Children's Ability to Compute Implicatures
with Availability of Contextual Alternatives and Prosodic Cues

Erica J. Yoon
ejyoon@stanford.edu
Department of Psychology
Stanford University

Charles Y. Wu
ywu15@wabash.edu
Department of Psychology
Wabash College

Michael C. Frank
mcfrank@stanford.edu
Department of Psychology
Stanford University

Abstract

Language comprehenders routinely make pragmatic inferences that go beyond the literal meanings of utterances. If A said "I ate some of the cookies," B would probably infer that A ate 'some *but not all*' of the cookies. However, children often seem to fail to compute implicatures despite their early-emerging sensitivity to pragmatic cues. The current work sought to explore potential factors responsible for children's successes and failures in computing pragmatic inferences. In two Experiments, we used eye-tracking paradigm to test children's ability to compute implicatures when they have access to contextual alternatives to the target word (Experiment 1), and when they hear prosodic cues that emphasize the contrast between the target and alternative (Experiment 2). We found that young children successfully compute implicatures with access to contextual alternatives (4 years and older) and supportive prosodic cues (3 years and older).

Keywords: Pragmatic cues; implicatures; cognitive development

Introduction

Language comprehension involves not only interpreting the literal meanings of words in utterances, but also understanding the communicative intentions behind what is said. Listeners often make inferences about *pragmatic implicatures*, or speaker's implied meaning that goes beyond the conventional meaning of the utterance (Grice, 1975).

For example, if A says to B, "Some of the students failed the test," B may infer that A intended to say "Some, *but not all*, of the students failed the test." That is, A's use of the term 'some' *implicates* that the stronger scalar alternative 'all' is negated. These implicatures that involve scales built based on the knowledge of *lexical* alternatives are called *scalar implicatures* (*SI*'s from here on).

Many studies have looked at the development of implicature understanding by testing adults' and children's ability to compute SI's. Whereas adults readily compute SI's, children tend to perform poorly on SI tasks (e.g., Noveck, 2001; Papafragou & Musolino, 2003; Huang & Snedeker, 2009; Barner, Chow, & Yang, 2009; Teresa Guasti et al., 2005). For example, in a context in which three out of three horses jumped over a fence and a puppet made a remark such as: e.g., "some of the horses jumped over the fence,?? most of the adults rejected the statement as infelicitous, whereas close to 90% of the children accepted it (Papafragou & Musolino, 2003).

Children's failures on SI computation are surprising, given their early-emerging sensitivity to informativeness of utterances. For example, by 5 years of age, children are able to adjust informativeness of their own expressions depending on the listeners' knowledge (Matthews, Lieven, Theakston, & Tomasello, 2006); reward speakers based on the informativeness of their utterances (Katsos & Bishop, 2011); and provide more information when disambiguation between potential referents is difficult (Matthews, Butcher, Lieven, & Tomasello, 2012). At two years of age, when they are still too young to produce many utterances, children are able to assess informativeness of their own gestures (O'Neill & Topolovec, 2001). Thus, even young children excel at assessing the informativeness of both their own and other people's utterances and communicative gestures.

Based on the research on children?s sensitivity to communicative informativeness, it seems unlikely that children?s lack of pragmatic understanding is the cause of their failures on SI tasks. What factors are then responsible for their failures on SI computation? The current Experiments investigate two potential factors: availability of alternatives to the term offered; and cues that highlight the contrast between term offered and its alternatives.

Access to contextual alternatives

Implicature computation involves generating and negating alternatives to a given term. For example, upon hearing 'some,' the listener needs to generate a stronger alternative (in this case, 'all') based on the lexical knowledge, and negate that alternative to compute the implicature.

One potential cause of children's difficulty with previous SI tasks is their lack of access to lexical alternatives to the term offered (Barner, Brooks, & Bale, 2011). When adults hear 'some,' they are able to generate the relevant scales and negate the stronger scalar alternative 'all' to the term 'some,' successfully computing implicatures. But for children, even if they know that there are alternatives to be negated, they may not be able to generate those relevant scalar alternatives.

Indeed, there is evidence that children can compute simpler, *ad-hoc* implicatures, which depend on contextually-derived scales rather than lexically-derived ones (Stiller, Goodman, & Frank, in press). Children saw three faces, one with glasses only, one with glasses and a top-hat, and one with none of the items. When children heard a puppet say: "My friend has glasses,?? 3.5-year-old children and older chose the face with glasses only as the referent above chance. Thus, children were able to compute the implicature "My friend has glasses, *but not a top-hat*?? given the contextual access to the stronger alternative (face with glasses and top-hat) to be negated.

There are still many remaining questions about children's ability to compute implicatures. First, while children are more successful on the ad-hoc implicature task, their decision-making process by which they arrive at the correct answer is still unclear. For example, how does children's implicature processing compare to how the processing of semantically unambiguous utterances, in speed and accuracy?

Second, even for Stiller et al. (in press)'s simplified task, children younger than 3.5 years still struggled to find the pragmatically correct referent. The reason for younger children's failures is yet to be resolved. One possibility is that younger children rely more heavily on the literal meanings of utterances; another possibility is that there is an aspect of implicature tasks, unrelated to pragmatic understanding, that older children perform better compared to younger children, which consequently obscures younger children's ability for pragmatic inference. To investigate these questions, we used the eye-tracking paradigm with even more simplified task in Experiment 1.

The eye-tracking paradigm offers several advantages for examining utterance processing; one can see how participants direct their eye gazes at each phase as an utterance is being produced, showing their judgment developing over time as compared to their one final judgment; also, eye gazes reflect a more implicit measure of comprehension than judgments made after conscious deliberation. Hence, eye-tracking paradigm is a useful tool in determining potential factors contributing to age differences in how fast children look toward inferential targets, and how much attention children give toward the targets at each phase of their utterance processing.

Experiment 1 explored children's on-line processing of ad-hoc implicatures through the eye-tracking paradigm. We sought to address three main goals: first, confirm whether, as Stiller et al.'s findings suggest, children younger than 5 years can compute implicatures; second, look at children's real-time decision-making process, as opposed to one-time judgments, for implicature computation; and third, identify potential factors that contribute to the developmental differences in implicature computation performance.

Experiment 1

Method

Participants. Parents and their 2- to 5-year-old children visiting Children's Discovery Museum in San Jose, CA, were invited to participate in a short video study. The current sample comprised of children who were exposed to English at least 50% of the time as indicated by their parents; individual trials with more than 50% missing gaze data were excluded from analysis, and only those who completed at least 8 of 16 trials according to this criterion were included in the analysis. This left 108 out of initial XX child participants whose data was analyzed: 24 2-year-olds (mean age = 2:6, range = 2:1-2:11, 10 female), 28 3-year-olds (mean age = 3:5, range = 3:1-3:11, 19 female), 24 4-year-olds (mean age = 4:6, range = 4:1-4:11, 13 female), 32 5-year-olds (mean age = 5:4, range = 5:1-5:9, 9 female). Children were given a sticker for participating in the study. 14 adult participants were undergraduate students recruited through Stanford Psychology credit pool.

Stimuli and Design. On each trial, participants saw two images: a target and distractor, which could either be an item with a single feature (e.g., a plate with only a carrot or only a banana), or an item with double features (e.g., a plate with a carrot and a banana). Each trial contained three phases: in the initial phase (8.5 seconds), two images were presented in silence for two seconds, then a pre-recorded voice said a sentence (e.g., "Look at these plates. Elmo's plate has a carrot."). Then, in the anticipatory phase (1.5 seconds), a chime sound played to induce participants' anticipatory gaze. In the following feedback phase (1.5 seconds), a character appeared next to the target with an amusing sound effect. This was to keep the task engaging for child participants.

There were three types of test trials. In an *inference* trial, the target item had a single feature (e.g., a carrot), and the distractor item had two features, one that was common with the target (e.g., a carrot) and the other feature that was unique (e.g., a banana). The test sentence named the feature that was common to the target and distractor. Thus, if participants understood that "Elmo's plate has a carrot" implicates "Elmo's plate has a carrot *but not a banana*" given the context, they should look more toward the target than the distractor; otherwise, they should equally to both.

There were two additional trial types, with semantically unambiguous targets: *control-double* trials looked identical to inference trials, but the target and distractor were switched, such that the double-feature item was the target and the single-feature item was the distractor, and the test sentence named the unique feature on the target. *control-single* trials presented two items that each had a unique single feature, and either could be the target. Children saw 4 inference, 4 control-double, and 4 control-single trials; adults saw 6 inference, 6 control-double, and 12 control-single trials.

There were six sets of item and feature types, and the features were named with nouns found in MacArthur-Bates CDI. Two orders of the test trials were created, such that trial types and item types were counterbalanced and trial order was pseudo-randomized across the two orders.

Procedure. Participants sat in a booster seat, approximately 60 cm away from the monitor of an SMI RED 120 Hz binocular remote eye-tracker. Participants were introduced to the task as watching a short video. The video began with a short Elmo video clip that lasted for 1-2 minutes, during which any necessary adjustments to the eye-tracker and participants' chair positions were made. The eye-tracker was then calibrated for each participant, using a 2-point calibration and validation of the calibration points. After calibration, participants were introduced to Sesame Street characters and were

told 'Today, [they] will show us lots of fun things. Are you ready? Let's go!'

Following the introduction, participants saw two gaze-contingent practice trials, with unambiguous targets that differed from the test items. Then children watched 16 test trials and adults watched 24 test trials, as well as 4 filler photos of children playing and 2 Elmo video clips, presented at a pseudo-random points between test trials. The video lasted approximately 8 minutes.

Results.

Participants of all age groups looked toward the targets in both control-double and control-single trials reliably above chance (50%; see Figure 1). This shows that after they heard the unambiguous targets being named, children were able to correctly identify the targets. There were age differences in the speed of looking at the target and the proportion of correct looking across both control trial types, extending on the findings by Fernald, Pinto, Swingley, Weinbergy, and McRoberts (1998), who found that children's efficiency of familiar word recognition over the second year; the current data show these gains in efficiency seem to continue to increase through the childhood.

These age differences were present for inference trials, and children older than 3 years showed robust looking to inferential targets. For example, upon hearing "Bert's plate has a carrot," older children were able to identify the plate with only a carrot as the referent rather than the plate with a carrot and a banana. These results replicate Stiller et al.'s findings and suggest that children's inferential ability might have been obscured in previous SI tasks due to the unavailability of lexical alternatives to offered terms.

A linear mixed-effects model analyzed the effects of trial type, age group (as continuous) on the proportion of children looking to the target between 1 s - 4 s after noun onset (see Table**??**). Results of this model indicate a significant interaction between the inference trial type and age group, such that older children looked more toward the inferential target compared to younger children after hearing the target noun.

There were two additional interesting patterns revealed in the data: first, looks to the target were slower and overall lower in proportion in inference trials compared to both control trial types across all age groups. switches to targets from

Table 1: Coefficient estimates from mixed-effects models predicting proportion of looks to target in Experiment 1.

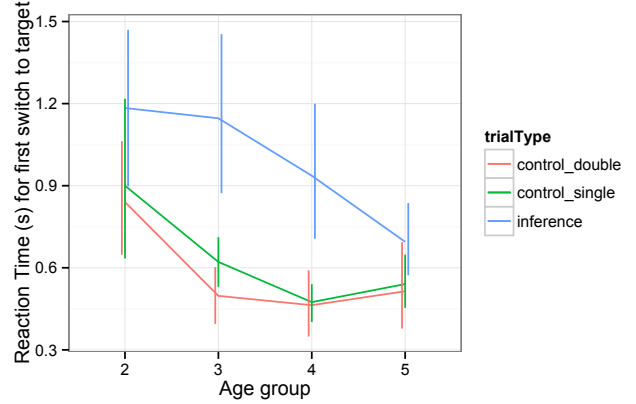| Predictor	Value (SE)	t-value
Intercept	.70 (.05)	15.06
Age	.02 (.01)	2.05
Control-single	-.10 (.06)	-1.57
Inference	-.34 (.07)	-4.91
Age*Control-single	.02 (.02)	.98
Age*Inference	.03 (.02)	1.71

Figure 2: Average reaction times for first switches to target in trials in which participants were looking at the distractor (and not the target) at the target word onset.

initial looks to distractors were slower for inferential than control targets (Figure 2). This suggests that implicatures are generally slower and harder to process compared to the unambiguous semantic meanings, regardless of the participants' age. Second, the two-year-olds' looking at the target was below chance, rather than at chance, which means they were looking significantly more at distractors than targets. Hence, two-year-olds did not seem to consider both the inferential targets and distractors as equally likely referents based on the literal meaning of the utterance; rather, the distractors attracted children's attention away from the target.

To look more closely participants' eye gaze shift patterns in the inference trials, participants' switches in looking were examined (a method first introduced by Fernald, Zangl, Portillo, and Marchman (2008); see Figure 3). For each age group, trials were divided into two groups: trials in which participants were initially looking at the distractor at the noun onset, and trials in which participants were initially looking at the target. If participants computed the implicature, then distractor-initial group should increase their looking to the target, whereas target-initial group should continue to remain looking to the target.

Current findings show that adults and children of 3 years and above follow these predictions: switch looks to the target after initial look at the distractor shoot up above chance after the target word has been produced. However, 2-year-olds actually show the opposite pattern: those who initially look at the target tend to switch and look at the distractor, whereas those who initially look at the distractor fail to switch to the target above chance.

One possible cause of this pattern is the differential saliency of the target and distractor, except in inference trials the relative saliency is switched between the target and distractor: the distractor is always perceptually and conceptually more salient, because it contains an extra item. Thus, the listener has to overcome the greater saliency of the dis-
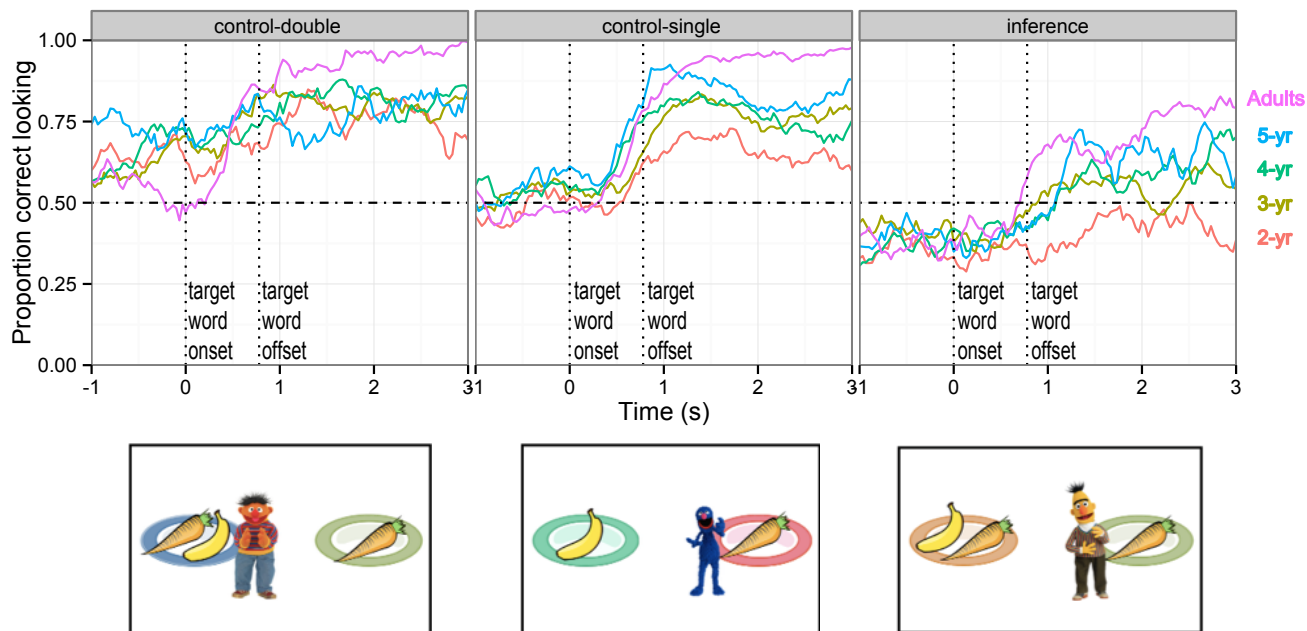
Figure 1: Proportion of 2- to 5-year-old children and adults looking to the target image as the utterance unfolds. Time 0 represents the target noun onset. Proportion correct looking is defined by looks to the target divided by the total looks to both the target and the distractor.
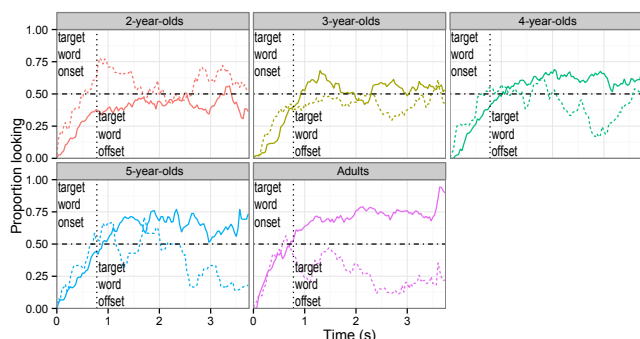

Figure 3: Looking to the target as a proportion of looking to the target and distractor across trial types. Children heard a sentence like "Elmo's plate has a carrot (target word)" then received feedback indicating the correct referent (i.e., characters? appearance next to the target item) 4 seconds after the target word onset.

tractor and devote more attention to the target based on the pragmatic inference, requiring his or her inhibitory control.

Inhibitory control is difficult for children and continues to develop through childhood, as shown in the literature on executive control (Davidson, Amso, Anderson, & Diamond, 2006; Gerardi-Caulton, 2000). A number of studies also found that children's lack of inhibitory control might affect recognition of newly learned words (Yurovsky & Frank, 2014) and processing of negative utterances (Nordmeyer & Frank, 2013). It is plausible that similar inhibitory control constraints hindered younger children's correct looking to the inferential targets on the current work.

Given this potential issue with inhibitory control for younger children, the current results have at least two different interpretations, both of which posit that older children have good pragmatic understanding and they are also better at inhibitory control than younger children, but make different predictions about younger children's pragmatic understanding: younger children might have poorer pragmatic understanding compared to older children, and they theoretically consider both objects as equally likely referents, but pay more attention to the more salient object. On the other hand, in another interpretation, both younger and older children might have good pragmatic skills, but younger children's attention to the more salient object is caused by their lack of inhibitory control.

Experiment 2

Method

Participants. Participants were recruited from Children's Discovery museum in San Jose as in Experiment 1. For Experiment 2, we recruited 3-year-olds, to see whether prosodic cues can help improve their performance in inference trials well above chance level. The final sample consisted of X 3-year olds (X female), X 4-year olds (x female), and X 5-year olds (x female).

Stimuli and Design.

Procedure.

Results and Discussion.

Conclusion

The current work looked at children's processing of ad-hoc implicatures with an eye-tracking paradigm, and found that adults and children older than 3 years show robust looking toward the inferential targets, although at slower and overall lower rate compared to semantically unambiguous targets, whereas younger children tend to show the opposite pattern of looking to the more salient distractor. One potential cause for younger children's failures on these implicature computation tasks might be relatively poor inhibitory control, which causes them to look toward more salient items despite utterance implicatures that indicate less salient items as inferential targets. In Experiment 2, we found some preliminary evidence that the relative gap between children's performance in finding semantically unambiguous target versus implicated target becomes greater as the saliency gap between two competing items increases.

In sum, the current work found that children older than 3 years are able to compute implicatures, when they have access to lexical alternatives in the context, even though these pragmatic inferences seem to be generally slower and harder to make than unambiguous interpretations of utterances, even for adults. Furthermore, younger children's failures on pragmatic tasks might be caused by their lack of inhibitory control to overcome differing saliency of potential referents. Overall, the current work is one step further towards reconciling children's early-emerging pragmatic abilities with their successes and failures in implicature tasks.

Acknowledgments

References

Barner, D., Brooks, N., & Bale, A. (2011). Accessing the unsaid: The role of scalar alternatives in children's pragmatic inference. *Cognition*, *118*(1), 84–93.

Barner, D., Chow, K., & Yang, S.-J. (2009). Finding one's meaning: A test of the relation between quantifiers and integers in language development. *Cognitive psychology*, *58*(2), 195–219.

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia*, *44*(11), 2037–2078.

Fernald, A., Pinto, J. P., Swingley, D., Weinbergy, A., & McRoberts, G. W. (1998). Rapid gains in speed of verbal processing by infants in the 2nd year. *Psychological Science*, *9*(3), 228–231.

Fernald, A., Zangl, R., Portillo, A. L., & Marchman, V. A. (2008). Looking while listening: Using eye movements to monitor spoken language. *Developmental psycholinguistics: On-line methods in children's language processing*, 113–132.

Gerardi-Caulton, G. (2000). Sensitivity to spatial conflict and the development of self-regulation in children 24–36 months of age. *Developmental Science*, *3*(4), 397–404.

Grice, H. P. (1975). Logic and conversation. *Syntax and semantics*, *3*, 41–58.

Horn, L. (1984). Toward a new taxonomy for pragmatic inference: Q-based and r-based implicature. *Meaning, form, and use in context*, *42*.

Huang, Y. T., & Snedeker, J. (2009). Semantic meaning and pragmatic interpretation in 5-year-olds: Evidence from real-time spoken language comprehension. *Developmental psychology*, *45*(6), 1723.

Katsos, N., & Bishop, D. V. (2011). Pragmatic tolerance: Implications for the acquisition of informativeness and implicature. *Cognition*, *120*(1), 67–81.

Matthews, D., Butcher, J., Lieven, E., & Tomasello, M. (2012). Two-and four-year-olds learn to adapt referring expressions to context: Effects of distracters and feedback on referential communication. *Topics in cognitive science*, *4*(2), 184–210.

Matthews, D., Lieven, E., Theakston, A., & Tomasello, M. (2006). The effect of perceptual availability and prior discourse on young children's use of referring expressions. *Applied Psycholinguistics*, *27*(03), 403–422.

Nordmeyer, A. E., & Frank, M. C. (2013). Measuring the comprehension of negation in 2-to 4-year-old children. In *Proceedings of the 35th annual meeting of the cognitive science society*.

Noveck, I. A. (2001). When children are more logical than adults: Experimental investigations of scalar implicature. *Cognition*, *78*(2), 165–188.

O'Neill, D. K., & Topolovec, J. C. (2001). Two-year-old children's sensitivity to the referential (in) efficacy of their own pointing gestures. *Journal of Child Language*, *28*(1), 1–28.

Papafragou, A., & Musolino, J. (2003). Scalar implicatures: experiments at the semantics–pragmatics interface. *Cogni-*

tion, *86*(3), 253–282.

Papafragou, A., & Tantalou, N. (2004). Children's computation of implicatures. *Language Acquisition*, *12*(1), 71–82.

Stiller, A., Goodman, N. D., & Frank, M. C. (in press). Ad-hoc implicature in preschool children. *Language Learning and Development*.

Sullivan, J., Davidson, K., & Barner, D. (2011). Children's conversational implicatures. In *Proceedings of BUCLD*.

Teresa Guasti, M., Chierchia, G., Crain, S., Foppolo, F., Gualmini, A., & Meroni, L. (2005). Why children and adults sometimes (but not always) compute implicatures. *Language and Cognitive Processes*, *20*(5), 667–696.

Yurovsky, D., & Frank, M. C. (2014). Beyond naïve cue combination: Salience and social cues in early word learning. In *Proceedings of the 36th annual meeting of the cognitive science society*.