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What Do You Mean, No? Toddlers' Comprehension of Logical "No" and "Not"

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ABSTRACT

For adults, "no" and "not" change the truth-value of sentences they compose with. To investigate children's emerging understanding of these words, an experimenter hid a ball in a bucket or a truck, then gave an affirmative or negative clue (Experiment 1: "It's not in the bucket"; Experiment 2: "Is it in the bucket?"; "No, it's not"). Replicating Austin, Theakston, Lieven, & Tomasello (2014), children only understood logical "no" and "not" after age two, long after they say "no" but around the time they say "not" and use both words to deny statements. To investigate whether this simply reflects improving inhibitory control, in Experiment 3 we showed children that one container did or did not hold the ball. Twenty-month-olds now succeeded. We discuss two possible factors limiting learning both "no" and "not"—a purely linguistic difficulty learning the labels, and the possibility that negation is unavailable to thought before age two.

One of the most remarkable things about human cognition is our ability to take a finite number of concepts and combine them to generate an infinite number of meaningful thoughts. An English speaker who has never heard the sentence, "There are no bears on Mars," has no trouble understanding what it means. Furthermore, we are able to judge that it is very likely true, and can infer that, if it is, then there are also no brown bears on Mars, no bear cubs, and no bears climbing Martian trees. The ease with which we can understand new thoughts, make judgments about their truth, and reason about related thoughts has just one plausible explanation—complex thoughts are generated by a system for combining the meanings of concepts in systematic ways.

Negation is an operation that flips the truth-value of a sentence, making negation words like "no" and "not" function words with highly abstract meanings. Unlike the vast majority of content words—nouns, verbs, and adjectives—they do not refer to anything in the world. Their meaning comes from the systematic way that they alter the meanings of the propositions they combine with. Yet despite the abstract meaning of negation, there is not a language in the world without a word for it and not a culture that has ever been reported to dispense with it in their thought.

This article explores the developmental origins of negation in language, taking it as a case study of the development of abstract, combinatorial concepts. By looking at the timing of children's comprehension of "no" and "not", we can learn about the conceptual and linguistic abilities that are required for using truth-functional negation. The age at which children first understand the truth-functional meaning of a negation word provides an upper bound on when truth-functional negation is available to productive thought. The relative timing of learning "no" and "not" is also informative. If children make the mappings for both "no" and "not" at the same time, it would suggest that a single conceptual or linguistic factor—something that the words have in common—limits the

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mapping of both words. If, on the other hand, children map truth-functional negation to "no" and "not" at different times, the mapping of the words is likely constrained by different factors—for example, by the input frequency of each word or their different grammatical properties.

What do we know about the acquisition of the truth-functional meanings of "no" and "not"? A first step is to look at when these words enter children's productive vocabulary. While over half of 15-month-olds say the word "no", it is not until 27 months—a full year later—that half the children say "not" (Dale & Fenson, 1996; see Figure 1). However, 15-month-olds may not be expressing truth-functional negation when they say "no". When children first begin to produce negation words, they use them for a narrower set of functions than do adults—to *reject* offers or commands, or to comment on the *nonexistence* of something they expected (Bloom, 1970; Pea, 1980a). It is not until 24–30 months that children use "no" or "not" to deny the truth of others' utterances (Bloom, 1970; Choi, 1988; Hummer, Wimmer, & Antes, 1993; Pea, 1980b, 1982), as when a parent points to a dog and asks, "Is this a bear?", and the child answers, "no" or "not bear". This *denial* function is the latest to emerge in children's usage, and is most closely associated with truth-functional negation (Pea, 1982). The production of denial negations tracks closely with the emergence of "not" in a child's productive vocabulary (Cameron-Faulkner, Lieven, & Theakston, 2007; Choi, 1988).

Given that children begin to produce denials between 24 and 30 months, why not simply conclude that this is when children map truth-functional negation to both "no" and "not"? The difficulty with data from language production is that it is impossible to distinguish the full range of meanings that a child might know from their pattern of usage. Perhaps a young child is in a position where she knows little about the world, but is confident about her distaste for bathing, and therefore has less occasion to deny a factual claim than to reject the offer of bath time, even if she can use negation as a truth-functional operator. To address this ambiguity, we can examine children's *comprehension* of negation. If negation words do not have a truth-functional meaning for young children, they should not understand sentences where negation words invert truth values.

Most studies of the comprehension of negation indicate that understanding truth-functional negation poses a significant challenge for children, even well past the age at which they are

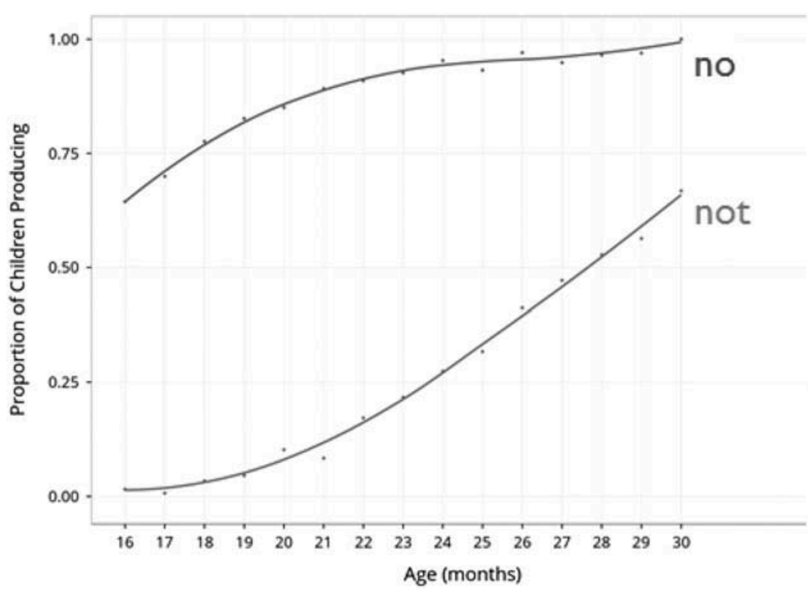

Figure 1. Production of the words "no" and "not" by age, based on data from Macarthur-Bates CDI population norms. Children's age in months is along the X-axis, and the percent of children producing the words is on the Y-axis. Points are means at each month. Lines are logistic regression curves. This figure was generated from the Wordbank repository (Frank, Braginsky, Yurovsky, & Marchman, 2016).

producing denial negations. When presented with true and false negative statements—for example, given a banana, and asked to judge whether "This is not a banana" or "This is not an apple" is right or wrong—even 5-year-olds answer incorrectly (Kim, 1985; see also Lloyd & Donaldson, 1976; Donaldson, 1970). Similarly, Nordmeyer and Frank (2014) measured children's spontaneous eye movements as they were presented with two pictures: a boy with apples and a boy with either wrapped gifts or nothing at all. When they asked 2- to 4-year-old children to "Look at the boy who has no apples", all children initially looked at the boy with apples; 2-year-olds never looked away from the boy with apples, and only 4-year-olds succeeded robustly.

However, these studies looked at the understanding of negation given little relevant context. This article is not an aardvark, but the irrelevance of that statement makes it a very odd speech act, and processing it involves considering aardvarks and their possible relation to psychology research papers for the first time. Using negated statements to introduce novel concepts into the discourse out of the blue imposes a processing load on adults (Kaup, Lüdtke, & Zwaan, 2006; Kaup, Yaxley, Madden, Zwaan, & Ludtke, 2007), while a pragmatically supportive context has been shown to facilitate the processing of negation both in adults (Wason, 1965) and children as young as 2 years old (DeVilliers & Flusberg, 1975). As Nordmeyer and Frank (2014) point out, it would be surprising if children all through the third or fourth year of life truly failed to understand logical negation, given that these children produce denial negations consistently (Hummer et al., 1993; Pea, 1980a, 1982).

Just one recent study has found evidence that children's comprehension of truth-functional negation emerges at an age more consistent with their production of denial negations. Austin, Theakston, Lieven, and Tomasello (2014) presented children with a pragmatically supportive context, in which both negative and affirmative statements were natural. An experimenter hid a block in either a bucket or a toy house. A second experimenter asked either "Is it in the house?" or "Is it in the bucket?", and the first experimenter answered with either an affirmative or negative clue. In a "single word" condition, the clue was simply, "yes" or "no", while in a "sentence" condition, the clue was, "It's in the [bucket/house]" or "It's not in the [bucket/house]". Following this exchange, children were asked to find the block. In contrast to previous studies, 27- and 24-month-olds, though not 21-month-olds, successfully used the negative verbal information, indicating that they understood both "no" and "not". This age tracks closely with the age when children begin to say "not", as well as when they begin to produce denial negations (Bloom, 1970; Choi, 1988; Hummer et al., 1993; Pea, 1980b, 1982). This suggests that the emergence of denials in children's language use does indeed reflect an emerging analysis of "no" and "not" as expressing truth-functional negation.

These results provide possible answers to the questions posed above. Since 24- to 27-month-old children could understand words expressing truth-functional negation, this concept must be available to thought by that age. Further, if this is indeed the earliest age at which they comprehend "no" and "not," children do not make the mapping between the concept and the words until *many months after* starting to produce "no". Finally, that children succeed with both "no" and "not" at the same age suggests that there is a single barrier preventing earlier mapping of both words to this concept.

The present experiments were conceived independently of Austin and colleagues' (2014) study, but use a similar method: we showed children that a ball was hidden in either a bucket or a truck, then gave them clues to its' location using sentences containing "no" and "not". Experiments 1 and 2 were completed before we knew about their findings, and are similar enough that they can serve as a conceptual replication. There is one crucial difference, however: in Austin and colleagues' experiments, the affirmative trials and negative trials were interleaved; in ours, these trials are blocked. It is plausible that this difference might affect children's performance on the task. Switching back and forth between approaching the named container and approaching the other container likely makes response conflict demands that are difficult for toddlers (Diamond, 2013). Indeed, Austin and colleagues had to exclude a very large number of participants from their study—as many as 46%

in some age groups—due to children failing to complete the study or perseverating in their responses across trials. Conversely, if in spite of this methodological difference, the pattern of results is replicated, we can be quite confident of the developmental picture of success on this task.

In addition to presenting the affirmative trials and the negative trials in separate blocks (Experiments 1–2), which might be expected to reduce executive function demands and decrease the participant exclusion rate, we include a control condition that makes many of the same inferential and executive function demands on children, but does not require understanding negation words (Experiment 3). To further explore whether the comprehension of "not" and "no" coincides with the emerging production of "not," we obtained parental reports of children's productive vocabulary using the short form of the MacArthur-Bates Communicative Development Inventory (CDI).

Experiment 1: Comprehending "not"

Experiment 1 asked when young children begin to understand the truth-functional meaning of the word "not", in the context of a hiding game. We presented children with both negative clues (e.g., "It's not in the bucket") and affirmative clues (e.g., "It's in the truck). In Experiment 1a, we presented children with a block of four negative trials first, followed by a block of four affirmative trials. To replicate our findings and check for any effect of trial order, we tested another set of children in Experiment 1b, moving the affirmative trials before the negative trials.

Experiment 1a: Negatives first

Method

Participants

The participants were 83 children across three age groups: 24 20-month-olds (mean age: 20.6 months, range: 19.0–22.0, 13 boys), 25 24-month-olds (mean age: 23.8, range: 22.1–25.6, 10 boys) and 34 27-month-olds (mean age: 27.0, range: 26.1–28.5, 17 boys).[1] All participants were monolingual English speakers, receiving fewer than 10 hours per week of input in any other language. Thirty-six participants were tested at the Boston Children's Museum. The remaining participants were recruited by phone and email from the greater Boston area and were tested at the Laboratory for Developmental Studies at Harvard University. Participants at the Boston Children's Museum were given a sticker for participating. Participants at the lab were given a small gift, and their parents were compensated $5.00 for travel expenses. Five additional participants were tested but excluded: 4 for having a 100% side bias (choosing either the truck or bucket on all trials) and one for finishing the practice phase, but failing to complete 75% of the test trials.

Materials

The stimuli consisted of a green bucket, a red-and-yellow toy dump truck, a small yellow ball, and a wide black cardboard occluder. The bucket and the truck were lined with felt to ensure that the ball would not make a sound when placed inside. These two containers were chosen because "bucket" and "truck" are the earliest known nouns that could readily name containers (Dale & Fenson, 1996). A "jingle box" was used as a reward for successfully finding the ball—the child inserted a ball into an opening on one end, which would roll down a xylophone hidden inside the box, and come out the

[1]We originally intended to use a more stringent exclusion criterion, keeping only children who passed the practice trials, aiming for $N = 24$ per age group. However, for a more accurate estimate of the average age of success and to make our data as comparable as possible to Austin and colleagues', we ultimately did not exclude children based on their performance in practice trials. This resulted in the uneven sample sizes we report. We chose to divide the total age range into contiguous age groups to aim for approximately even representation through different parts of the range over which there is reason to think the comprehension of negation words may be emerging.

other end. We also measured children's productive vocabulary using the Macarthur Bates CDI short form (Fenson et al., 2000). We modified this form to include the additional words, "not", "bucket", and "truck." Parents were instructed to indicate the words that their children produced, and completed this form before the start of the experiment.

Procedure

The experimenter stood behind a 2.5′ tall table and the child sat in their parent's lap on the floor, 5 ft in front of the table. The child could not see into the containers when they were placed on the table, though they could reach up and touch them. Parents were instructed to release the child to search only once the experimenter asked the child to find the ball, and to encourage the child to find the ball if the child was shy, but without naming or pointing to either container. Each child participated in three practice trials and eight test trials.

We counterbalanced the following variables across participants: the container used for the first practice trial (bucket or truck), the side of the table that the bucket and the truck were on, and the container that the ball was hidden in on the first test trial. Across test trials, the ball was hidden in the containers in the pattern A-B-B-A-A-B-B-A, where A and B are the bucket and the truck (or vice versa).

Practice trials

The first practice trial was designed to familiarize children with the occlusion of a container. On this trial, the experimenter placed only one container on the table directly in front of her, and then put the occluder in front of the container. She lowered the ball into the container, removed the occluder, and gave a verbal clue to its location (e.g., "It's in the truck"). She then invited the child to search by saying, "Can you find it? Can you find the ball?"

The second and third practice trials were designed to familiarize children with making a choice between the two containers, given a clue. On the second practice trial, the experimenter first placed both the bucket and truck on the table, one to her left and the other to her right; the positions of the two containers stayed the same throughout the rest of the study. She lowered the ball into one of the containers in plain sight (the opposite to that used in the first practice trial), without using the occluder, and then gave the child an affirmative verbal clue (e.g., "It's in the bucket"). On the third practice trial, the ball was hidden in the same container as on the second practice trial, and the experimenter gave a negative clue (e.g., "It's not in the truck"). She then invited the child to search. On all practice trials, if the child searched in the wrong container or refused to search, the trial was repeated once.

Test trials

Eight test trials followed the practice trials. On each test trial, the experimenter first covered the bucket and truck with the occluder. She held the ball above the center of the occluder with both hands and said, "Ready? Watch where it's going!", then lowered the ball straight down behind the occluder. While looking down at the center of the table, she separated her hands behind the occluder and placed the ball in either the bucket or truck, touching the bottoms of both containers to equate the sound. She then gave the child either a negative or affirmative clue. Finally, looking at the child until the child responded, she invited the child to search by saying, "Can you find it? Can you find the ball?"

The first four test trials were negative trials: the experimenter told the child where the ball was not ("It's not in the bucket" or "It's not in the truck"). The last four test trials were affirmative trials: the experimenter told the child where the ball was ("It's in the bucket" or It's in the truck"). The experimenter gave affirmative and negative clues with the same friendly prosody and gave no additional clues through body language.

The child's choice was taken to be the first container they touched or pointed to. If the child chose the container that had the ball in it, they could put the ball in the jingle box before the next trial. If the child chose the incorrect container, they were shown that this container was empty and told, "It's not in there". They were then shown that the ball was in the other container and told, "Look! There it is!", but were not given the ball to put in the jingle box. This was meant to encourage children to try to find the ball on their first try. If the child did not indicate either bucket—for example, if they stood in front of a container but never touched it or pointed to it—the trial was excluded.

Results

Practice trials

One 27-month-old failed the second practice trial twice. Eight children failed both tries of the third practice trial (six 27-month-olds; one 24-month-old; one 20-month-old). Unless these children met other criteria for exclusion, we included their test trial data.

Test trials

Across all age groups, 17 trials were excluded because the child did not make a clear response. One additional trial was excluded because the parent told the child where to search. For all nonparametric analyses below, we used the remaining trials to calculate the percentage of correct choices on affirmative and negative trials for each child. For the logistic regression analyses, excluded trials were simply treated as missing data.

Performance relative to chance

Figure 2a shows children's performance in Experiment 1a, separated by age group and trial type. We used Mann-Whitney tests to compare the performance of each age group to chance, for both negative and affirmative trials. Children at all three ages succeeded on affirmative trials, choosing the correct container significantly more often than chance (27-month-olds: M = 77.2%, S.E. = 7.3, W = 395.5, $p < 0.0001$; 24-month-olds: M = 80.3%, S.E. = 4.8, W = 189, $p < 0.0001$), or marginally more often (20-month-olds: M = 59.4%, S.E. = 5.2, W = 111.5, $p = 0.09$). On negative trials, 27-month-olds chose the correct container significantly more often than chance (M = 66.4%, S.E. = 6.3, W = 235, $p = 0.009$). However, 24-month-olds performed at chance levels (M = 56.3%, S.E. = 6.2, W = 116, $p = 0.4$), and 20-month-olds chose the correct container significantly *below* chance (M = 37.5%, S.E. = 4.6, W = 25.5, p = 0.01).

Given that the 20-month-olds chose the correct container below chance on negative trials, yet marginally above chance on affirmative trials, we recoded their performance in terms of searches of the *mentioned* container rather than the correct container. Using this coding, we found no difference between 20-month-olds' choices on affirmative and negative trials (W = 312.5, $p = 0.6$); they chose the bucket just as often when they heard, "It's not in the bucket" as when they heard "It's in the bucket."

Comparison of age groups

We conducted nonparametric analyses to compare the age groups' performance. Children's performance improved with age on both types of trials: Kruskal-Wallis tests revealed significant differences in the rates of correct responding across the three age groups on affirmative (χ^2 (2) = 9.45, $p = 0.009$) and negative (χ^2(2) = 11.85, $p = 0.003$) trials. A series of pairwise Mann-Whitney tests revealed that 20-month-olds performed significantly worse than 24-month-olds on both affirmative (W = 167, $p = 0.006$) and negative (W = 176.5, $p = 0.01$) trials. However, the 24-month-olds did not significantly differ from the 27-month-olds on either affirmative (W = 431, $p = 0.93$) or negative (W = 351.5.5, $p = 0.25$) trials.

Regression analysis by age and trial type

To examine the effects of age and trial type on children's performance, we constructed a mixed-effects logistic regression model with as close to a maximal random effect structure as possible (Barr, Levy,

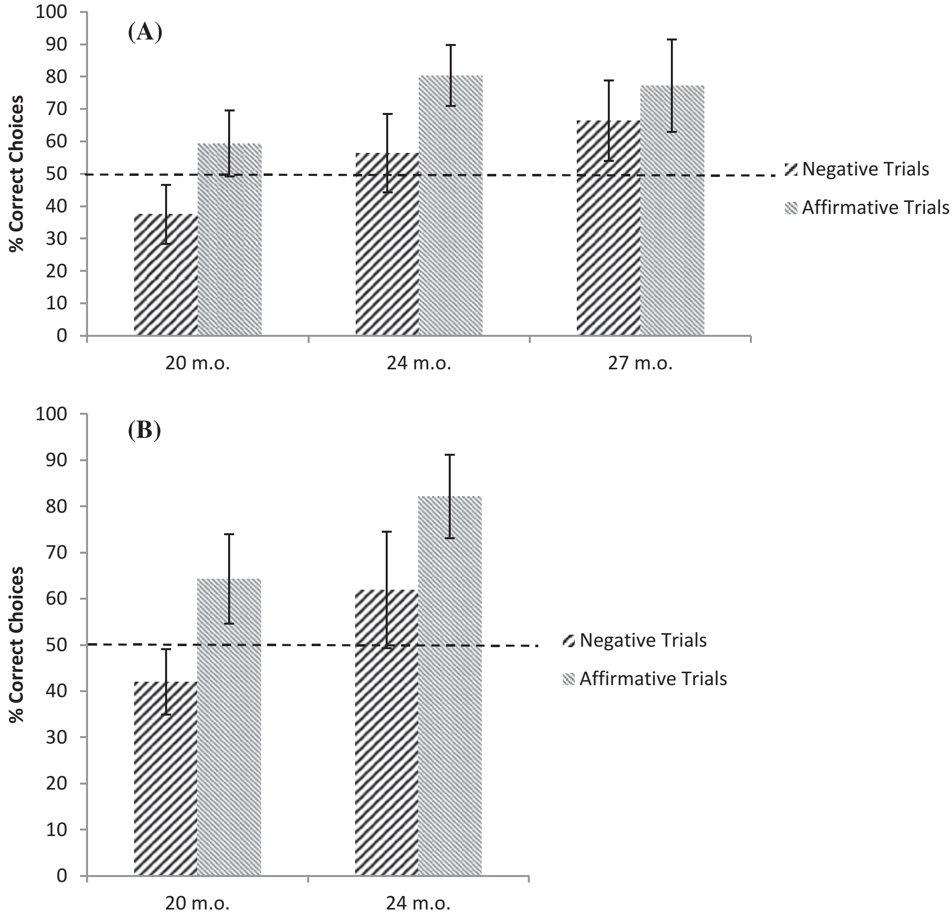

Figure 2. Children's performance on affirmative and negative trials in (A) Experiment 1a and (B) Experiment 1b, broken down by age group. Error bars are 95% confidence intervals.

Scheepers, & Tily, 2013).[2] This model took participants' response on a given trial as a binary dependent measure (correct or incorrect), with two fixed effects of Age Group (20, 24 and 27-month-olds) and Trial Type (Affirmative and Negative), along with their interaction. We found a main effect of Age Group (χ^2 (2) = 19.11, $p < 0.0001$), as expected based on the results above. We also found a main effect of Trial Type, with children performing better on affirmative trials than negative trials, but no significant interaction.

Experiment 1b: Affirmatives first

Methods

Participants

We recruited an additional 56 monolingual English-speaking children from the greater Boston area: 28 20-month-olds (mean age: 20.5 months, range: 19.1–22.0, 16 boys) and 28 24-month-olds (mean

[2]Since there were only four trials of each type and eight trials total, there was insufficient data to model trials as a random effect. We included a random intercept for Subjects and a random slope of Trial Type by Subjects (but no random slopes for the between-subject effect of Age Group). The full model specification in glmer syntax is: Response ~ TrialType*AgeGroup + (1+TrialType|Subject)
For each fixed effect and interaction, χ^2- and p-values were obtained by likelihood ratio tests of the model including that effect relative to the model without it.

age: 23.6, range: 22.2–25.6, 12 boys). These age groups correspond to the two youngest age groups in Experiment 1a. All children participated at the Harvard Lab for Developmental Studies. Seven additional toddlers were tested, but excluded from analysis for searching in the same container on all trials (i.e., side bias). None of the children who finished the practice phase failed to complete the study.

Materials and procedure

This experiment was identical to Experiment 1a, with two exceptions. First, the order of affirmative and negative test trials was flipped: children completed the four affirmative trials before the four negative trials. Second, if they did not search or searched incorrectly on any practice trial, they could repeat the trial up to two additional times.

Results

Across both age groups, one trial was excluded because the child did not respond clearly.

Performance relative to chance

Figure 2b shows the results separated by age group and trial type. Broadly, children's performance was quite similar to Experiment 1a. On affirmative trials, 24-month-olds chose the correct container significantly more often than chance (M = 82.1%, S.E. = 4.6, W = 228.5, $p < 0.0001$), as did 20-month-olds (M = 64.3%, S.E. = 5.0, W = 145, $p = 0.007$). On negative trials, 24-month-olds chose the correct container marginally more often than chance (M = 61.9%, S.E. = 6.4, W = 212, $p = 0.07$), while 20-month-olds again performed significantly worse than chance (M = 42.0%, S.E. = 3.6, W = 10, $p = 0.03$).

As in Experiment 1a, we recoded 20-month-olds' responses relative to the mentioned rather than the correct container. Using this coding, we found no difference between 20-month-olds' choices on affirmative and negative trials (W = 333, $p = 0.3$), again indicating that children at this age chose the bucket just as often whether they heard, "It's not in the bucket" or "It's in the bucket".

Comparison of age groups

As in Experiment 1a, 24-month-olds did significantly better than 20-month-olds on both negative (W = 240, $p = 0.01$) and affirmative (W = 240, $p = 0.009$) trials.

Comparison of Experiments 1a and 1b: Order effect

To investigate whether the order of negative and affirmative trials had an effect on children's performance, we compared the results of Experiment 1a and 1b. We constructed a logistic regression model with a maximal random effect structure, pooling the data from 20- and 24-month-olds in Experiment 1a with those from 1b. In addition to the two fixed effects of Age Group (20-month-olds and 24-month-olds) and Trial Type (Affirmative and Negative), we also included the between-subjects fixed effect of Trial Order (Affirmative or Negative trials first), as well as all interactions.[3]

We found a significant main effect of Trial Type ($\chi^2(1) = 37.66$, $p < 0.0001$), with children overall performing better on affirmative than negative trials. There was also a main effect of Age Group ($\chi^2(1) = 25.67$, $p < 0.0001$). However, there was no significant effect of Trial Order ($\chi^2(1) = 1.35$, $p = 0.25$) and no interactions.

Discussion

In both Experiments 1a and 1b, we found that children's performance on affirmative trials improved with age, yet across both experiments, even 20-month-olds did better than chance on them. This

[3]In glmer syntax, the model is: Response ~ TrialType*AgeGroup*BlockOrder + (1+TrialType|Subject)

indicates that children at all ages understood the search task, were listening to the clues the Experimenter was giving, and could use the words for the containers to guide their search. However, performance on the negative trials lagged behind affirmative trials, with 20-month-olds' performance worse than chance, 24-month-olds at or marginally above chance, and only 27-month-olds robustly succeeding. Note that 20-month-olds' below-chance performance is exactly what one would expect if they did not know the word "not": they ignored it entirely, searching in the named container just as often as they did on affirmative trials.

Given that children younger than two do not produce the word "not", it is perhaps not surprising that they did not understand it in our study. However, they certainly have access to another word that can be used to express logical negation: "no". In contrast to "not", "no" is one of the earliest words children produce; 55% of 15-month-olds say "no", at an age when there are almost no reports of any child producing "not" (Dale & Fenson, 1996; Figure 1). Yet despite this, Austin and colleagues (2104) found that children comprehend "no" as a logical operator at the same age as "not". In Experiment 2, we attempted to verify this finding, asking when children can use a negative sentence containing "no" to direct their searching behavior.

Experiment 2: Comprehending "no"

We adapted our paradigm to explore the comprehension of "no" by using a question-answer interaction between the parent and the experimenter, similar to the design of Austin and colleagues (2014). The parent sat with the child and asked the experimenter, "Is it in the bucket?" or "Is it in the truck?" The experimenter answered, "Yes, it is" or "No, it's not", and the child was then invited to search for the ball.

Methods

Participants

The participants were 82 monolingual English-speaking participants: 24 20-month-olds (mean age: 20.7 months, range: 19.2–22.0, 13 boys), 33 24-month-olds (mean age: 23.3, range: 22.2–25.9, 16 boys) and 25 27-month-olds (mean age: 27.3, range: 26.2–29.0, 13 boys). Recruitment and compensation were identical to Experiment 1. An additional 11 children were tested, but excluded from analysis: 6 for searching in the same container on every trial (i.e., side bias), 3 for failure to complete 75% of test trials, and 2 due to parental error in reading the script.

Materials and procedure

The only difference from Experiment 1 was in how the clues were given. Parents were given a script to follow during the experiment. After the experimenter hid the ball and removed the occluder, the parent turned to the child and said, "Hm, where did it go?" or, "I wonder where it is!" The parent then looked at the experimenter and asked, "Is it in the bucket?" or, "Is it in the truck?" The script told parents which container to ask about, with the order counterbalanced in an ABBA pattern, as in Experiment 1. Parents were not aware of the actual location of the ball until the experimenter answered their question.

On affirmative trials, the experimenter answered, "Yes, it is". On negative trials, the experimenter answered, "No, it's not". Although the negative verbal clue included the word "not", we had already determined in Experiment 1 that 20- and 24-month-olds do not comprehend "not", and thus that its inclusion was unlikely to have an impact on their performance. It did, however, have the benefit of making the utterance sound more natural and less abrupt.

As in Experiment 1, the four affirmative trials and the four negative trials were blocked. We counterbalanced the order of these blocks across subjects, so that half of the children received the four affirmative trials first, and half received the four negative trials first. The test trials were preceded by three practice trials, with the same structure as in Experiment 1b, except that clues were given in the same question-answer format as in the test trials.

Results

Practice trials

One 20-month-old failed all three tries of the first practice trial, and one 24-month-old failed all three tries of the second practice trial. Eight children failed all tries of the third practice trial (six 24-month-olds and two 20-month-olds). Unless these children met other criteria for exclusion, we included their test trial data.

Test trials

Across all age groups, seven trials were excluded because the child did not make a clear response. One additional trial was excluded due to experimenter error and one for parental interference.

Performance relative to chance

Figure 3 shows the results of Experiment 2, broken down by age group and trial type. When comparing performance to chance, the results closely mirrored those of Experiment 1. On affirmative trials, all three age groups chose the correct container more often than chance (27-month-olds: M = 79.0%, S.E. = 4.8, W = 221, p = 0.0002; 24-month-olds: M = 72.2%, S.E. = 4.7, W = 261, p = 0.0001; 20-month-olds: M = 74.0%, S.E. = 4.6, W = 148, p = 0.0005). On negative trials, 27-month-olds chose the correct container significantly more often than chance (M = 79.0%, S.E. = 5.7, W = 230, p = 0.0005), 24-month-olds performed at chance (M = 57.1%, S.E. = 5.5, W = 202, p = 0.12), and 20-month-olds were *below* chance (M = 35.1%, S.E. = 5.1, W = 18, p = 0.01).

As in Experiment 1, we recoded 20-month-olds' choices as searches of the mentioned container rather than the correct container. We again found no difference between children's choices on affirmative and negative trials (W = 226, p = 0.19)—when hearing the question, "Is it in the bucket?", 20-month-olds chose the bucket just as often when the answer was "No, it's not" as "Yes, it is".

Comparison of age groups

Post-hoc nonparametric analyses revealed that, unlike Experiments 1a and 1b, children's performance on affirmative trials was not significantly different across the three age groups (Kruskal-Wallis test, $\chi^2(2)$ = 1.56 p = 0.45), likely due to 20-month-olds' stronger performance relative to

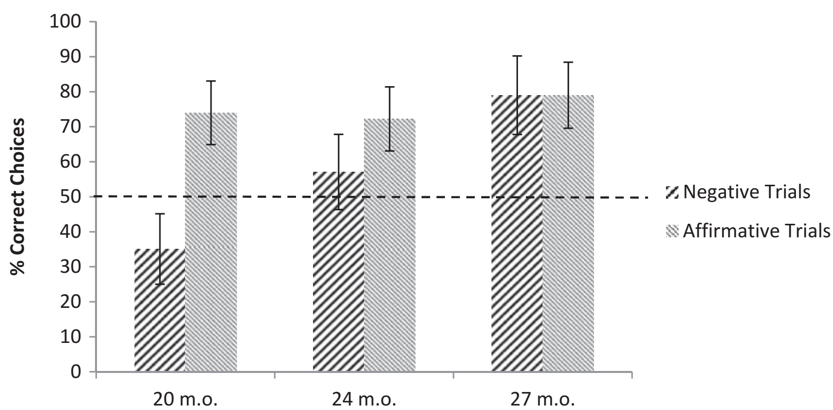

Figure 3. Children's performance on affirmative and negative trials in Experiment 2, broken down by age group. Error bars are 95% confidence intervals.

Experiment 1 (Figures 2 and 3). In contrast, children's performance on negative trials differed depending on age ($\chi^2(2) = 22.07$, $p < 0.0001$). We further examined the age effect on negative trials using pairwise Mann-Whitney tests, which revealed that 20-month-olds chose the correct container significantly less often than 24-month-olds ($W = 241.5$, $p = 0.01$), and that 24-month-olds chose the correct container significantly less often than 27-month-olds ($W = 236$, $p = 0.004$).

Order effects within Experiment 2

Having manipulated the order of affirmative and negative trials within Experiment 2, we looked for an order effect by fitting a model that included Trial Type (Affirmative and Negative), Age Group (20-, 24-, and 27-month-olds), and Trial Order (Affirmative or Negative trials first) as fixed effects.[4] While there were main effects of Trial Type ($\chi^2(1) = 9.25$, $p = 0.002$) and Age Group ($\chi^2(2) = 14.36$, $p = 0.0007$), as well as a significant interaction between them ($\chi^2(2) = 7.49$, $p = 0.02$), as in Experiment 1, there were no significant main effects nor interactions involving Trial Order.

Comparison of Experiments 1 and 2: "Not" vs. "no"

To examine the effect of giving children negative information using the word "no" vs. "not", we constructed another logistic regression model, pooling the data from Experiments 1a, 1b, and 2. We examined the effects of Age Group, Trial Type (Negative vs. Affirmative), and Word ("no" vs. "not"; i.e., Experiment 1 vs. 2).[5] As in the previous analyses, we found significant main effects of Trial Type ($\chi^2(1) = 18.45$, $p < 0.0001$) and Age Group ($\chi^2(2) = 20.9$, $p < 0.0001$). There was no significant main effect of Word ($\chi^2(1) = 0.48$, $p = 0.49$), indicating that there was no overall advantage to children who heard "no" rather than "not". However, there was a significant three-way interaction between Trial Type, Age Group, and Word ($\chi^2(2) = 6.44$, $p = 0.04$). To explore which type of trial drove this interaction, we constructed separate models for affirmative and negative trials.[6] On affirmative trials, there was a significant interaction of Age Group by Word ($\chi^2(2) = 6.07$, $p = 0.048$): children's performance on affirmative trials increased with age in Experiment 1, but there was no such increase in Experiment 2. In particular, 20-month-olds performed as well as older children on affirmative trials in Experiment 2; parents' greater participation may have motivated or otherwise helped the youngest children on those trials. However, on negative trials, there was no interaction between Age Group and Word ($\chi^2(2) = 3.3$, $p = 0.19$): the age trends in Experiment 1 and Experiment 2 did not differ, despite using different negation words. We therefore conclude that there were no differences between the ages at which children begin to comprehend "no" and "not".

To further examine any effects of hearing the word "no" vs. "not", we followed up with nonparametric Mann-Whitney tests comparing children in each age group across experiments. We found no significant differences between children's performance on negative trials containing "not" (Experiment 1) and those containing "no" (Experiment 2) in any age group (27-month-olds: $W = 166$; $p = 0.16$; 24-month-olds: $W = 931.5$, $p = 0.61$; 20-month-olds: $W = 675.5$, $p = 0.55$).

Convergence with Austin and colleagues (2014)

The most theoretically significant point of convergence is that in both studies, children succeeded when given negative information with "no" at the same age as with "not". They failed on both at 20 months, and succeeded robustly on both by 27 months. This is the case, even though Austin and colleagues used a single word "No" response, while we used "No, it's not" in Experiment 2, and even though they used a question-answer dialogue in testing both words, while Experiment 1 used a simple declarative statement rather than a dialogue.[7] Beyond that, our data differ from Austin and colleagues' in two respects. First, successful performance on negative trials in our study was delayed

[4]Response ~ TrialType*AgeGroup*TrialOrder + (1 |Subject)
[5]Response ~ TrialType*AgeGroup*Word + (1+TrialType|Subject)
[6]Within each trial type: Response ~ AgeGroup*Word + (1|Subject)
[7]Note, along the same lines, that neither the sentence-final position of "not", nor the VP ellipsis involved in "No, it's not" (elided from "No, it's not in the bucket") appear either to help or hinder children's performance.

relative to Austin and colleagues' findings. The 20-month-olds in our study were significantly *below* chance on negative trials with both words, while the 24-month-olds were at chance. In contrast, the 20-month-olds tested by Austin and colleagues performed at chance, while the 24-month-olds succeeded with both words. This difference is most probably due to different exclusion rates between our studies. Adopting the same exclusion criteria, we excluded only 9% of our 242 participants, contrasting with 37% of the 201 participants in Austin and colleagues' "no" and "not" conditions. This was most likely due to our presenting affirmative and negative trials in separate blocks rather than intermixing them. By reducing task switching costs and children's resulting frustration and fussiness, over 90% of children who participated in our task were able to complete it. However, if Austin and colleagues' intermixed design made it particularly hard for lower-performing children to complete the task, their resulting sample would show a slightly earlier age of success, which is indeed what they found.

Second, children in our study succeeded on affirmative trials at all ages, whereas even the oldest children in Austin and colleagues' study apparently failed to understand the affirmatives, leading them to conclude that negative sentences are understood earlier than affirmatives in this context. This is a striking and unlikely conclusion. Understanding a negative like, "It's not in the bucket" requires all the same knowledge of language as understanding its affirmative counterpart, "It's in the bucket", plus the additional negation. Additionally, within the context of the search task, affirmatives should be easier than negatives in many ways: affirmatives do not require making an inference, do not require inhibiting attention or behavior to the named container, and do not require knowing a word for negation (either "no" or "not") or combining it with word meanings—one can just go to the named container. We therefore find it encouraging that we found success on affirmative trials even at the youngest age, replicated in all three of our experiments.

Furthermore, we believe the differences in the two data sets are more apparent than real, deriving from the fact that Austin and colleagues used the very conservative Bonferroni correction in their analyses.[8] In our data, success rates on affirmative trials (averaging across the "no" and "not" conditions) were 66% at 20 months, 78% at 24 months, and 78% at 28 months. The success rates found by Austin and colleagues were 59% at 21 months, 74% at 24 months, and 78% at 28 months.[9] There is likely no significant difference between the two sets of data.

On the whole, the convergence across the two data sets is remarkable. Most importantly, children's performance on "no" is identical to their performance on "not" in each study. While children succeed on affirmative trials at 20 months of age, success on negative trials emerges between 24 and 27 months. Notably, this age range corresponds to children's emerging production of the word "not".

Production and comprehension

Looking at children's CDI production scores, we found that almost all of the children in our sample produced "no", including the 20-month-olds. However, "not" was not produced until much later: at 27 months, when we found children robustly succeeded in comprehending both "no" and "not", just over 50% of children were producing "not". Both of these rates match CDI population norms (Dale & Fenson, 1996; see Figure 1). In other words, comprehending truth-functional "no" does not track with producing "no" at all—in fact, it lags behind it by about a year. This lag suggests that mapping the concept of negation to the word "no" poses a significant challenge—either because this concept is not available at 13- to 15-months when the word is first learned, or because the language mapping problem is a particularly difficult one. It also suggests that when younger toddlers say "no", they are expressing some meaning other than the logical one. Young children's early uses of "no"—to signify

[8]We do not believe a Bonferroni correction is warranted here. Many comparisons are not independent: Affirmatives should be easier than negatives, and children should improve with age on both trial types. Nevertheless, success on affirmative trials by 24- and 27-month-olds in our data was robust, with uncorrected p-values at 0.0002 or lower.

[9]Note that, although 20-month-olds succeeded at only around 60% of affirmative trials, this rate of success has now been found five times (in our Experiments 1a, 1b, 2, and in both verbal conditions in Austin and colleagues).

rejection, prohibition, or absence—are indeed likely to rely on distinct concepts rather than being specific usages of the logical negation concept, just as Bloom (1970) hypothesized. We explore these issues in more detail in the General Discussion.

However, an additional possibility remains: toddlers may understand the language of truth-functional negation perfectly well, but have difficulty in acting on negative information. Successfully acting on negative information—as in, “It’s not in the bucket” or, “Is it in the bucket? No, it’s not!”—requires *some* additional mental computation relative to the affirmative. This computation could be a logical inference about the location of the ball (using the disjunctive syllogism: A or B, not A, therefore B), or it could be a decision to avoid the empty container, coupled with a representation of where else the ball *might* be (see Mody & Carey, 2016). In either case, children could face difficulties in holding negated information in memory, or combining negation with location information. Alternatively, they could face difficulties inhibiting their actions or attention to the negated location.

Inhibitory control and attention shifting undergo dramatic development from infancy all through the preschool years (Diamond, 2013). A failure of executive function may thus explain the failure of 24-month-olds on the task, as well as the systematically incorrect choices of the 20-month-olds: these youngest children could be choosing the named container, regardless of whether the word is in a negative or an affirmative statement, because they hear its name and cannot shift their attention away from it. In contrast, on affirmative trials children can simply search in the named container.

In Experiment 3, we placed similar inhibitory and attention-shifting demands on children as in Experiments 1–2, but eliminated the need to understand logical negation language. Instead of being told where the ball was not, they were *shown* that one of the containers was empty: the experimenter lifted the empty container and tilted it to show its contents to the child. Importantly, as in the negative trials of the previous experiments, the empty container was named: while tilting it, the experimenter said, “Look at the bucket!” or “Look at the truck!”, whereas the other container was not highlighted in any way. We tested only 20-month-olds, since this is the age at which both we and Austin and colleagues found abject failure on the negative trials. If 20-month-olds’ failure on negative trials was due to the inhibitory and attention shifting demands of the task, they should fail in this experiment as well. If, on the other hand, their failure was due to trouble understanding the logical meanings of “no” and “not,” then we would expect success when they are given visual evidence that one of the containers does not contain the ball.

Experiment 3

Methods

Participants

We recruited 28 monolingual English-speaking participants (mean age: 21.0 months, range: 19.2–22.7, 14 boys), none of whom had participated in any of the above experiments. Recruitment and compensation were identical to Experiment 1. Eleven additional toddlers were tested but excluded from analysis: 6 for failure to complete 75% of test trials, 2 for choosing the same container on every trial (side bias), and 3 because their parent interfered or failed to restrain them while the experimenter was giving instructions.

Materials

The stimuli were identical to those of Experiments 1–2, except that a slightly larger yellow ball was used so it would be more easily visible to children on affirmative trials.

Procedure

The verbal clues in Experiments 1–2 were replaced by visual clues, and as in Experiment 1, there was no dialog between the parent and the experimenter. To provide information about the location of the ball, the experimenter looked at the container, picked it up and tilted it until it was lying sideways on the table and the child could see inside it for approximately 2 s, while saying, "Look at the bucket/truck!" On affirmative trials, the ball was visible within the container, and on negative trials the container was empty. If the child was not looking when the container was first tilted, the experimenter called the child's attention to the container, and held the container down until the child looked. The experimenter then returned the container to its upright position and invited the child to search.

Since the experimenter had just told the child to look at the container, we reasoned that the phrase, "Can you find it, can you find the ball?" might confuse children, because "it" could refer to the container instead of the ball. So in Experiment 3, we reversed this instruction, asking the children, "Can you find the ball, can you find it?" All other details were the same as in the previous experiments, and the order of the negative and affirmative blocks of trials was counterbalanced as in Experiment 2.

Results

Four trials were excluded because the child did not make a clear response. Figure 4 shows the results, alongside the 20-month-olds' results from the previous experiments. The 20-month-olds in Experiment 3 chose the correct container significantly above chance on both Affirmative ($M = 87.5\%$, S.E. = 3.3, $W = 334.5$, $p < 0.0001$) and Negative trials ($M = 67.3\%$, S.E. = 4.6, $W = 215$, $p = 0.003$).

Performance relative to Experiments 1 and 2

We compared 20-month-olds' use of the visual clues in this Experiment versus the verbal clues used in Experiments 1 and 2 with a logistic regression examining performance as a function of the fixed effects of Trial Type (Affirmative or Negative) and Experiment (3 vs. 1–2),[10] and their interactions. There was a significant main effect of Experiment ($\chi^2(1) = 24.72$, $p < 0.0001$), due to better performance in Experiment 3 than in the Experiments with verbal clues, and a main effect of Trial Type ($\chi^2(1) = 54.81$, $p < 0.0001$), due to better performance on affirmative trials than on negative trials. There was no significant interaction between these two variables ($\chi^2(1) = 0.2$, $p = 0.66$): the size of the difference in performance between Affirmative and Negative trials was constant across both nonverbal and verbal clues.

We confirmed these results non-parametrically using Kruskall-Wallis tests comparing the performance of children in Experiment 3 to the same age groups in Experiments 1 and 2 combined. Children in Experiment 3 searched in the correct container significantly more often than those in the other Experiments on both affirmative (χ^2=20.93, $p = 0.0001$) and negative (χ^2=24.68, $p < 0.0001$) trials.

Discussion

Experiment 3 yielded two important results. First, the negative trials were again harder than the affirmative trials, despite not involving any negation words. There are many reasons affirmatives should be easier to process than negatives: on affirmatives, the child does not need to make the additional step of negating a representation of where the ball is, nor inhibit attention to the container they have heard named and seen the experimenter attend to, nor infer where the ball is. Children might also be biased to the last-mentioned container if they think the pronoun *it* in the experimenter's, "Can you find it?" refers to the last-named container rather than the ball.

[10]The model specification was: Response ~ TrialType*Experiment + (1+TrialType|Subject)

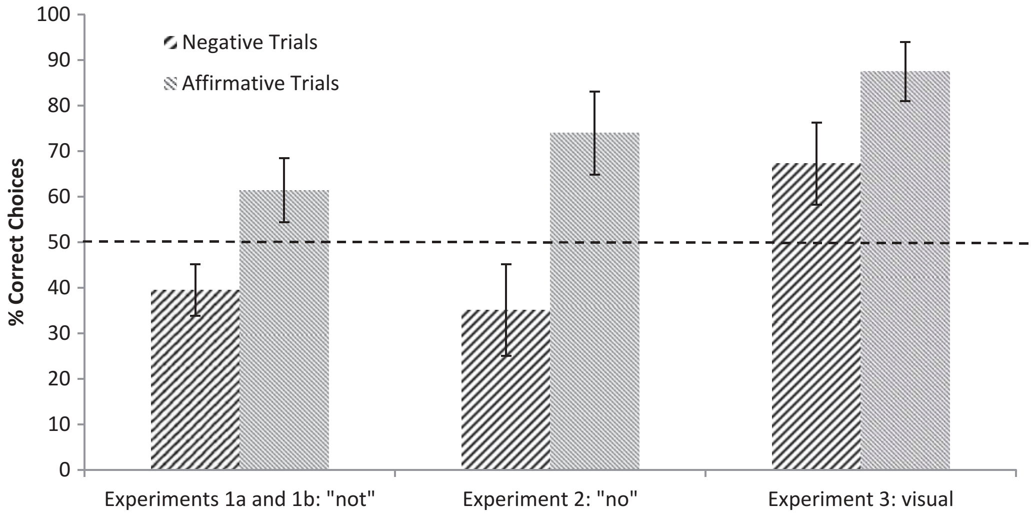

Figure 4. Performance on negative and affirmative trials of the 20-month-old age group in Experiments 1–3. Data from Experiments 1a and 1b is combined, with the mean reflecting average comprehension performance with "not", across both block orders. Error bars indicate 95% confidence intervals.

The factors that make negative trials in Experiment 3 difficult presumably also contribute to the difficulty of negative trials in Experiments 1 and 2—but they cannot fully explain 20-month-olds' poor performance in the previous studies. In Experiments 1–2, toddlers did not just fail to search the correct container—they systematically searched the wrong one. Experiment 3 shows that this failure is not due to 20-month-olds simply being unable to inhibit their attention to the named container and inevitably searching there: children in Experiment 3 searched in the correct container roughly 70% of the time, despite the other container being named. Their abject failures in Experiments 1–2 are therefore likely due to an additional factor: not understanding the language of negation. These children appear to have difficulty establishing that there is no ball in the bucket when they hear "It's not in the bucket" or "Is it in the bucket? No,"—whereas they can do so, and act accordingly, when they see the empty bucket with their own eyes.

One might argue that, even if children understood the verbal negative clues, seeing that one container is empty for themselves is better evidence than hearing about it from the experimenter. Indeed, that 20-month-olds can better use visual than verbal information is shown by their better performance on affirmative trials in Experiment 3 than in Experiments 1–2. However, if 20-month-olds did not understand or did not trust verbal clues generally, they would have performed equally poorly on affirmative and negative trials in Experiments 1–2. Instead, they searched correctly on affirmative trials, while searching systematically *incorrectly* on negative trials. They did not search at chance on either kind of trial, which would be expected if they did not understand or believe the verbal testimony. They reliably used verbal information involving the words "bucket" and "truck" to guide their search; they just did not use "no" and "not".

Experiment 3 shows that 20-month-olds' failures in Experiments 1 and 2were not due solely to the performance demands of the two-location search task. Although children's executive function is certainly improving between 20 and 27 months, their increasing ability to use negative verbal clues in this paradigm also reflects their increasing comprehension of the logical meaning of "no" and "not".

General discussion

Reports collected from the parents of children in Experiments 1 and 2 demonstrated the well-attested fact that children *produce* "no" much earlier than "not". In contrast, confirming Austin and colleagues' (2014) findings, Experiments 1 and 2 found that the *comprehension* of truth-functional "no" and "not" undergo parallel developmental trajectories. When told "It's not in the bucket" or "Is it in the bucket?—No, it's not", 20-month-olds searched for a hidden ball in the bucket, ignoring the negative information. At 24 months, children no longer ignored the negative language, but they searched at chance. It is not until 27 months that children robustly searched in the truck after being told that the ball is not in the bucket.

Experiment 3 ruled out several possible causes for the 20- to 24-month-olds' failure in the search task, independent of understanding verbal negation. That children performed better on the affirmative than the negative trials, even when they *saw* where the ball was or was not, shows that there *is* an information-processing cost to the negative trials—a cost of the inference that leads to searching the other container, or a cost of inhibiting attention to the named and manipulated container. But importantly, 20-month-olds *succeeded* with the negative trials in Experiment 3, indicating that an additional factor contributed to their failure at 20 and 24 months in Experiments 1–2: the understanding of "no" and "not".

Below, we discuss how our findings, together with data on children's production of "no" and "not", constrain accounts of what non-logical meanings children might initially assign to both words. We then explore what common factor might limit younger children in mapping the truth-functional negation operator to "no" and "not" until age two, and why it is mapped to both words simultaneously.

What "no" and "not" mean to a toddler

In studying the production of negation, Bloom (1970) and Pea (1980a), suggested that children's utterances of "no" and "not" may reflect several different meanings, emerging at different ages: *rejection, nonexistence*, and *denial*. While younger children produce "no" mainly in rejection contexts (e.g., "No!", pushing carrots away) and nonexistence contexts (e.g., "No juice" indicating an empty cup), Pea found that robust production of denials (e.g., "No, bear" correcting a statement that a stuffed animal is a cat) does not emerge until 24–30 months (Pea, 1980b; 1982; see also Hummer et al., 1993; Choi, 1988). Pea argued that denial uses of negation reflect an ability to use a truth-functional operator, since they explicitly deny the truth of a preceding statement or question under discussion. As we argued in the introduction, contrary to Pea and Bloom, production data alone cannot license the conclusion that distinct meanings exist. A single truth-functional meaning of negation could be reflected in speech acts that include rejecting, proclaiming nonexistence, and denying, and the sorts of things children are likely to say at different ages could explain why these functions emerge in their particular order.

However, when the production data is taken together with comprehension data from the present task, there is now good reason to believe that at least some of the meanings posited by Bloom and Pea are indeed distinct and independently acquired, rather than being different usages of a single extant concept. While rejection and nonexistence negations are produced earlier, the ability to comprehend "no" and "not" in the present search task emerges at the same age at which children begin to produce denial negations, between 24 and 27 months. The only meaning that is common to denial uses of "no" and "not" and to the comprehension of these words in the search paradigm is logical, truth-functional negation.

The convergence of evidence from production and comprehension argues against a number of alternatives concerning the early meanings of "no" and "not". While children could plausibly succeed on our comprehension task using nonexistence negation, nonexistence negation cannot underlie the production of denials. And while children's production of denials might plausibly reflect metalinguistic judgments, a metalinguistic interpretation cannot underlie performance on our comprehension task.

Could children be solving the search task using nonexistence negation?

The hiding-game paradigms used both by us here and by Austin and colleagues (2014) are readily viewed as testing the comprehension of nonexistence negation rather than denial—the negative clue gives information about the ball's nonexistence in one of the containers. However, children succeed in these tasks at around the same age as they begin to produce denials, and not the age when they produce nonexistence negations. In corpus studies, "nonexistence" negations are always produced before age two, with the first such utterances typically occurring around 19 months (Bloom, 1970; Choi, 1988; Pea, 1980a). Therefore, if nonexistence negation did underlie success on the verbal task, we would expect success much earlier than 27 months.

Could children's early uses of negation be metalinguistic?

While Pea claimed denial negations require the use of a truth-functional operator, others have suggested that they are metalinguistic rather than truth-functional (Guidetti, 2005; Horn, 2001; Hummer et al., 1993; Moll, 2013). A metalinguistic negation expresses a judgment that the negated statement is in some way conversationally inappropriate. When an adult points to a picture of a bear and calls it a cat, causing the child to say, "No, bear!" (Hummer et al., 1993), the child may not be expressing that it is false that the picture depicts a cat. Instead, the child might notice that no cats are present or had been mentioned previously, and anyway that it is weird to call this thing that is clearly a bear anything else. Children's "no" may be metalinguistic, commenting on the inappropriate naming act of the adult rather than on whether the statement is true.

But while it is plausible that a child saying "No!" is expressing a metalinguistic disagreement, what metalinguistic interpretation could be given to sentence-internal negations like those in Experiment 1, where the experimenter simply says, "It's not in the bucket"? To be metalinguistic, the experimenter would have to be commenting on the inappropriateness of the claim that the ball is in the bucket, when no such claim had been made. That 27-month-old children correctly understood the sentence-internal "not" in Experiment 1 suggests that they understood that "not" as a truth-functional operator. Consequently, that they understood an anaphoric "no" response in Experiment 2 just at the same age suggests that they took that "no" to have the same truth-functional, rather than metalinguistic meaning. And finally, that the age at which children increasingly produce denial negations matches the age at which they come to understand both "not" and "no" in the search paradigm, suggests that denials reflect the use of the same logical operator in production.

Although comprehension in the search task could plausibly be based on nonexistence negation, and producing denials could plausibly be based on a metalinguistic negation, the comprehension and production data provide evidence that both of these draw on a single concept of truth-functional negation.

What do younger children lack?

Why do children younger than two fail to comprehend both "no" and "not" as truth-functional logical operators? We see two viable possibilities. One is that the limiting factor on children's performance is entirely linguistic. On this "linguistic limit" account, children do have the concept of a logical negation operator, but making the mapping between this operator and the words "no" and "not" requires discovering how one's language expresses this logical function—a difficult problem that most children will not solve until they turn two. The second possibility is that the limiting factor in children's mastery of the logical meanings of "no" and "not" is at least partly conceptual—that younger children do not have the concept of logical negation, and what is changing between 24 and 27 months is that this concept is coming online. On this "conceptual limit" account, only upon acquiring this concept around 27 months can the child map it to both of the words "no" and "not".

The linguistic limit account

If the limitation on children learning the logical meaning of "no" and "not" is solely linguistic, what kind of linguistic limitation could it be? What features of language learning might account for the relatively late mastery of "no" and "not" as truth functional connectives? One obvious possibility is that young toddlers simply hear truth-functional uses of negation much less frequently than other uses. In this case, the linguistic limit would be in the input they receive. One detailed case study analyzed parents' negation production (Cameron-Faulkner et al., 2007), finding that the two most frequent functions of all negation words were "prohibition", followed closely by "denial". That these parents produced denials more frequently than any other function (except prohibition) indicates that there was no general shortage of truth-functional negation in this child's input. Cameron-Faulkner and colleagues also found that over 50% of these parents' uses of "no"—but only 6% of their uses of "not"—were for prohibition. This suggests that children's *simultaneous* mapping of "no" and "not" to truth-functional negation between 24 and 27 months, as well as their failure to do so earlier, do not derive from identical uses of these words by parents.

Another possible explanation of the difficulty children have mastering truth-functional negation is that negation is expressed in a wide variety of syntactic contexts. However, the grammatical properties of "no" and "not" are quite different. In adult speech, English "no" can be quantificational, anaphoric, a single word prohibition, or an answer to a question. In contrast, "not" cannot be used in any of these constructions. If analyzing the different syntactic contexts in which "no" and "not" appear is the main impediment to mastering verbal truth-functional negation, we might expect this meaning of "no" and "not" to be acquired at different ages, as they master these constructions at different times. That the two words are comprehended simultaneously suggests that grammatical variability is not the single limiting factor behind children's learning "no" and "not".

The relevant feature "no" and "not" do share is that both are truth-functional operators that change the truth-value of propositions. While children need not have any metalinguistic knowledge of this fact, acquiring the truth-functional meaning of "no" and "not" requires that the child have a representation that instantiates this logical property. It therefore stands to reason that a child must understand how positive propositions such as *the ball is in the bucket* are expressed in English before they can figure out the role "no" or "not" play in determining the meaning of "The ball is not in the bucket" or "Is the ball in the bucket? No." They would need to have the relevant vocabulary and the syntactic and semantic rules for combining words into propositions in order to comprehend any given negated instance. Only then can they notice that the meaning of "The ball is in the bucket" is opposite to "The ball is not in the bucket," and begin to analyze the contribution of "not" to this difference.

This version of the linguistic limit account is consistent with all of the data before us. It is consistent with negative sentences being understood later than their affirmative counterparts, since understanding a negative involves all of the same computations as the affirmatives, plus the additional negation. It is also consistent with the relatively late emergence of the production and comprehension of truth-functional negation, as mastering the vocabulary and syntactic structures that linguistically encode propositions clearly takes time. Finally, it is consistent with the fact that the truth-functional role of "no" is mastered at the same time as the truth-functional role of "not," as the hypothesized linguistic limit is common to analyzing this meaning for both words.

Finally, the success of 20-month-olds in Experiment 3 could offer support for the linguistic limit account, if one takes success on this task to mean that truth-functional negation is conceptually available at 20 months of age, which is well before children map this concept to language. On this interpretation, 20-month-olds use the perceived absence of a ball in the truck to represent the proposition *The ball is not in the truck*, and on the basis of this proposition infer that it must be in the bucket.

The conceptual limit account

The other possibility is that, in addition to the language learning problem of mapping the words "no" and "not" to the concept of truth-functional negation, the concept itself is not available for mapping—a conceptual limiting factor. Before describing how this accords with the present data, we first need to clarify what we mean, and do not mean, by the proposal that conceptual truth-functional negation might not be available to the child until age two.

Even the most basic mental computations very likely use some computation-internal version of logical negation. Logical NOT-gates are among the most basic building blocks of all computation. The smallest of these intra-computational elements can be instantiated as inhibitory activation even in the intracellular mechanisms of individual cells. At a higher level, such computations are likely involved in many behaviors present at birth in infants, as well as in much simpler organisms. For example, dishabituation to novel stimuli must involve some kind of recognition that the new stimuli are *not* the old. However, such computations of negation are most likely content- and computation-specific to the mechanisms in which they are embedded. It is not at all clear that these computations are related to—let alone the same as—the conceptual representation of logical negation that is the adult's meaning of "no" and "not", and which combines so freely with concepts like IN and BUCKET. The hypothesis that conceptual truth-functional negation is not available is the hypothesis that there is no computation in the mind that negates propositions, or composes with the concepts that make up propositions, independently of their specific content.

This account, too, is consistent with all the present data. If conceptual truth-functional negation becomes available for productive propositional thought early in the third year, children's simultaneous comprehension of "no" and "not" would reflect the simultaneous mapping of both words to this new concept. That they begin to produce denials at the same age with both words would reflect a new understanding that these words can be used to comment on the truth-value of propositions.

Twenty-month-olds' success on the non-linguistic task in Experiment 3 might reflect their having a concept of *nonexistence* that is separate from (and does not require) conceptual truth-functional negation. This concept could involve a computation-internal negation—just like the NOT-gates described above—that is restricted to negating existence (or perhaps just physical presence) but not other kinds of predicates, making it unable to serve as conceptual negation in productive propositional thought. Such a concept may not constitute the meaning of truth-functional "no" and "not", but it could be the meaning of other abstract words, like "allgone" and "empty".

Future work should test for the contributions of conceptual and linguistic factors directly. Studies of other aspects of language acquisition have successfully isolated the contributions of conceptual and linguistic factors by looking at special populations, such as bilingual (Wagner, Kimura, Cheung, & Barner, 2015) and internationally adopted children (Snedeker, Geren, & Shafto, 2007, 2012). By finding a population that does not face a conceptual limit (either because they have already learned the word in one language or because they are much older) and investigating their trajectory, we might isolate the contributions of linguistic limitations to language learning in this case as well. Similarly, cross-linguistic comparisons could be informative; if the truth-functional meaning of negation words is mastered much earlier in other languages than in English, that would provide evidence against a conceptual limit at 24 months.

Conclusion

The present studies, along with Austin and colleagues (2014), provide strong evidence that English-learning children acquire the truth-functional meanings of the words "no" and "not" at the same time, between 24 and 27 months of age. This demonstrates that a concept of truth-functional negation is available to children's thought at least by early in the third year of life. As of yet, there are no conclusive data that could decide between two possible explanations for the simultaneous mappings of "no" and "not": one, that the only factor limiting an earlier mapping is the language acquisition challenge of mapping the words to an extant concept of negation; and two, that there is the additional conceptual limit of logical negation not yet being available to propositional thought. The tension between these two possibilities highlights several open questions for future research: Is conceptual truth-functional negation available to non-linguistic thought, both in pre-linguistic infants and in non-human animals? If this concept is learned, what are the pre-existing representations that support it and the learning mechanisms that construct it? What role, if any, does language learning play in developing the ability to represent propositions, and in turn, conceptual and propositional operators like negation?

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