $SE = 6%$  vs.  $M = 30%$ ,  $SE = 9%$ ),  $t_1(19) = 2.37$ ,  $p < .05$ ,  $\eta^2 = .23$ ;  $t_2(15) = 3.47$ ,  $p < .01$ ,  $\eta^2 = .44$ , and continued into the 1,000-ms time window ( $M = 87%$ ,  $SE = 5%$  vs.  $M = 65%$ ,  $SE = 8%$ ),  $t_1(19) = 2.75$ ,  $p < .05$ ,  $\eta^2 = .28$ ;  $t_2(15) = 2.30$ ,  $p < .05$ ,  $\eta^2 = .26$ .

**Children: Post-quantifier switch analysis.** Among the children, we found equal looks to the Target ( $M = 38%$ ,  $SE = 2%$ ) and Distractor ( $M = 37%$ ,  $SE = 2%$ ) prior to the onset of the quantifier across both conditions,  $t_1(23) = 0.13$ ,  $p > .80$ ,  $\eta^2 = .01$ ;  $t_2(15) = 0.17$ ,  $p > .80$ ,  $\eta^2 = .01$ . Furthermore, during the quantifier phase, children, like adults, generated more switches to the Target than the Distractor in the one-referent trial ( $M = 34%$ ,  $SE = 4%$  vs.  $M = 18%$ ,  $SE = 4%$ ,  $p < .05$ ). In contrast, Target and Distractor switches did not differ from each other in the two-referent trials ( $M = 18%$ ,  $SE = 4%$  vs.  $M = 21%$ ,  $SE = 5%$ ,

$p > .60$ ). This led to a significant interaction between condition and type of switch in this period,  $F_1(1, 23) = 4.62$ ,  $p < .05$ ,  $\eta^2 = .17$ ;  $F_2(1, 15) = 1.18$ ,  $p < .30$ ,  $\eta^2 = .08$ .

To understand this interaction, we examined Target- and Distractor-initial trials separately using the switch analysis described above (see Figure 7). In the Target-initial trials, there were no reliable differences between the two conditions. However, on Distractor-initial trials, children in one-referent contexts began switching to the Target following quantifier onset, whereas children in two-referent contexts were more likely to continue to look at the Distractor. As with the adults, this led to a significant difference between trial types that began 300 ms after quantifier onset ( $M = 43%$ ,  $SE = 6%$  vs.  $M = 22%$ ,  $SE = 5%$ ),  $t_1(23) = 2.52$ ,  $p < .05$ ,  $\eta^2 = .22$ ;  $t_2(15) = 2.37$ ,  $p < .05$ ,  $\eta^2 = .27$ , and continued into the 900-ms time window ( $M = 73%$ ,  $SE = 5%$  vs.  $M = 52%$ ,  $SE = 5%$ ),  $t_1(23) = 4.10$ ,  $p < .01$ ,  $\eta^2 = .42$ ;  $t_2(15) = 3.08$ ,  $p < .01$ ,  $\eta^2 = .39$ .

**Comparisons between adults and children.** Finally, we directly compared changes in fixation in adults and children after the onset of *some* by conducting a series of ANOVAs on the switch data with condition (one-referent vs. two-referent) as a within-subject variable and age (adult vs. child) as a between-subjects variable. In the Target-initial trials, adults were less likely to switch to the Distractor in the one-referent trials than in the two-referent trials, whereas children demonstrated no difference in switches across the two conditions. This led to a significant difference between conditions,  $F_1(1, 42) = 16.15$ ,  $p < .01$ ,  $\eta^2 = .28$ ;  $F_2(1, 30) = 11.80$ ,  $p < .01$ ,  $\eta^2 = .28$ , as well as an interaction between age and condition,  $F_1(1, 42) = 10.67$ ,  $p < .01$ ,  $\eta^2 = .20$ ;  $F_2(1, 30) = 17.41$ ,  $p < .01$ ,  $\eta^2 = .37$ , which began 200 ms after quantifier onset,  $F_1(1, 42) = 6.74$ ,  $p < .05$ ,  $\eta^2 = .14$ ;  $F_2(1, 30) = 7.09$ ,  $p < .05$ ,  $\eta^2 = .19$ , and continued into the 700-ms time window,  $F_1(1, 42) = 6.81$ ,  $p < .05$ ,  $\eta^2 = .14$ ;  $F_2(1, 30) = 4.37$ ,  $p < .05$ ,  $\eta^2 = .13$ .

In the Distractor-initial trials, however, we found that both adults and children were more likely to switch their looks to the

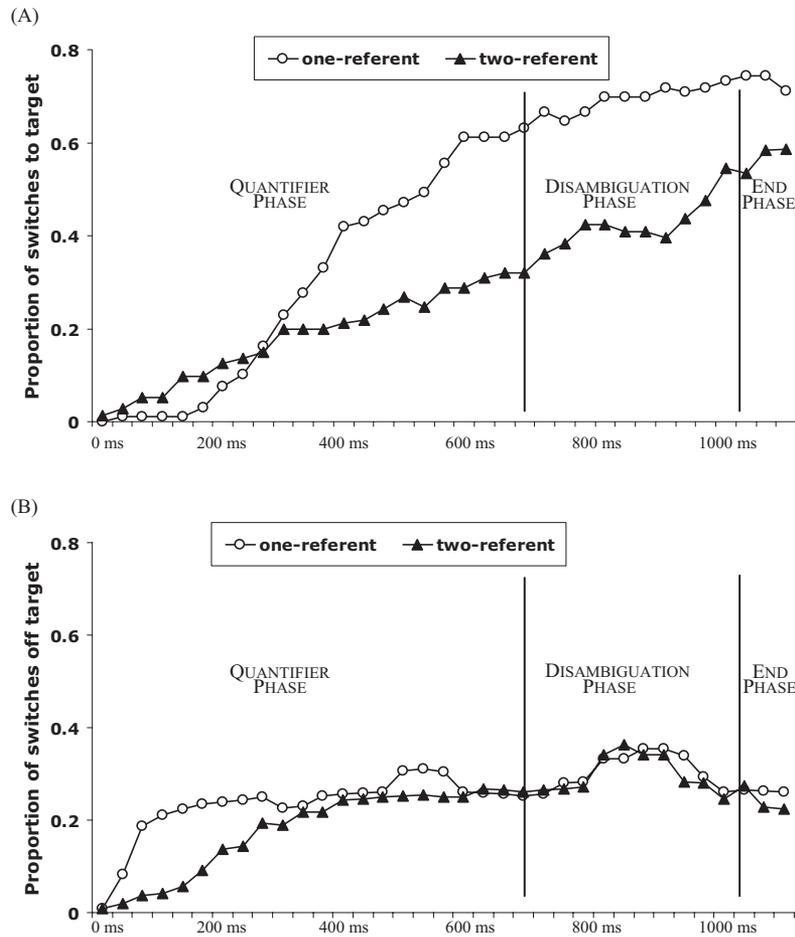


Figure 7. Experiment 2, children. Trials were separated on the basis of fixations prior to the onset of the quantifier. (A) Distractor-initial trials: proportion of switches to the Target. (B) Target-initial trials: proportion of switches off the Target.

Target in the one-referent trials than in the two-referent trial. This led to a significant difference between conditions,  $F_1(1, 42) = 15.83, p < .01, \eta^2 = .27$ ;  $F_2(1, 30) = 34.82, p < .01, \eta^2 = .54$ , but no interaction between age and condition,  $F_1(1, 42) = 1.35, p > .20, \eta^2 = .04$ ;  $F_2(1, 30) = 9.65, p < .01, \eta^2 = .24$ . In fact, there were no time windows in which adults and children differed in their switches to the Target across the two conditions ( $ps > .15$ ). These results demonstrate that both adults and children rapidly restrict the referent of *some* when the Distractor is inconsistent with the semantics of the quantifier.

### Discussion

In Experiment 2, we again found that children were delayed in their looks to the Target for trials that contrasted *some* with a total set (two-referent trials). However, similar delays were not seen in trials that contrasted *some* with an empty set (one-referent trials). This pattern was confirmed when we separated trials by initial fixations: Following the onset of *some*, both adults and children were faster to switch their looks to the Target in the one-referent trials but slower to do so in the two-referent trials. These results

suggest that resolution of the Target is quicker via semantic analysis than pragmatic inference.

However, although these findings suggest that children might altogether fail to generate scalar implicatures during comprehension, one feature of the data might lead some to be more skeptical. In both Experiments 1 and 2, children were somewhat slower than adults in using the control quantifiers to restrict reference and demonstrated a 100- to 200-ms delay across the various conditions. The delay in the case of *some* is clearly greater (600 ms in Experiment 1); however, we cannot rule out the possibility that children, like adults, calculate the scalar implicature online but do it so slowly that the information becomes available only after phonological disambiguation. In Experiment 3, we explored this possibility by presenting children with situations in which the implicature was explicitly violated by the context. We reasoned that if children were spontaneously generating the inference, there should be delays when *some* ultimately refers to the total set. In contrast, if they never calculated the inference, processing in these trials should be no different than in trials where *some* refers to the subset.

As in the previous experiments, children in one condition were asked for “some of the socks” in a context in which one girl had some but not all of the socks and another had all of the soccer balls. We call these “SI-consistent trials,” because the Target possesses a quantity that is consistent with the scalar implicature. Children in a second condition were asked for “some of the socks” in a context in which one girl had all of the socks and another had some but not all of the soccer balls. These are called “SI-violating trials,” because the Target possesses a quantity that violates the scalar implicature. Our critical analyses focused on eye movements after the disambiguating phoneme. If children implicitly generate scalar implicatures, we would expect greater delays in looks to the Target following the disambiguating phoneme in these trials. However, if children fail to generate an implicature, we would expect that latency to the Target would be the same in these two trials.

### Experiment 3

#### Method

**Participants.** Twenty adults and twenty-four 5-year-olds (ranging from 5 years 6 months to 6 years 8 months; mean age 6 years 0 months) participated in this study. The data from these adults have not been previously published. The children were recruited from Columbus Elementary School in a suburb of Boston, and their demographics match those of participants in Experiment 2.

**Procedure and materials.** The materials compared the interpretation of *some* in two different referential contexts by adopting displays, stories, and instructions similar to the those for the scalar trials in Experiment 1 (see Figure 8). One set of three items was given to one character from the first pair (girl with three socks and boy with no socks), and another set of six items was split evenly between the remaining pair (girl with three soccer balls and boy with three soccer balls). In the SI-violating trials, participants heard instructions asking them to select the Target with the total set (e.g., “Point to the girl that has some of the socks”). In contrast, in the SI-consistent trials, the instructions requested the Target with the subset. We also included 16 filler trials to prevent predictability of the Target prior to the onset of the quantifier. These trials used the same displays as the ones described above but used different quantifiers to describe the various sets (e.g., “all/three/none of the socks”).

**Coding.** Approximately 0.8% of adult trials and 1.7% of child trials were excluded from further eye-movement analyses because of incorrect actions. Approximately 1.2% of adult trials and 1.7% of child trials were excluded due to experimenter error. Finally, missing frames due to blinks or looks away accounted for 3.8% of all coded frames in adults and 4.4% of all coded frames in children. Intercoder reliability was 94.1% in adults and 93.4% in children.

#### Results and Discussion

In adults, the proportions of Target looks did not differ between SI-consistent and SI-violating trials during the baseline, gender, and quantifier phases ( $t_s < 1.50$ ,  $p_s > .15$ ). Figure 9 illustrates that in the children, however, there was a reliable effect of trial in the gender phase: Target fixations in the SI-violating trials were

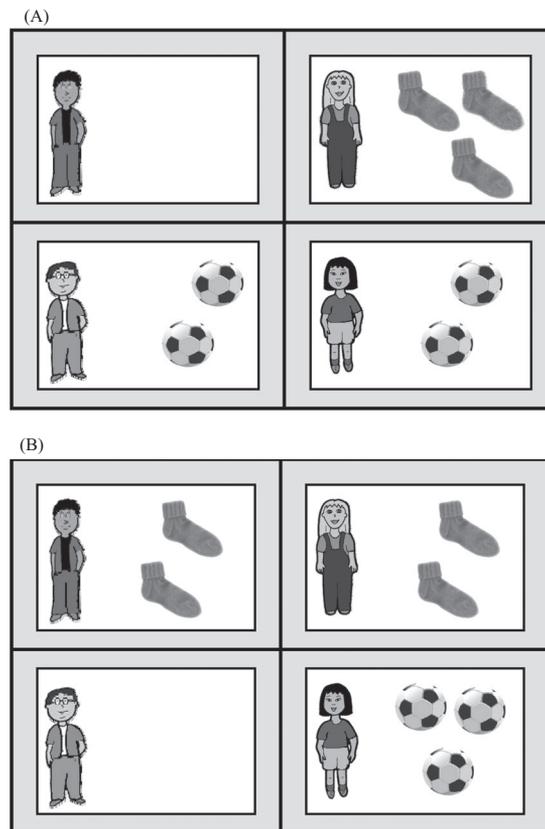


Figure 8. In Experiment 3, example of a visual-world display for the (A) SI-violating trials and (B) SI-consistent trials. Participants were instructed to “Point to the girl that has some of the socks.” SI = scalar implicature.

greater than in the SI-consistent trials,  $t_1(23) = 2.80$ ,  $p < .05$ ,  $\eta^2 = .25$ ;  $t_2(15) = 3.99$ ,  $p < .01$ ,  $\eta^2 = .51$ . This pattern is similar to the bias seen in the initial periods of Experiment 1; in both cases, children preferred to look at the character with the unique set (the girl with all the soccer balls). Nevertheless, during the quantifier phase, this difference across the two trial types disappeared ( $p > .20$ ).

**Adults: Post-disambiguation switch analyses.** In this experiment, the critical time window was the disambiguation phase, which begins at the onset of the disambiguating phoneme and ends at the offset of the command (“-ks”). This region averaged 467 ms in length. On the frame immediately before disambiguation, adults exhibited equal looks to the Target ( $M = 48\%$ ,  $SE = 3\%$ ) and the Distractor ( $M = 46\%$ ,  $SE = 3\%$ ) across both conditions,  $t_1(19) = 0.21$ ,  $p > .80$ ,  $\eta^2 = .01$ ;  $t_2(11) = 0.13$ ,  $p > .80$ ,  $\eta^2 = .01$ . However, during the disambiguation phase, we found that the switch patterns varied across conditions. Although switches to the Target exceeded switches to the Distractor in both the SI-consistent trials ( $M = 64\%$ ,  $SE = 6\%$  vs.  $M = 2\%$ ,  $SE = 1\%$ ) and the SI-violating trials ( $M = 49\%$ ,  $SE = 4\%$  vs.  $M = 11\%$ ,  $SE = 4\%$ ,  $p_s < .05$ ), they did so to a greater degree in the SI-consistent trials. This led to a significant interaction between condition and type of switch during this period,  $F_1(1, 19) = 35.40$ ,  $p < .01$ ,  $\eta^2 = .65$ ;  $F_2(1, 11) = 3.94$ ,  $p < .10$ ,  $\eta^2 = .27$ . These results suggest that adults had generated the scalar implicature and were having

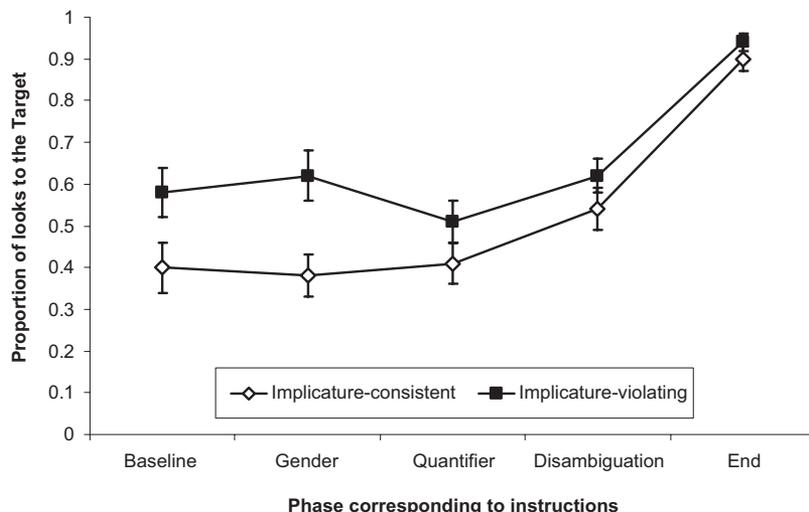


Figure 9. Experiment 3, children. Looks to the Target for the four trial types in coarse-grained time windows. Vertical lines represent standard error of the means.

greater difficulty integrating the disambiguating information when it violated the implicature.

We explored this difference in greater detail using the fine-grained switch analysis from Experiment 2. On Target-initial trials, adults generated more switches to the Distractor in the SI-violating trials, presumably because the Target with the total set violated the pragmatically felicitous use of *some*. In contrast, adults in the SI-consistent trials were more likely to continue looking at the Target with the subset, as was consistent with the inferred meaning of *some*. This led to a significant difference between trial types that began 600 ms after disambiguation ( $M = 3\%$ ,  $SE = 2\%$  vs.  $M = 16\%$ ,  $SE = 5\%$ ),  $t_1(19) = 2.11$ ,  $p < .05$ ,  $\eta^2 = .19$ ;  $t_2(11) = 0.47$ ,  $p < .70$ ,  $\eta^2 = .02$ , and continued into the 800-ms time window ( $M = 1\%$ ,  $SE = .01\%$  vs.  $M = 6\%$ ,  $SE = 3\%$ ),  $t_1(19) = 2.17$ ,  $p < .05$ ,  $\eta^2 = .20$ ;  $t_2(11) = 1.55$ ,  $p < .15$ ,  $\eta^2 = .18$ . Similarly, on Distractor-initial trials, adults generated more switches to the Target in the SI-consistent trials than in the SI-violating trials. This led to a significant difference between trial types that began 200 ms after disambiguation ( $M = 35\%$ ,  $SE = 7\%$  vs.  $M = 16\%$ ,  $SE = 4\%$ ),  $t_1(19) = 2.70$ ,  $p < .05$ ,  $\eta^2 = .28$ ;  $t_2(11) = 0.60$ ,  $p < .60$ ,  $\eta^2 = .03$ , and continued into the 400-ms time window ( $M = 75\%$ ,  $SE = 6\%$  vs.  $M = 60\%$ ,  $SE = 6\%$ ),  $t_1(19) = 2.15$ ,  $p < .05$ ,  $\eta^2 = .19$ ;  $t_2(11) = 0.52$ ,  $p < .60$ ,  $\eta^2 = .02$ .

*Children: Post-disambiguation switch analyses.* Prior to the disambiguating phoneme, children looked equally at the Target ( $M = 44\%$ ,  $SE = 2\%$ ) and the Distractor ( $M = 43\%$ ,  $SE = 2\%$ ) across the two conditions,  $t_1(23) = 0.21$ ,  $p > .80$ ,  $\eta^2 = .01$ ;  $t_2(11) = 0.13$ ,  $p > .80$ ,  $\eta^2 = .01$ . During the disambiguation phase, children, like adults, generated more switches to the Target than the Distractor in both the SI-consistent trials ( $M = 25\%$ ,  $SE = 4\%$  vs.  $M = 7\%$ ,  $SE = 3\%$ ) and the SI-violating trials ( $M = 30\%$ ,  $SE = 4\%$  vs.  $M = 7\%$ ,  $SE = 3\%$ ,  $ps < .05$ ). However, Figure 10 illustrates that, unlike adults, children were equally likely to generate new looks to the Target in both conditions. This led to a significant difference in type of switch,  $F_1(1, 23) = 28.79$ ,  $p < .01$ ,  $\eta^2 = .56$ ;  $F_2(1, 11) = 6.15$ ,  $p < .05$ ,  $\eta^2 = .36$ , but no critical

interaction between condition and switch type,  $F_1(1, 23) = 0.27$ ,  $p > .60$ ,  $\eta^2 = .01$ ;  $F_2(1, 11) = 1.25$ ,  $p < .30$ ,  $\eta^2 = .09$ . In fact, there were no time windows on either the Target-initial trials or the Distractor-initial trials on which switches differed between the two conditions ( $ps > .15$ ). Thus, we found no evidence that children were slower in their reference resolution in the SI-violating trials even after the onset of the disambiguating phoneme. Altogether, these results suggest that the children failed to calculate the inference during comprehension.

*Comparisons between adults and children.* To directly compare the adults and children, we entered the switch data for each time window in an ANOVA with condition (SI-consistent vs. SI-violating) as a within-subject variable and age (adult vs. child) as a between-subjects variable. On the Target-initial trials, adults were more likely to switch their looks to the Distractor in the SI-violating trials than in the SI-consistent trials, whereas children demonstrated no difference in switches across the two conditions. This led to a significant interaction between age and condition during the disambiguation phase,  $F_1(1, 42) = 4.11$ ,  $p < .05$ ,  $\eta^2 = .09$ ;  $F_2(1, 22) = 1.65$ ,  $p < .30$ ,  $\eta^2 = .07$ , that began 500 ms after disambiguation,  $F_1(1, 42) = 6.66$ ,  $p < .05$ ,  $\eta^2 = .14$ ;  $F_2(1, 22) = 0.92$ ,  $p < .40$ ,  $\eta^2 = .04$ , and continued into the 800-ms time window,  $F_1(1, 42) = 4.15$ ,  $p < .05$ ,  $\eta^2 = .09$ ;  $F_2(1, 22) = 0.31$ ,  $p < .60$ ,  $\eta^2 = .01$ . On the Distractor-initial trials, we found that adults were more likely to switch their looks to the Target in the SI-consistent trials than in the SI-violating trials, whereas children again demonstrated no difference in switches across the two conditions. This led to another significant interaction between age and condition during the disambiguation phase,  $F_1(1, 42) = 5.92$ ,  $p < .05$ ,  $\eta^2 = .12$ ;  $F_2(1, 22) = 15.81$ ,  $p < .01$ ,  $\eta^2 = .42$ , which began 200 ms after disambiguation,  $F_1(1, 42) = 6.56$ ,  $p < .05$ ,  $\eta^2 = .14$ ;  $F_2(1, 22) = 1.43$ ,  $p < .30$ ,  $\eta^2 = .06$ , and continued into the 400-ms time window,  $F_1(1, 42) = 4.19$ ,  $p < .05$ ,  $\eta^2 = .09$ ;  $F_2(1, 22) = 2.42$ ,  $p < .20$ ,  $\eta^2 = .10$ . Altogether, these findings demonstrate that although adults were slower to resolve the referent of *some*

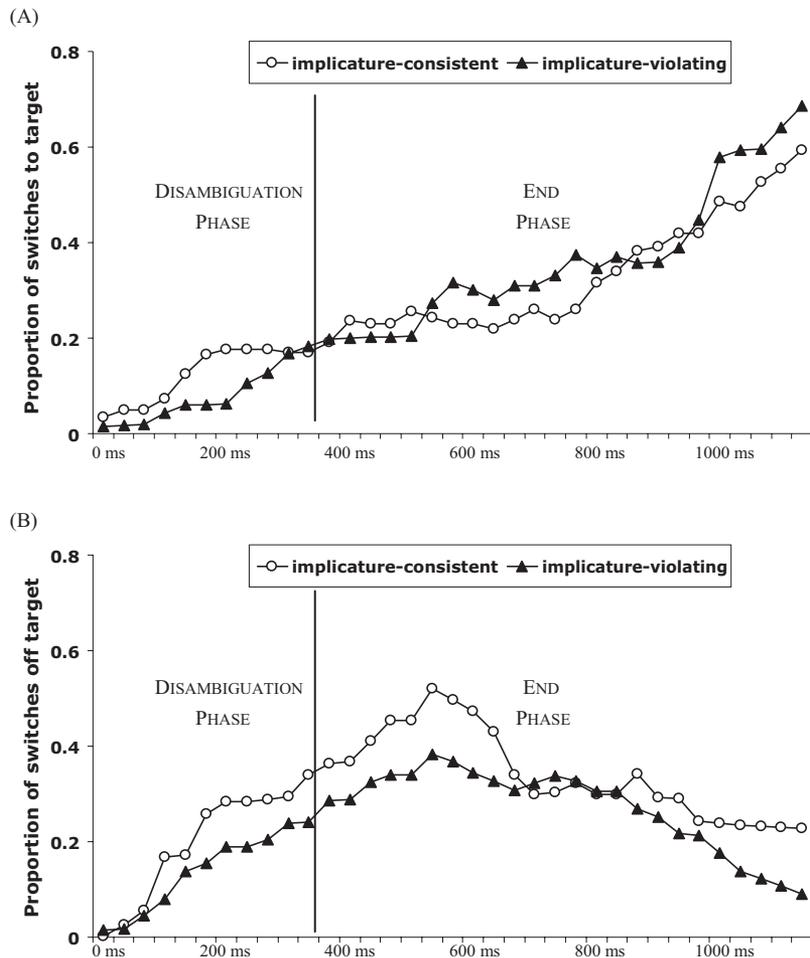


Figure 10. Experiment 3, children. Trials were separated on the basis of fixations prior to the onset of disambiguation. (A) Distractor-initial trials: proportion of switches to the Target. (B) Target-initial trials: proportion of switches off the Target.

when it violated the implicature, children showed no sensitivity to this pragmatic infelicity.

### General Discussion

This study explored the development of semantic and pragmatic interpretation by examining children’s ability to generate scalar implicatures. In Experiment 1, we found quick resolution of the referent when adults and children heard *two*, *three*, and *all* but delays when they heard *some*. Although adults eventually generated the scalar implicature and used it to restrict reference, children failed to generate it and relied instead on the phonological disambiguation to determine reference. Experiment 2 demonstrated that this delay occurs only when reference restriction requires an implicature and not when semantic analysis is sufficient. Finally, in Experiment 3, we found that children, but not adults, failed to distinguish between contexts that are consistent with the implicature and those that violate it. Altogether, these results indicate that children do not calculate scalar implicatures during online language comprehension. Instead, their moment-to-moment interpre-

tation of quantified phrases appears to be predominantly guided by the semantics of these phrases.

In the remainder of this discussion, we focus on two additional issues. First, we integrate our findings with the existing literature on children’s generation of scalar implicatures. Second, we return to the puzzle of why children appear to exhibit pragmatic sophistication in early word learning but fail to generate pragmatic inferences in the case of scalar implicatures.

### Why Don’t Children Calculate Scalar Implicatures?

Our findings demonstrate that children as well as adults initially interpreted *some* with respect to its lower bounded semantics. Although adults calculated a scalar implicature to exclude referents compatible with *all* prior to the disambiguating phoneme, children never invoked this late inferential process. Instead, they strictly adhered to the semantics of the quantifier. These findings add to a growing literature demonstrating that children rely heavily on the logical meaning of utterances and have only a limited ability to generate postsemantic inferences (Noveck, 2001; Papafragou &

Musolino, 2003; Smith, 1980). Our data offer two new insights into this limitation. First, they demonstrate that this difficulty persists in a naturalistic task that requires no overt judgment or action. Second, by revealing how interpretation evolves over time, our findings demonstrate developmental continuity in the initial semantic processes, followed by developmental discontinuity in subsequent pragmatic processing.

So what accounts for children's failure to make implicatures? The gradual pattern of acquisition and the partial success of young children in some tasks suggests that their failures cannot be attributed to global ignorance of the process (see Introduction). Several other possibilities have been suggested in the literature. One hypothesis, suggested by Relevance theory, is that children simply have lower thresholds for the relevance of an utterance and thus do not need to engage in the effortful process of generating this inference (Carston, 1998; Recanati, 2003; Sperber & Wilson, 1986/1995). A second hypothesis suggests that the generation of scalar implicatures is linked to an ability to engage in controlled analytic reasoning that is not possessed by children (De Neys & Schaeken, 2007; Feeney, Scafton, Duckworth, & Handley, 2004; Scafton & Feeney, 2006). However, neither account clearly describes the nature of the computational problem that makes scalar implicatures so difficult they require this extra effort or controlled processing.

We see two reasons why these inferences may be particularly tricky for children. First, the contexts of language use typically do not provide evidence that the implicature is necessary. Any situation compatible with the upper bounded reading of *some* (e.g., cases in which not all cookies were eaten) is also consistent with the lower bounded reading (e.g., possibly all cookies were eaten), creating a subset problem. Thus, once the child has settled on a lower bounded meaning, individual examples of this kind cannot demonstrate that the implicature is necessary. A second possibility is that children fail to make implicatures because they are less likely to retrieve the stronger scalar alternative during language comprehension (Gualmini, Crain, Meroni, Chierchia, & Guasti, 2001; Pouscoulous et al., 2007; Reinhart, 1999). On most theories, the calculation of the implicature is prompted by awareness of a more informative alternative (for *some*, the term *all*). If this alternative is not retrieved, there is no reason to make the inference. This might explain why children were much more likely to generate the inference in tasks that highlighted the need for the stronger term (Papafragou, 2006; Papafragou & Tantalou, 2004).

Nevertheless, it is difficult to see how a failure to retrieve the contrasting term could fully account for children's failure to generate implicatures in the present task. In these experiments, participants saw the subset explicitly contrasted with the total set in both the story and the visual displays as well as in the use of the critical term (*all*) in target utterances throughout the task. This fact suggests another hypothesis. Remember that we found that adults demonstrated a lag between semantic processing and the calculation of the pragmatic inference. This delay is consistent with adult studies on the processing of scalar implicatures (Bott & Noveck, 2004; Breheny, Katsos, & Williams, 2006; Huang & Snedeker, 2009b, 2009c) and suggests a possible linkage between the sluggish processing of these inferences in adults and their sluggish development in children (Gualmini et al., 2001; Pouscoulous et al., 2007; Reinhart, 1999). In particular, it may be the case that the

procedures that require more cognitive resources in adults are in turn less likely to be available in children.

### *Bottom-Up Versus Top-Down Pragmatic Processes*

In the Introduction, we noted a curious disconnect in the literature on the development of pragmatic competence. Toddlers are frequently depicted as pragmatic sophisticates who engage in a rich interpretation of speakers' communicative intentions to learn novel words (Baldwin, 1993; Tomasello, 1992). In contrast, school-age children are surprisingly poor at going beyond the literal meaning of an utterance to infer the speaker's intended meaning (Bernicot et al., 2007; deVilliers et al., 2008; Harris & Pexman, 2003; Noveck, 2001; Papafragou & Musolino, 2003; Vosniadou, 1987). What accounts for this apparent developmental discontinuity?

One possibility lies in the inherent asymmetry between the roles of pragmatics in word learning as compared to scalar implicatures. In a typical word learning scenario, the child can directly infer the meaning of a novel word (e.g., *doggie*) on the basis of a nonlinguistic analysis of the speaker's intentions (i.e., seeing the mother point to or look at the family pet). Here, pragmatics plays a top-down role in constraining the range of candidates for the meaning of a lexical item. In this situation, the pragmatic processes can begin independently of and prior to any linguistic semantic analysis. In the case of scalar implicature, however, the child can generate the relevant implicature only after some degree of semantic analysis is completed. That is, in the present case, the child must identify the word *some* and access its meaning before he can evaluate its informational strength relative to *all* and make the upper bounding inference. Thus, the scalar inference depends on the coordination of semantic and pragmatic processes in real time.

This distinction between top-down inferences about communicative intentions and the inferences that build off bottom-up semantic processes appears to correctly predict which tasks will be easy for toddlers and which will be tricky for schoolchildren. Children struggle with irony, metaphor, and relevance implicatures in addition to scalar implicatures (Bernicot et al., 2007; deVilliers et al., 2008; Harris & Pexman, 2003; Vosniadou, 1987). In each case, development is gradual, variable, and prolonged. In each case, pragmatic success requires listeners to calculate an interpretation that builds upon but goes beyond the initial linguistic meaning. These postsemantic processes may be particularly difficult, because they require that some feature of the child's initial analysis be revised. This may be another manifestation of the general difficulty that children have in overriding an initial misinterpretation, parallel to the difficulties that they have in revising syntactic garden paths (Snedeker & Trueswell, 2004; Trueswell, Sekerina, Hill, & Logrip, 1999), accessing the dispreferred meaning of a homonym (Doherty, 2004; Mazzocco, 1997), or identifying a word relative in the presence of competitors (Arnold, 2008; Huang & Snedeker, 2009a).

What changes over the course of development to make implicature generation more robust? Preliminary cross-sectional work suggests that children gradually begin to reliably generate scalar implicatures during middle childhood and early adolescence (Feeney et al., 2004; Guasti et al., 2005; Scafton & Feeney, 2006). This period is characterized by substantial improvements in cognitive control mechanisms that have been implicated in the ability

to revise garden-path sentences and other default interpretations (Novick, Trueswell, & Thompson-Schill, 2005; Trueswell et al., 1999). In the case of scalar implicatures, these changes in the language processing system may help children to revise their initial semantic interpretation or may increase the salience of stronger terms on the scale during real-time comprehension. Future studies focusing on comparisons across age-groups may permit us to explore these possibilities more deeply.

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