

Infants' Adherence to Principle C: Evidence from 30-month-olds

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In this paper we investigate infants' adherence to syntactic constraints. By investigating infants' abilities in this domain, we can explore their knowledge of abstract grammatical representations. We focus on knowledge of Principle C, a grammatical constraint on coreference, which requires a hierarchical representation of language to be computed. We tested 30-month-old infants' knowledge of Principle C in a preferential looking task, and found that overall infants of this age succeed. This is one of the earliest ages at which success with grammatical constraints has been attested. Additionally, we found differing patterns of success correlated with vocabulary size: only high-vocabulary infants demonstrated knowledge of Principle C. We conclude that 30 months is the earliest age at which infants are able to demonstrate this knowledge, and we explore several developmental correlates of increasing vocabulary size and their potential as explanations for this lower limit on infants' ability succeed with Principle C.

1. Introduction

Knowledge of the syntax of a language determines the connection between a sentence's spoken form and its meaning. Syntactic rules are of two types: those that specify the construction of a phrase structure, and those that determine the mapping of phrase structures onto meanings.

Knowing these rules allows a person to determine both what sentence forms are possible and how these forms map onto meanings. In this paper we focus on children's knowledge of coreference, which is constrained by the rules that restrict the mapping of sentences onto meanings.

Coreference constraints determine the permissible referents for a pronoun in a sentence. For example, the grammar dictates that in (1) the pronoun *she* may only refer to Anna, and not to Katie, despite the fact that both characters are made available in the context.

- (1) Anna thinks that she hugged Katie.

Constraints on the interpretation of pronouns are based on structural relations between referring expressions within the sentence (Langacker 1969, Lasnik 1976). This conclusion derives from the asymmetry between (1) and (2).

(2) While she was making dinner, Katie heard the phone ring.

In both of these examples, the pronoun *she* precedes the name *Katie*, but only in (2) is coreference possible. This observation leads to the conclusion that the constraint must be captured in terms of an abstract hierarchical relation between noun phrases in the sentence, and hence that acquiring adult-like competence with this grammatical constraint requires a system that makes reference to such abstract relations (Wexler & Chien 1990, Crain 1991, Lidz 2007).

The two primary questions that arise regarding children's acquisition of grammatical constraints are the following: (a) how do children come to have knowledge of the constraints, and (b) when are children able to demonstrate this knowledge? How children achieve adult competence given limited evidence, often framed as a question of whether constraints are innate or learned, is an open question that we will not address in this paper. However, because abstract representation is a prerequisite for adult-like competence in this domain, the study of children's knowledge of coreference constraints is an ideal window into the abstract nature of their linguistic representations. Observing an early age at which infants are able to demonstrate knowledge of a particular grammatical constraint minimally reveals a part of the pattern of acquisition of that constraint, but also reveals aspects of the pattern of acquisition of abstract syntactic representation. Note, however, that because there exist performance factors that affect language understanding, the ability to demonstrate a particular type of knowledge in the laboratory may arise at a time later than the point at which the child came to have that knowledge. For example,

to be able to compute the constraint over a sentence like (3), the child must be able to represent the relevant hierarchical structure and the relevant relation over hierarchical structures, in addition to having the processing efficiency to compute these for a given sentence in real-time.

(3) She is patting Katie.

If children are missing any of these three factors, they will fail to demonstrate knowledge of the constraint. This makes the question of when children begin to show evidence of a particular type of knowledge independent from the questions of how and when they come to have it.

With the goal of establishing a developmental pattern, we focus on the question of when children are able to show knowledge of a particular constraint on coreference, Principle C (Chomsky, 1981), which entails that a pronoun cannot asymmetrically c-command its antecedent. In order to identify correlates of the developmental pattern we observe, we will ask what young children's ability to demonstrate this knowledge can tell us about the state of their linguistic system. Because Principle C relies on abstract elements of the grammar, by observing that children are able to show knowledge of a constraint, we can make inferences about their knowledge of the abstract grammatical elements necessary to do so.

Principle C is the constraint responsible for the pattern of coreference in (1). Like other constraints on coreference, Principle C restricts the permissible form-meaning pairs in a language by limiting the coreference possibilities within a particular type of sentence. Specifically, Principle C prohibits coreference between a name and a c-commanding pronoun (Chomsky, 1981). Consider the following sentences:

- (4) She's patting the puppy.
- (5) She's patting Katie.

In (4) Principle C does not constrain the meaning of the pronoun, and *she* can refer to any female in the discourse model, including Katie. In (5), Principle C limits the possible referents of *she*, which may therefore not refer to Katie. Thus, a grammar unconstrained by Principle C would allow both (6) and (6) below as potential meanings for (5), while in a grammar constrained by Principle C only (6) is permissible as a meaning for (5).

- | | | |
|--------|--|-----------------------------|
| (6) a. | She _i is patting Katie _j . | NON-REFLEXIVE (SHE ≠ KATIE) |
| b. | * She _i is patting Katie _i . | REFLEXIVE (SHE = KATIE) |

Recall that the constraint on coreference must be described in terms of a structural relationship within the sentence, as shown in (7).

- (7) Her puppet is patting Katie's head.

Here the pronoun *her* precedes the name, but does not c-command it, and coreference between the two is possible. Because Principle C operates over a specific syntactic relation, asymmetric c-command, knowing when children demonstrate knowledge of the constraint can act as an index of their knowledge of this relation. By investigating children's developing ability to show knowledge of Principle C, we can discover when children have the requisite structural resources, thereby adding to what is known about the timeline of linguistic development.

Children as young as 3 and 4 years old were first shown to reliably demonstrate knowledge of Principle C by Crain & McKee (1985). This study used the Truth-Value Judgment Task, which allows researchers to explore the properties of children's grammars by testing children's acceptance of specific sentence-meaning pairs. Children watch a short story acted out in front of them using small toys, and then judge a potentially ambiguous description of the story, uttered by a puppet, to be true or false. Stories are designed to make the two potential meanings for the

test sentence salient, and to make one meaning true and the other false. Children's judgments of the puppet's description reveal which meaning they associated with the test sentence. From these judgments, researchers can infer which interpretations children allow, and make inferences about their grammars.

To demonstrate children's knowledge of Principle C, Crain & McKee (1985) tested 3- and 4-year-olds on sentences like (8) and (9) below. They found that children correctly rejected these sentences on the coreferential reading 88% of the time.

- (8) He ate the hamburger when Smurf was on the fence.
- (9) He washed Luke Skywalker.
- (10) When he stole the chickens, the lion was in the box.

To be sure that the children were not using a linear constraint against backwards anaphora, Crain and McKee also tested them on sentences like (10). They found that children correctly and reliably accepted a coreferential reading for these sentences, showing that they do obey Principle C. This finding has been supported in studies by Lust & Clifford (1986), Guasti & Chierchia (1999/2000), Kazanina & Phillips (2001) and Leddon & Lidz (2005).

However impressive these demonstrations are, it may not be surprising that 3- and 4-year old children have mastered this constraint. After all, at this age, children already have large vocabularies and regularly form complex sentences. And, we have since learned that at this age children show knowledge of many other related grammatical constraints (for a review, see Goodluck, 2007 and Lidz, 2007). If we are interested in identifying a developmental pattern, however, we must find the point at which children first begin to demonstrate knowledge of Principle C. Therefore, in this paper we examine children at an earlier stage of linguistic

development. Children begin producing the 2- to 3- word sentences over which Principle C could be calculated between the ages of 2 and 3 years (Miller & Chapman, 1981), and typically comprehend more complex sentences than they produce. It is plausible, then, that this is an early age at which infants have both the structural and processing resources necessary to demonstrate knowledge of Principle C. For these reasons, our study examines knowledge of Principle C in 30-month-olds.

We approach our goal of identifying and exploring the significance of the earliest age at which infants demonstrate knowledge of Principle C in three steps. First we identify 30 months as an early age at which infants exhibit knowledge of the constraint. Second, we ask whether this is plausibly the earliest age at which infants have the ability to demonstrate this knowledge, and find, based on the uneven distribution of the experimental effect across participants, that it is. Because the ability to demonstrate knowledge of the constraint consists of three parts, when we observe infants failing to adhere to Principle C, it may be because they lack one or more of the following: knowledge of the constraint, the ability to build the relevant grammatical structures, or the processing efficiency to understand and respond to the test sentences in the time the task allows. Our third step, given this estimate of the earliest age at which infants can demonstrate knowledge of Principle C, is to ask what factors might contribute to the unfolding of this ability at this stage in development.

The standard tasks used to test 4-year-olds are not appropriate for use with 30-month-olds. For instance, the Truth-Value Judgment Task makes heavy demands on children's language processing abilities and working memory by requiring them to follow a story from start to finish,

remember key events, and then make a true or false judgment about the puppet's sentence¹. To test younger children, we need a task that makes fewer demands on the child. Therefore, we chose a preferential looking task, which simply requires participants to look at a video and map an audio stimulus onto a video stimulus, and which has been successfully used with infants as young as two months of age (Pegg, Werker & McLeod, 1992). The task is based on the finding that infants will look longer at a visual stimulus that matches audio they hear than at one that does not (Spelke, 1979; Hirsh-Pasek & Golinkoff, 1996). For example, if a picture of a ball and a picture of a truck are displayed on a screen in front of a child, and he or she hears "Ball! It's a ball! See the ball?", he or she will look longer at the picture of the ball than at that of the truck (Hirsh-Pasek & Golinkoff, 1996).

Recall that a grammar unconstrained by Principle C provides two potential meanings for the sentence in (11), shown in (12) (repeated from (5) and (6), respectively). Because the two potential meanings correspond to different events, we can use the preferential looking task to determine which events infants understand the sentence in (11) to describe.

- | | | |
|------|--|---------------|
| (11) | She's patting Katie. | |
| (12) | a. She _i is patting Katie _j . | NON-REFLEXIVE |
| | b. *She _i is patting Katie _i . | REFLEXIVE |

These two meanings each describe a different event. (12) describes a non-reflexive event in which someone else pats Katie, for example, *Anna pats Katie*. (12), on the other hand, must describe a reflexive event in which *Katie pats herself*. If both interpretations are available to the infants, that is, if Principle C is not active in their grammar, either (12a) or (12b) represents a possible meaning for (11). If Principle C is active in infants' grammars, the reflexive

¹ Though the Truth-Value Judgment task has been done with children as young as 2;8 (Kazanina & Phillips, 2001), it cannot be done reliably with most children in this age group. Therefore, it is not a useful tool for gathering representative data from this age group.

interpretation in (12), which requires the coreference of a name and a c-commanding pronoun, will be ruled out, and only the non-reflexive interpretation shown in (12) will be permissible.

Using this task we observe that 30-month-olds can demonstrate knowledge of Principle C.

However, observing an ability broadly within a certain age group is not sufficient to identify the earliest age at which infants have that particular ability. In order to determine whether 30 months is the earliest point at which infants are able to demonstrate knowledge of Principle C, we examine the distribution of the experimental effect with respect to participants' linguistic development. To do this, we use vocabulary size as an independent measure of linguistic development by which to group participants. Age is only a coarse measure, as infants of the same age often differ drastically in their linguistic development. Vocabulary, on the other hand, has been shown to be closely correlated with two measures of increasing syntactic complexity in the grammar: an increasing proportion of function words to content words in productive vocabulary and an increasing Mean Length of Utterance (MLU) (Devescovi, et al., 2005). We can therefore use vocabulary size as a finer measure of infants' linguistic development by which to examine the distribution of the experimental effect across participants. We find a distinct difference in the performance of the high-vocabulary and the low-vocabulary groups. Based on this difference, we argue that we have identified a lower bound on infants' ability to demonstrate knowledge of Principle C.

Using the approach outlined above, we find that 30-month-olds show knowledge of Principle C, and we argue that this is the earliest age at which infants can demonstrate this ability. In what

follows, we describe our experimental design, methodology and results. We then discuss our results and their implications for our research question.

2. Study

We used a preferential looking task to test 30-month-olds' knowledge of Principle C in order to identify the earliest point at which infants are capable of demonstrating knowledge of Principle C. In this section we describe in detail the materials and procedure used, the participants and our results.

2.1 Materials

The preferential looking paradigm makes use of the finding that infants will look longer at a visual stimulus that matches audio they hear than at one which does not (Spelke, 1979; Hirsh-Pasek & Golinkoff, 1996). In our particular implementation of the paradigm, infants are presented with two simultaneous event videos, one on each side of a television, accompanied by an auditory stimulus. The event videos are of two types, each corresponding to a potential interpretation of (11): reflexive, corresponding to the interpretation shown in (13), and non-reflexive, corresponding to the interpretation in (13). In each trial the pair of videos is accompanied by one of two sentence types, shown in (14).

- | | | | |
|------|----|--|---------------|
| (13) | a. | She _i is patting Katie _j . | NON-REFLEXIVE |
| | b. | * She _i is patting Katie _i . | REFLEXIVE |
| (14) | a. | She's patting Katie. | PRINCIPLE C |
| | b. | She's patting herself. | REFLEXIVE |

Because of the syntax of the sentences in (14), a non-reflexive event, (13), is the only possible match for the Principle C sentence in (14), and a reflexive event, (13), is the only possible match for the Reflexive sentence in (14b).

The video each infant saw was made up of three components: an introduction to the characters, six short “face checks”, and eight trials. The introduction consisted of a series of video clips showing the two characters individually, accompanied by audio naming them. This served to familiarize infants with the characters and teach them the characters’ names. Note that though learning the names may help infants to process subsequent sentences, the nature of the test sentences made knowing the characters’ names unnecessary. The face checks, spaced throughout the video, presented infants with two images simultaneously, one of each character, accompanied by audio directing them to find one character or the other. The processes required for this task are a subset of those required to process and match an entire sentence with a visual stimulus. Therefore, the face checks provide both an independent measure of infants’ ability to succeed with the task and an independent measure of whether infants had learned the characters’ names. The test trials are the final component of the video. There were eight trials, each showing a different continuous transitive action (e.g. fanning, spinning). Each trial included a test sentence, half of which were of the Principle C type shown in (14) and half of which were Reflexive, as in (14). A schematic of a video is shown in Table 1, below.

Table 1: Schematic of a Video

Items	Length	Sample Audio
Character Introduction	58 s	Hey look! There's Anna! She's waving! Wow! There's Katie! She's waving too!
Face Check 1	6 s	Where's Katie? Do you see Katie?
Face Check 2	6 s	Where's Anna? Do you see Anna?
Trial 1	27 s	She's drying Anna!
Face Check 3	6.5 s	Find Anna! Do you see Anna?
Face Check 4	6.5 s	Find Katie! Do you see Katie?
Trial 2	27 s	She's patting Katie!
Trial 3	27 s	She's painting herself!
Trial 4	27 s	She's fanning Anna!
Face Check 5	6 s	Where's Katie? Do you see Katie?
Trial 5	27 s	She's spinning herself!
Trial 6	27 s	She's washing Katie!
Trial 7	27 s	She's squeezing herself!
Face Check 6	6 s	Anna's waving! Do you see Anna waving?
Trial 8	27 s	She's covering herself!





Each of the eight trials is made up of three phases: familiarization, salience and sentence mapping. These are shown graphically in Table 2. During the familiarization phase, the two videos, reflexive and non-reflexive, are shown sequentially, accompanied by audio that directs infants' attention to the action being shown, as in (15).

(15) It looks like someone is getting patted!

We chose to use a passive sentence with an indefinite subject because it introduces the relevant verb, while being non-specific as to the identity of the participants in the event and applying equally to the reflexive and non-reflexive events without biasing listeners toward one or the other. This allows infants to hear the verb that will be used in the test sentence and to see each of the event-videos before being presented with them at test. During the salience and sentence mapping phases, the reflexive and the non-reflexive videos are shown simultaneously, one on each side of the screen. The salience phase lasts 3 seconds, during which the audio is entirely neutral, simply drawing infants' attention to the screen. This allows us to determine infants'

baseline preference for the videos. The sentence mapping phase is 9 seconds long, during which the test sentence is repeated three times. If infants show a preference for one video of the other as a result of their interpretation of the sentence, we expect it to surface here.

Table 2: Trial Layout

Phase	Familiarization		Test	
			Salience	Sentence Mapping
Time	6 s	6 s	3 s	9 s
Audio	Hey look! It's Anna and Katie! It looks like someone's getting patted!	Wow! There they are again! It looks like someone's getting patted again!	Hey look! Now they're different!	She's patting Katie!* Do you see the one where she's patting Katie? Find the one where she's patting Katie!
Video			 	

* Note: Half the trials each infant sees use this sentence type. The other half substitute sentences of the same form as (14).

Videos were created in the following way. All visual stimuli were recordings of live actors performing continuous transitive actions. These recordings were imported into FinalCut Express, and edited for length, size, and position on the screen. Audio was digitally recorded in a sound attenuated room by a native speaker of American English using child-directed speech intonation. Tokens of each utterance were selected for clarity and consistency of speaking rate, and then imported into FinalCut Express and synchronized with the video. Audio always began 600ms after the corresponding video. The three instances of the test sentence in the sentence mapping

phase are synchronized by their offsets, which occur 4.5, 7.5 and 10.5 seconds into the test phase.

Eight orders were created by counterbalancing stimuli for a number of factors. Across subjects, videos were counterbalanced for the order of trials, the trial type used with each verb and the video seen first during familiarization. Half of the infants saw trials in the order shown in Table 1, and half saw them in the reverse order. For each of the actions, half of infants heard a Reflexive test item (14), and half of infants heard a test sentence governed by Principle C(14). Additionally, for each trial, half of infants saw the reflexive action first and half saw the non-reflexive action first. Within trials, stimuli were counterbalanced for the side the correct answer was on, the first video in familiarization and trial-type. In half of the trials, the correct (adult-like) answer was on the left side, and in the other half it was on the right. Likewise, in half of the trials any individual infant saw, the non-reflexive video came first in familiarization, and in the other half, the reflexive video did. Because trial-type was a within subjects factor, half of the trials each infant saw were Reflexive, and half were Principle C.

2.2 Participants

Thirty-two infants (19 males) ranging in age from 28;14 to 33;1 (mean= 30;6) were included in the final sample. All participants were recruited from the College Park, Maryland area and all were exposed to English more than 80% of the time. Parents filled out a MacArthur Communicative Development Inventory: Words and Sentences questionnaire (Fenson, et al., 1994). Mean productive vocabulary was 446 words (range: 76 to 675 out of 680 possible). An

additional 2 infants were excluded from the sample for refusal to sit through the experiment (n=1) and for incomplete MCDI (n=1).

2.3 Procedure

Infants and their parents were greeted and shown to the laboratory play room, where the parents filled out the consent form and MCDI while infants played freely. When the forms were complete and infants were acclimated to the laboratory surroundings, one parent and the infant were shown to the adjacent testing room. The testing room was 8.5x10.3 feet, sound-attenuated, and had white walls.

Infants were seated in a high-chair centered in front of a 51-inch plasma television at a distance of 6 feet. Parents were seated behind the infant's high-chair, out of the infant's field of vision, and out of physical contact with the infant. Parents were asked not to talk to their infant or direct the infant's attention during the course of the experiment. Overhead lights were dimmed so that most of the light in the room came from the television. A camera mounted directly over the television captured the infant's eye movements for subsequent off-line coding.

Researchers controlled stimulus presentation from the adjacent control room. They were not visible from inside the testing room. Researchers could control the position and zoom of the camera in order to keep the child's eyes in sight throughout the experiment, even if the infant moved. This, however, was almost never necessary. Visual stimuli appeared on a 3.5x1.7 foot area of the screen. Audio was presented at 65 ± 5 dB.

The video-feed from the camera, with the addition of a picture-in-picture window of the video being shown to the infant, was recorded to a lab computer using QuickTime. This was subsequently coded frame-by-frame (30 frames per second) for looks to the left, right or neither, using SuperCoder software (Hollich, 2005). Coders were blind to condition and could not hear the audio.

2.4 Predictions

Recall that in the preferential looking paradigm we expect infants to look longer at an event video that matches the audio they hear. Recall also that for each of the two test-sentence types (Principle C and Reflexive), only one of the two event videos presented represents a syntactically permissible meaning.

In Principle C trials, if Principle C is active in infants' grammars, the reflexive interpretation of the test sentence will be ruled out, and only the non-reflexive event will represent an appropriate meaning for the sentence. Therefore, infants should consider only the non-reflexive video an appropriate match for the test sentence, and we predict that they will spend longer looking toward that video. Specifically, we predict that during the sentence mapping phase infants will show an increase in looks to the non-reflexive video compared with the baseline we measured during the salience phase. However, if Principle C is not active in infants' grammars, the test sentence will be ambiguous, and either event video will represent an appropriate match for the test sentence. In this situation we predict that infants will look at the two videos equally, and that they will show no change in behavior between the salience and sentence mapping phases.

In the Reflexive trials, if infants know the relevant property of reflexive pronouns, namely that they require a local antecedent, only the reflexive video will represent an appropriate match for the test sentence. Therefore, we predict that they will show an increase in looks to the reflexive video, (13), between salience and sentence mapping. If they do not know the relevant property, then either of the characters will be a possible referent for *herself*, and we predict that infants will show no change in behavior between the salience and sentence mapping phases.

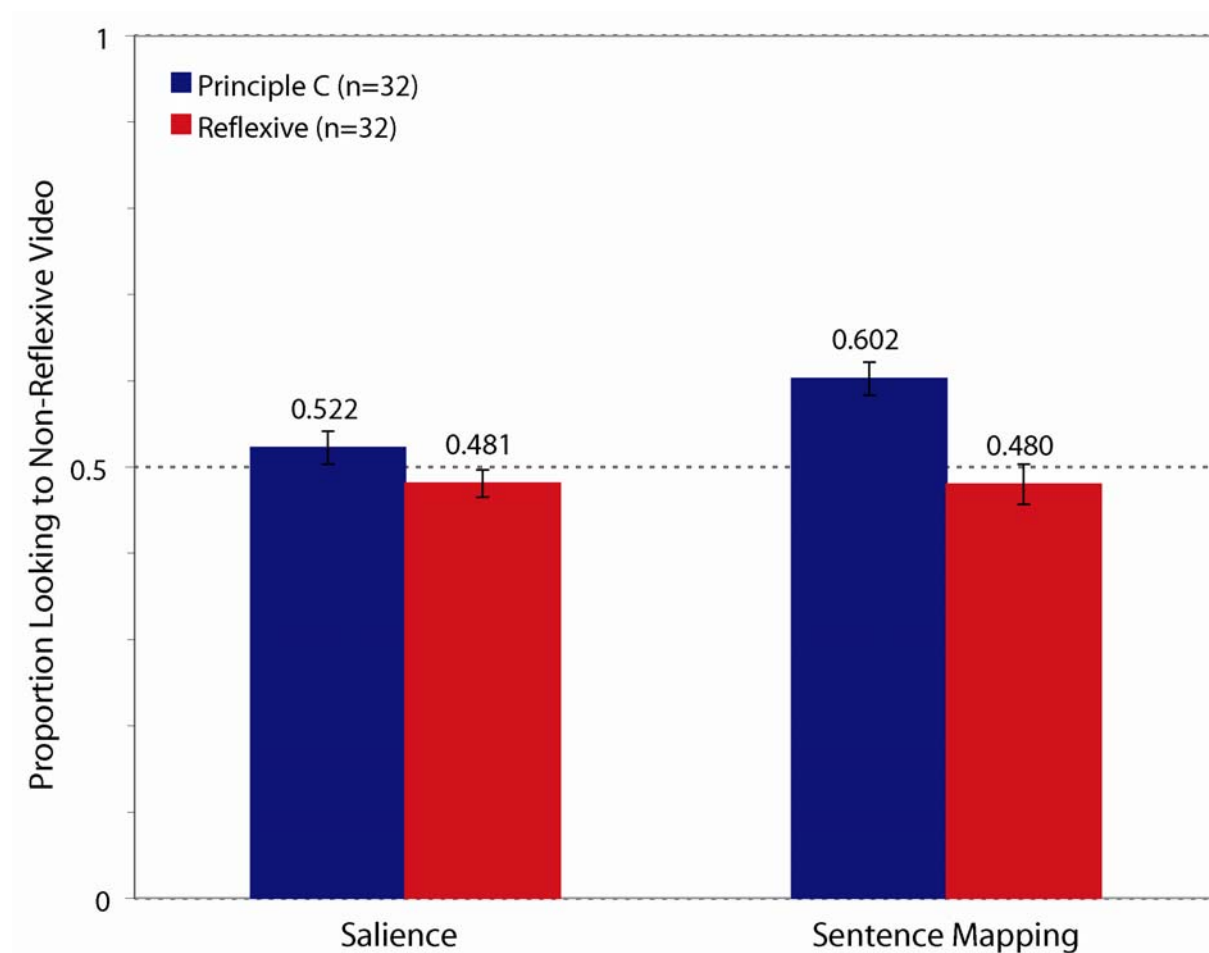
2.5 Results

Let us now turn to our results. First, during the face check portion of the videos, we measured the proportion of time infants spent looking to the character named by the audio. Infants looked significantly more toward the correct character than toward the incorrect one ($t(31)=3.04$, $p<.005$). This indicates that participants knew the characters' names and were able to successfully perform a task that requires a subset of the processes necessary for matching a full sentence with a visual stimulus.

During the test portion of the trials, we measured the proportion of time infants spent looking toward the non-reflexive video during salience and during sentence mapping. This was calculated for each infant by dividing the number of frames (30 frames per second/33 ms) in which the infant was looking to the non-reflexive video by the number of frames in which the infant was looking to either video. Any frame in which the infant was not attending to either video was excluded from the calculation. One trial was excluded because the subject attended to neither video for >80% of the time. Any infant who watched fewer than half the trials was excluded entirely ($n=1$). The proportion of infants looking to the non-reflexive video for each

frame was then averaged over the salience and sentence-mapping phase, for each of the trial-types. These results are shown in Figure 1.

Figure 1: Average looking time to Non-Reflexive video



This graph shows the average proportion of time infants spent looking toward the non-reflexive video during salience and sentence mapping for each trial-type, Principle C and Reflexive.

Proportion is plotted on the y-axis. During the salience phase, the proportion of time infants spent looking at the non-reflexive video in both trial-types is equivalent to chance (Principle C ($t(31)=1.17$, $p>.25$), Reflexive ($t(31)=-1.18$, $p>.24$), suggesting that infants had no bias to look at one video over the other. In the Reflexive trials we see no change in behavior from salience to

test, but in the Principle C trials we see a clear increase in the proportion of time infants spent looking to the non-reflexive video in the sentence mapping phase.

These proportions were entered into a multiple effects ANOVA with three within-subjects factors: phase (salience vs. sentence mapping) x trial-type (Principle C vs. Reflexive) x order. We found a main effect of trial-type ($F(1,119)=17.8, p<.0001$), and of phase ($F(1,119)=4.14, p<.05$) as well as a significant interaction between the two ($F(1,119)=4.36, p<.04$). There was no significant interaction between order and trial type ($F(1,119)=.003, p>.96$), or between order and phase ($F(1,119)=.24, p>.63$). Order was therefore discounted for further analyses. A multiple effect ANOVA with the two remaining within-subjects factors, phase x trial-type, also revealed a main effect of trial-type ($F(1,123)=17.37, p<.0001$), and of phase ($F(1,123)=4.04, p<.05$), and a significant interaction between the two ($F(1,123)=4.25, p<.05$). Planned comparisons revealed that during the sentence mapping phase of Principle C trials, infants looked significantly longer at the non-reflexive video than they did during the salience phase ($t(62)=2.95, p<.005$). Twenty-nine of the thirty-two infants looked at the non-reflexive video more than 50% of the time during the sentence mapping phase in this condition ($p<.0001$, by sign test). During Reflexive trials, the proportion of infants looking toward the non-reflexive video was not different from chance in either phase. Additionally, in the Reflexive trials infants showed no significant difference in looking patterns between salience and sentence mapping ($t(62)=-.04, p>.9$).

As predicted, given neutral audio during the salience phase infants looked equally at the two videos, but given a Principle C test sentence, infants showed a clear increase in looking at the non-reflexive video. This supports the hypothesis that Principle C is active in 30-month-olds'

grammars because it reflects a clear disinclination to map the test sentence to the reflexive meaning prohibited by Principle C. These results suggest that Principle C is active in the grammars of 30-month-old infants, and therefore that this is an early age at which infants can succeed with the constraint.

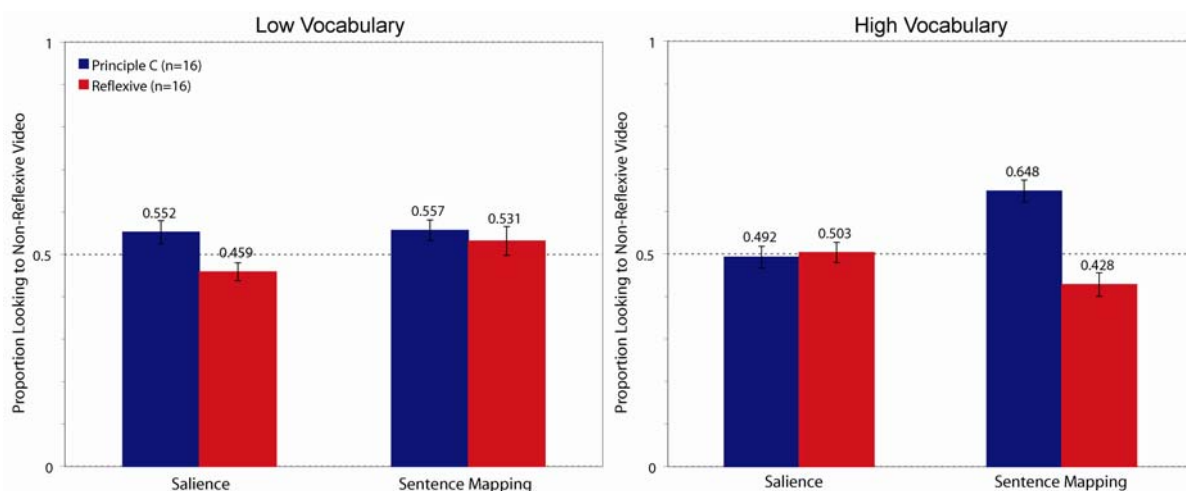
Because we have found an early age at which infants exhibit knowledge of Principle C, we move to the second step of our original question: is this plausibly the earliest age at which infants can demonstrate this knowledge? Because this age-range may include infants with very different levels of linguistic development, we examined the distribution of the experimental effect across infants with respect to vocabulary. Recall that age is not a very sensitive predictor of linguistic development, but that vocabulary correlates closely with several indicators of increasing syntactic competence (Devescovi, et al., 2005). If, around the time they are 30 months old, infants are in the earliest stage of linguistic development at which they can demonstrate knowledge of Principle C, we predict that the effect will be unevenly distributed between infants with large vocabularies and those with small vocabularies. If these infants are already past the stage at which the ability to demonstrate this knowledge first appears, we expect the effect to be evenly distributed across the infants.

To test this, we split infants into two groups around the median vocabulary (509 words), such that the 16 infants with productive vocabularies greater than 509 words on the MCDI make up the high-vocabulary group and the remaining 16, with productive vocabularies less than 509 words, make up the low-vocabulary group. If infants have the ability to show knowledge of Principle C before 30 months, we predict that the high and low-vocabulary groups will show

similar behavior. If this is the earliest point at which infants can demonstrate this knowledge, then we predict that the behavior of the low-vocabulary infants will not differ as a function of the grammar of the test sentence, but that the behavior of the high-vocabulary infants will.

Figure 2 shows the proportion of infants looking to the non-reflexive video averaged over the salience and sentence mapping periods, split by vocabulary group. As in Figure 1, the y-axes display the proportion of infants looking to the non-reflexive video, for both trial-types.

Figure 2: Average looking to Non-Reflexive video by Vocabulary



The proportions for both vocabulary groups were entered into a multiple effects ANOVA with three within-subjects factors: phase (saliency vs. sentence mapping) x trial-type (Principle C vs. Reflexive) x order. For the low vocabulary group we found a main effect of trial-type ($F(1,55)=5.11, p<.03$), but there was no significant interaction of trial-type and phase ($F(1,55)=1.68, p>.2$). Order did not interact significantly with either phase ($F(1,55)=.17, p>.68$) or trial-type ($F(1,55)=.004, p>.95$), and was therefore discounted in further analyses. A multiple effects ANOVA with two within-subjects factors, trial-type and phase, also showed a main effect

of trial-type ($F(1,59)=4.82, p<.04$), and no significant interaction of trial-type and phase ($F(1,59)=1.59, p>.21$).

In the high-vocabulary group, on the other hand, the multiple effects ANOVA (trial-type x phase x order) revealed both a main effect of trial-type ($F(1,55)=15.54, p<.0005$), and a significant interaction between trial-type and phase ($F(1,55)=18.93, p<.0001$). Again, order did not interact significantly with either trial-type ($F(1,55)=.006, p>.94$), or phase ($F(1,55)=.1, p>.75$), and was discounted for further analyses. A multiple effects ANOVA with the remaining two within-subjects factors, trial-type and phase, also showed a main effect of trial-type ($F(1,59)=16.52, p=.0001$) and a significant interaction between trial-type and phase ($F(1,59)=20.17, p<.0001$). Planned comparisons revealed that infants in the high-vocabulary group looked significantly more at the non-reflexive video during the sentence mapping phase of Principle C trials than during salience ($t(30)=4.29, p<.001$), and significantly less at the non-reflexive video during the sentence mapping phase of Reflexive trials than during salience ($t(30)=-2.06, p<.05$).

We see that the effect is not distributed evenly among infants. The high-vocabulary infants show a pattern of behavior that looks much like what we saw in our first analysis, which included all participants. They show an increase in looks to the non-reflexive action between the salience and sentence mapping phases. The low-vocabulary infants, however, fail to show the same pattern. They show little or no difference in their behavior between salience and sentence mapping in the Principle C trials. These results suggest that 30-month-olds are in the vicinity of a lower bound on infants' ability to demonstrate knowledge of Principle C, and that this lower bound is a function of development as indexed by vocabulary.

3. Discussion

We began with the goal of finding the earliest age at which infants are able to demonstrate knowledge of Principle C, and we approached this goal in two steps. First, we found an early age at which infants are capable of demonstrating knowledge of Principle C. Second, we examined the distribution of the experimental effect among the infants in order to determine whether this was the earliest such age. To do this we used a preferential looking task, in which infants were presented with two videos that were potential matches for the test sentence. In this section we discuss and discount several potential alternative explanations of our results, and we discuss the factors that correlate with infants' emerging ability to demonstrate knowledge of Principle C.

In answer to our first question, we found that, overall, the proportion of infants looking at the non-reflexive video increased significantly between salience and sentence mapping in the Principle C trials. This suggests that Principle C is active in 30-month-olds' grammars. However, these results are only robust to the degree that we can exclude all other possible explanations of the effect. There are several other potential explanations of our results, including (a) infants using knowledge of reflexives and a process of elimination reasoning to arrive at the correct answer in Principle C trials, (b) infants having a bias to assume that transitive sentences have two participants, and (c) infants making use of a linear (i.e., nonstructural) constraint against backwards anaphora. Below we discuss these potential explanations and show that they do not undermine our account.

One potential explanation of our results is that infants know a great deal about the properties of reflexive pronouns, and that they succeed in both trial types as a result of this knowledge and the ability to use process-of-elimination reasoning. In other words, infants succeed in Reflexive trials because they know how reflexive pronouns work, and they succeed in Principle C trials because they reason that if the sentence were intended to describe the reflexive event, it would have needed a reflexive pronoun. Since there was no reflexive pronoun, the infants infer that the sentence must describe the non-reflexive event video. This possibility is called into question by the lack of a strong decrease in looking to the non-reflexive video during Reflexive trials overall, and is ruled out based on an additional analysis of the existing data.

If infants were succeeding in Principle C trials based on their strong knowledge of reflexives, we would expect their success in the Reflexive trials to match or even exceed their success in the Principle C trials. However, we see that while there is a marked change in behavior between salience and sentence mapping in the Principle C trials, there is no change in behavior between the two phases in the Reflexive trials. This casts doubt on the idea that infants' mastery of reflexive constructions is strong enough that they are able to use it to deduce the meaning of unfamiliar sentences types. Though infants overall do not succeed in the Reflexive trials, infants in the high-vocabulary group do show a significant decrease in looks to the non-reflexive video in Reflexive trials. Since this is also the group that shows strong success in the Principle C trials, we ran a further analysis of the data to determine whether infants might be using process of elimination reasoning to succeed in the Principle C trials.

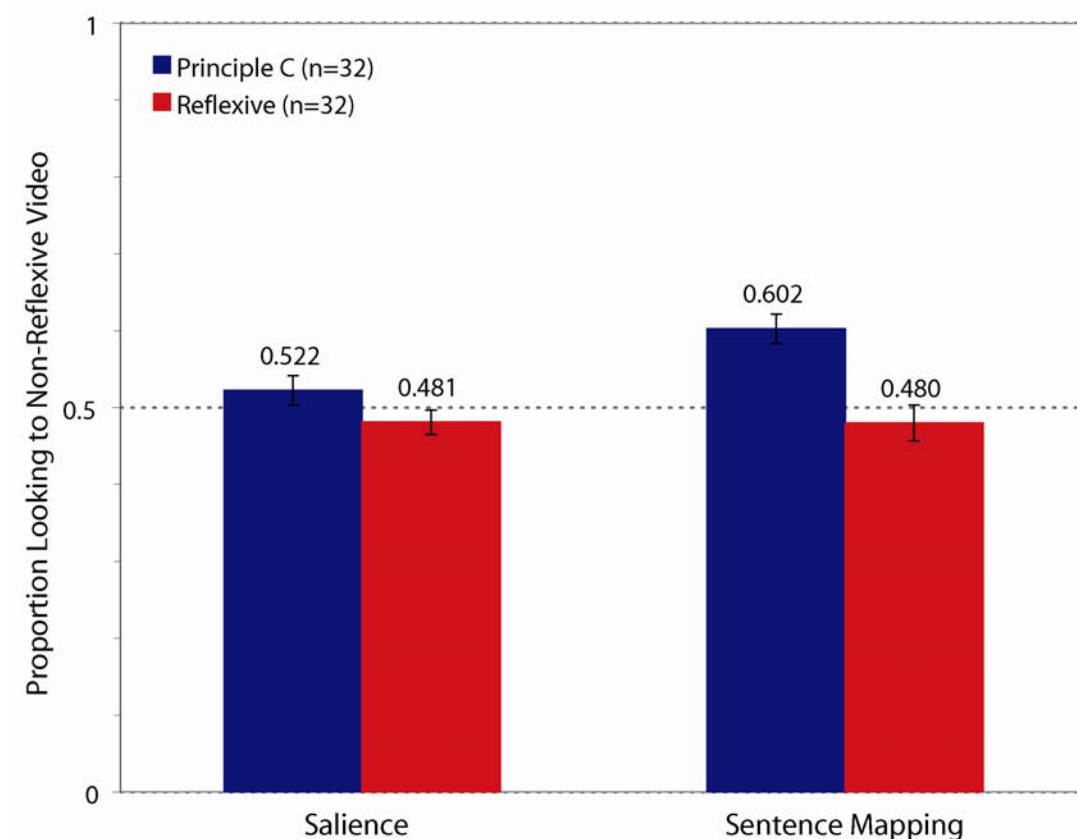
So far we have been examining overall tendencies in infants' looks to one video or another, but specific patterns of looking, separate from the overall averages, can also be informative about the patterns of reasoning infants use (cf. Swingley, Pinto & Fernald 1999, Halberda, 2006). The explanation of the data under consideration attributes infants' success to a step of reasoning that they make in the Principle C trials, which is unnecessary in the Reflexive trials. Infants in both trial-types look back and forth between the reflexive and non-reflexive videos. Because in Principle C trials infants must compute the process of elimination reasoning based on their knowledge of reflexive pronouns, and because in the Reflexive trials they can rely on their knowledge directly, if infants are succeeding by using this strategy, we would expect them to spend a longer time looking at the reflexive video during the Principle C trials than they spend looking at the non-reflexive video during the Reflexive trials.

For each trial type we measured the length of infants' first look to the non-matching video after the offset of the first instance of the test sentence. That is, in Principle C trials we measured the length of infants' first look to the reflexive video, and in Reflexive trials, we measured the length their first look to the non-reflexive video. For the group as a whole, the average length of the first look to the reflexive video in the Principle C trials was 2.3 seconds. In the Reflexive trials, the average first look to the non-reflexive video was 2.2 seconds. The lengths of these looks are not significantly different ($t(56) = .52, p > .6$). Furthermore, even among infants in the high-vocabulary group, who showed greater success in Reflexive trials than did the group of all infants, the length of the first look to the non-matching video is not significantly different between Principle C and Reflexive trials. In Principle C trials, high-vocabulary infants' average first look to the reflexive video was 2.4 seconds, while their average first look to the non-reflexive video in Reflexive

trials was 2.1 seconds ($t(29)=.85, p>.4$). This suggests that infants use the same process of reasoning in the two trial-types, and therefore that our results are not the product of infants' knowledge of reflexives and use of process-of-elimination reasoning in the Principle C trials.

A second possible account of our results is that infants are interpreting the Principle C test sentences on the basis of their transitivity rather than correctly determining the reference of the pronouns based on the structure. This would imply that the increase in the proportion of infants looking to the non-reflexive video in the sentence mapping phase is the result of infants' preference that a transitive sentence describe an event with two participants (Naigles, 1990). To determine whether our results can be satisfactorily explained in this way, we need only look at our existing data.

Figure 1: Average looking time to Non-Reflexive video



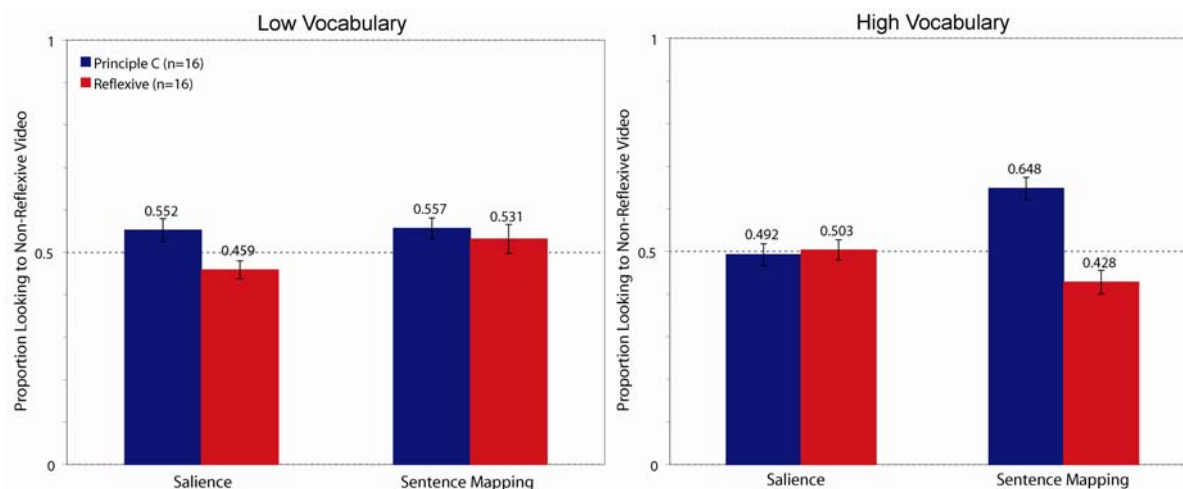
Because all the test sentences, both Principle C and Reflexive, are transitive, if infants are succeeding based on a preference that transitive sentences describe actions with two participants, we would expect infants to look significantly more at the non-reflexive video during sentence mapping than during salience in both trial-types. As we saw in Figure 1, reprinted above, this is not the case. In the reflexive trials, the proportion of infants looking to the non-reflexive video does not increase from salience to sentence mapping.

A third possible explanation of our results is that infants are demonstrating a combination of knowledge of reflexives and a transitivity bias. In other words, infants have a strong knowledge of reflexive pronouns, which competes against their transitivity bias in the Reflexive trials, pulling the proportion of infants looking toward the non-reflexive video down. This explanation correctly predicts that infants will show an increase in looking to the non-reflexive video in the Principle C trials, and that they show no increase in looking to the non-reflexive video in the Reflexive trials.

However, infants have been shown to demonstrate a bias to interpret transitive sentences as involving two participants (Gertner, Fisher & Eisengart, 2006). Therefore, if infants appear to succeed with Principle C because of a transitivity bias and strong knowledge of reflexives, we would expect all infants to show the same preference for the non-reflexive video in the Principle C trials. As we saw in Figure 2, reprinted below, this is not the case. In the low-vocabulary group there was no increase in proportion of time infants spent looking to the non-reflexive video from salience to sentence mapping, while the high-vocabulary infants showed a clear increase, with most of the infants (15/16) showing a positive change in the proportion of time they spent

looking at the non-reflexive video. The fact that the effect is concentrated in one group, and not shared among all the infants suggests that our data are not the result of a combination of infants' transitivity bias and knowledge of reflexives.

Figure 2: Average looking to Non-Reflexive video by Vocabulary



A final potential account of our data is that infants are adhering to a non-adult constraint against backwards anaphora. If this were the case, infants would have a constraint that, for example, prohibits a name from coreferring with a *preceding* pronoun. To rule out the possibility that our results come from infants' adherence to this type of constraint further research is necessary. Our next research question is to find out whether or not infants will allow backwards anaphora in sentences like (16), where the pronoun does not c-command the name, despite preceding it, and coreference is possible for adults.

(16) Her_i puppet is patting Katie_i's arm.

If infants allow coreference in these cases, we can conclude that they are not using a linearly defined version of the constraint, but that they are, in fact, using an adult-like version of Principle C. Critically, although the precise nature of the constraint infants are using remains uncertain, our data clearly show that the form of the sentence determines infants' behavior.

Because we have found an early age at which infants demonstrate knowledge of Principle C and because it does seem to be Principle C that infants are using, our second step was to explore the distribution of the effect across infants. We found that only infants in the high vocabulary group showed a significant increase in the proportion of looks to the non-reflexive video from salience to sentence mapping in Principle C trials. Infants in the low vocabulary group showed no change in behavior between the two phases. This suggests that we have located the lower bound on infants' ability to demonstrate knowledge of Principle C in this task.

This lower bound correlates with vocabulary, but since no model predicts that vocabulary will directly affect Principle C, it seems unlikely that vocabulary is the factor restricting infants' ability to demonstrate knowledge of the constraint. Finding the factor that does restrict infant's ability to show knowledge of the constraint is a goal for future research. There are two potential explanations. Because we know that vocabulary correlates with both grammatical development (Devescovi, et al., 2005) and processing efficiency (Fernald, Perfors & Marchman, 2006), and because Principle C requires processing the effects of a constraint over syntactic structure, either of these factors may play a role in explaining this lower bound. Though in this paper we will not attempt to determine which of these two is the limiting factor, we outline the two accounts below.

If processing efficiency is the restricting factor, then presumably the low-vocabulary infants fail to demonstrate knowledge of Principle C because the task demands more of them in terms of cognitive resources and speed than they are able to provide. On this hypothesis, the high-

vocabulary infants succeed because they have the processing efficiency necessary to calculate the meaning of the test sentence and map it onto one of the event videos in the time allowed by the task. Computing the meaning of the test sentence within the time given requires the resources to both assign a syntactic structure to the sentence, and to assign meaning to the structure. In addition, these processes must be completed relatively quickly and integrated with the infant's understanding of the events being presented in the two videos. If infants are unable to complete either of these processes with sufficient speed, they may be unable to comprehend the sentence and match it with a video before the trial ends. Alternatively, the sentence may be spoken too quickly, or followed too quickly by a subsequent sentence for the low-vocabulary infants to register and process the information it contains. One possible avenue of future research involves attempting to simplify the task. Though we do not know specifically what processing problems the infants may be facing, we can make modifications to the video, such as allowing more time between video clips, recording slower audio, or lengthening the sentence mapping period, and see whether these improve the performance of low-vocabulary infants.

If the limiting factor is grammatical development, then presumably the low-vocabulary infants fail because they do not have the structure over which to process the constraint. Without this structure, there is no way to calculate the asymmetric c-command that Principle C is based on and no way to know whether the constraint should apply or not. Additionally, this predicts that the reason the high-vocabulary infants succeed is that they do have sufficient grammatical structure over which to calculate Principle C.

Identifying which of these potential limiting factors is placing the restriction on infants' ability to exhibit knowledge of Principle C is essential to better understanding the processes by which grammatical constraints become a part of children's grammars and those by which children come to implement these constraints in real time sentence understanding. The first step in doing this is to attempt to reduce the processing demands the task makes on the infants. If this change allows low-vocabulary infants to succeed at the task, we may conclude that processing efficiency is indeed the limiting factor on 30-month-olds' ability to demonstrate knowledge of Principle C. If the low-vocabulary infants' performance does not improve we can make no conclusion: either the task still demands too much from the infants' processing abilities, or the restricting factor is grammatical structure. Alternatively, finding independent correlates of processing speed and grammatical structure, and exploring which of these correlates most strongly predicts infants' ability to demonstrate knowledge of Principle C may help identify the limiting factor.

4. Conclusion

Overall, our findings suggest that grammatical constraints can be evident as early as 30-months of age, and that vocabulary is a useful predictor of the increasing linguistic competence that makes this possible. Zeroing in on the precise cause of the vocabulary effect we see in this study will further contribute to our understanding of the way in which grammatical constraints come to be an active part of infants' language abilities. Additionally, we take Principle C to be a representative constraint, but looking into the timecourse of the acquisition of other constraints will also be necessary to fully understand the acquisition of grammatical constraints by infants.

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